

Urban Stormwater Management in Oslo, Norway

Barriers and policy instruments in the transition to sustainable stormwater management



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Abstract

Nowadays, urban floods are phenomena that become more familiar. Due to climate change and the increase of impermeable surfaces more stormwater is produced. Currently, the stormwater is caught in the urban sewerage system. During heavy rainfall events the capacity of these systems can be exceeded. The concept of sustainable stormwater management is getting more attention. This way of management stimulates to catch precipitation on a local scale and use it for other purposes. In this thesis the barriers and policy instruments are discussed to see why sustainable stormwater management is a concept that is not known and widely applied yet. The thesis focuses on the financing aspect of stormwater management. Also, the barriers and the legislation on the institutional level are investigated. Eventually, all these results must clarify the extent to which sustainable urban stormwater management is known, used and how it can be the foremost solution.

Preface

First, I want to thank Isabel, Marianne, Line and the other colleagues of NIVA that helped me with giving feedback, preparing the online surveys and always supporting me in the things I did during my internship. Without them it would not be possible to write this thesis. Also, I want to thank Petra Hellegers who is my supervisor at Wageningen University she gave me good feedback during the time I stayed in Norway and during the time I wrote my thesis in the Netherlands. Finally, I want to thank my roommate Tonje, because she always helped me if I felt alone and asked me to do many things during my stay in Oslo. Without her it would be very hard for me to have a nice time and do the internship.

Tabel of contents

Abstract	5
Preface.....	6
1 Introduction.....	9
1.1 Research questions.....	11
1.1.1 General research question	11
1.1.2 Specific research question 1.....	11
1.1.3 Specific research question 2.....	11
1.1.4 Design of the report	11
2 Methodology and conceptual framework.....	12
2.1 Concepts.....	13
2.2 Online survey.....	13
3 Case study area, the city of Oslo, Norway.....	15
3.1 General information.....	15
3.2 Climate.....	15
3.2.1 Green Capital of Europe	15
3.3 Conventional and sustainable drainage system.....	16
4 Literature study about the financing of urban stormwater management.....	17
4.1 Policy instruments used to finance urban stormwater management	17
4.1.1 Monthly fee and stormwater tax	17
4.1.2 No financing mechanism	18
4.1.3 Norway	18
4.2 Difference in financing between sorts of measures.....	18
4.2.1 Financing mechanism dependent on measure	18
4.2.2 Difference between conventional and sustainable.....	19
4.3 Difference between countries.....	19
4.3.1 United Kingdom.....	19
4.3.2 United States	Fout! Bladwijzer niet gedefinieerd.
4.3.3 Developing countries.....	20
4.4 Conclusion	20
5 Literature study about the barriers and challenges in urban stormwater management	21
5.1 Urban stormwater management on the institutional level	21
5.1.1 Transition in institutions.....	21
5.1.2 Centralized underground piped systems	22

5.1.3	Change in drainage system.....	22
5.1.4	Institutions in different countries.....	22
5.1.5	Involvement of stakeholders.....	23
5.1.6	Role of institutions	23
5.2	Legislation of urban stormwater management.....	24
5.2.1	Water quality.....	24
5.2.2	Return period of floods	24
5.2.3	Norway	24
5.3	Conclusion	25
5.3.1	Barriers	25
5.3.2	City of Oslo	25
5.3.3	Enablers	25
6	Results online survey.....	26
6.1	Results	26
6.1.1	Urban water challenges.....	26
6.1.2	Knowledge gaps and needs.....	27
6.1.3	Financing.....	27
6.1.4	Enablers and drivers	28
6.1.5	Challenges.....	28
6.2	Conclusion	29
7	Discussion.....	30
	Sustainable stormwater management upcoming topic.....	30
	Reflection about financing of stormwater management.....	30
	Improvement for online survey.....	30
	Relevant information about Oslo	31
8	Conclusion	32
	Barriers and challenges in urban stormwater management	32
	Financing of urban stormwater management	32
	Progress of sustainable stormwater management	32
9	Reference list.....	33
10	Annex.....	37

1 Introduction

Nowadays, more than half of the population lives in cities. This results in higher production of food and more extraction of resources from other places. The resource water is during this thesis focus point. Many cities over the world are already experiencing water scarcity or floods (Cosgrove and Loucks, 2015; Madsen *et al.*, 2017). In cities where water is scarce the problem is likely to become worse in the future because of the increase in population and the fast rate of urbanization. Climate change is a factor that got more attention during the last decades. The difficulty of climate change is that it will change the climate over time, but how it will change and what the impact will be differs per region and time. So, taking all these factors into account many cities face huge challenges with respect to the future (Bos, Brown and Farelly, 2015).

Urban stormwater is a term used to describe the water that runs off after precipitation mostly coming from impervious surfaces. Cities in developed countries exist for the most part of impervious areas such as streets, buildings and industry. In these areas the water cannot infiltrate, that is why a drainage system is designed to catch this runoff water. Developed countries have a large concrete infrastructure that combines the sewerage together with the stormwater (Brown, Farelly and Looibach, 2013). There are also cities that separate the sewerage and the stormwater, but these systems are still made of concrete. After a rainfall event all the water from roofs and streets ends up in the urban sewerage system. This kind of system is implemented in one time and covers a large catchment area. These systems are developed over time but cannot keep up with the rate of urbanization and the impact of climate change. The purpose is to drain the water to the sewerage system as fast as possible (Madsen *et al.*, 2017). Looking at the hydrological cycle, the existing cycle will be disturbed, because there is almost no time for evapotranspiration and infiltration. The precipitation is immediately turned into run off that is drained to the drainage system. The consequence is that the hydrological cycle is accelerated what can result in more extreme events (Cosgrove and Loucks, 2015).

There are several cities that experienced floods in the last years which was caused by extreme weather events and urbanization. Cities always try to expand, but the drainage system is designed for a certain catchment area. If new built areas are connected to the existing drainage system, the capacity is exceeded and can have big impact such as combined sewer overflows or even urban floods (Madsen *et al.*, 2017) (Larsen *et al.*, 2016). It is likely that the situation in the future will be worse with the climate change that is expected. Another problem that exists is the pollution in cities. Cities with a combined sewer and stormwater system cause pollution in times of overflow, because of the nutrients in the sewerage water. Also, the runoff water from streets has a high concentration of heavy metals that are caught in the drainage system or are spread out over the city and reaches rivers and seas (Dhakal and Chevalier, 2016).

Recently, more and more cities are thinking about sustainable urban stormwater management. This means that water is caught and stored on a more local scale and maybe can be used for other purposes (Ferguson, Frantzeskaki and Brown, 2013). This new kind of management gives vegetation more space and the water more time to infiltrate and evaporate, so the traditional hydrological cycle will be maintained. Sustainable stormwater measures such as rain gardens and green roofs have smaller catchment areas compared to concrete sewerage systems and can be implemented in common and private areas. The point with sustainable stormwater management is that the current way of management needs to be changed. The large end-of-pipe systems are managed by engineers and are centralized. Sustainable stormwater management requires management on local scale and a good collaboration between stakeholder groups (Ferguson, Frantzeskaki and Brown, 2013; Larsen *et al.*, 2016; Dunn *et al.*, 2017).

The city of Oslo is chosen as case study because it is a fast-growing city which uses a concrete sewerage system like other cities in developed countries. Therefore, it is an interesting city taking stormwater management into account. The increase in total impervious areas and lack of capacity of the drainage system makes the city vulnerable in the future. Together with the impact of climate change resulting in more extreme events more measures are needed. The recent floods some years ago confirm that the city must change its way of management (Departementenes sikkerhets- og serviceorganisasjon and Informasjonsforvaltning, 2015).

1.1 Research questions

The purpose of this thesis is to investigate the progress of sustainable urban stormwater management in the city of Oslo, Norway.

1.1.1 General research question

Which factors determine the transition from traditional to sustainable stormwater management in the city of Oslo, Norway?

1.1.2 Specific research question 1

How is the financing of urban stormwater management done?

1.1.3 Specific research question 2

What are the challenges and barriers on the institutional and legislative level?

1.1.4 Design of the report

The focus is on the city of Oslo, but there is also literature used of other cities and areas to compare with Oslo due to the limited literature about the city of Oslo alone. In that case, areas with similar circumstances are used.

In the following chapter the methodology of the paper is discussed. Then there is a short description of the case study area. In the main part, the specific research questions are answered. The paper ends with a discussion and conclusion.

2 Methodology and conceptual framework

During this thesis there two literature reviews were conducted to answer the specific research questions. For the first question the financing of urban stormwater management was investigated. To answer this question 60 articles were read and compared by making several categories. The articles and case studies were compared by making categories such as the country, type of framework, obstacles and enablers. After filling in the complete table with all these different categories the main similarities could be found (Annex). This literature review was conducted until there were no more new findings.

The same was done for the second specific research question. Here also a literature review was conducted with the same categories as the first question. In the end the results were compared to get the main similarities. The literature study for this question did not cover the whole question, so some additional research was done to answer the question completely.

For both literature studies there was already a list made with relevant literature. Almost all the articles in these lists are used for the research. The other literature is found on the internet with search engines via the Wageningen University such as Google Scholar, Scopus and Web of Sciences. Policy documents were found via Google, especially the documents from Norway.

In addition, there is an online survey made with questions about the same subject as the first two specific research questions. The purpose of the online survey was to get answers and opinions of municipalities in different cities and countries. The answers give a real image about the situation of urban storm water management in their city. The online survey is sent to municipalities in Australia, Germany, the Netherlands, Norway, Sweden, United Kingdom and United States. These are all developed countries with relatively the same social and economic circumstances, so the situation can be compared in certain situations. More will be explained in the section below.

2.1 Concepts

In this paragraph the concepts barrier, challenge, enabler and policy instrument are explained. These concepts are used in the specific research questions. A barrier in this research is meant as an obstacle why the transition from a conventional drainage system to a sustainable drainage system is not happened yet. With challenge almost the same is meant. A challenge is also a reason why the transition didn't occur yet and a target to reach this transition. The difference between a barrier and challenge is that a barrier is an obstacle which already exists, while a challenge can be an obstacle later in time. The concept enabler is in this research an organization or approach which helps to cause the transition from a conventional to a sustainable drainage system. The last concept is policy instrument which is a way to provide the financing or legislation of urban stormwater management.

2.2 Online survey

For this thesis there is an online survey made in addition to the two literature studies. The two literature studies answered the questions well, but the online survey adds the value of opinions of municipalities of different cities in different countries. The survey is made with the program called Enalyzer. In the beginning there is a selection made about which questions to ask. Finally, there are 25 questions asked that take approximately ten minutes to fill in.

The purpose of the online survey is to see how urban stormwater management is done in different cities over the whole world. The management of stormwater is done differently over the world, so with this online survey it is interesting to see what the differences are in management and to find out what the reason is behind these differences. For example, in Australia water scarcity is in general a bigger problem than floods. The result is the use of a system where stormwater is caught and used for other purposes while the Netherlands and Denmark use systems which focus more on the protection of the city. The online survey is divided in eight sections with every section having another subject. The following subjects are used: Urban water challenges, knowledge gaps and needs, planning, challenges and opportunities, responsibilities, financing, stormwater as a resource and general information about the respondent. Not all the questions and answers are used for this thesis, because some questions were not relevant for this research. Only the questions focusing on urban water challenges, challenges and opportunities, knowledge gaps and financing are used. The questions asked can be found in the annex.

The online survey is sent to more than 400 addresses to municipalities in the countries: Australia, Germany, the Netherlands, Norway, Sweden, United Kingdom and United States. The survey is sent on the 18th of June 2018 and for this thesis the answers of 40 respondents are used.

The survey is made and sent quite late which resulted in a low response rate. A reason is the summer holidays in the countries to which the online survey is sent to, especially in Norway and Sweden this resulted in a low response rate. The online survey is still running, but for this thesis there is chosen to use the answers of 40 respondents who responded before the 18th of August.

The survey is not only made for this thesis it is also valuable for the project where the researcher worked on during his internship. The online survey contains sections and questions that are not relevant for this research, but for the project they are important.

The online survey consisted of multiple choice, open questions, yes/no questions and questions with a scale. Most questions could be answered in multiple choice. It was possible to click more options for the same question, so the total percentage of the answer options can be over 100%. For some questions it was possible to give an open answer by the answer option they had chosen.

Eventually, the answers are used to get an idea about how the municipalities think about urban stormwater management and how it will evolve in the future. For this research it is very valuable to not only have literature about the subject, but also to have opinions of people. Even though, the literature studies give the main answer and the online survey is an addition to fill the gaps and as a representation of the opinion of the people.

3 Case study area, the city of Oslo, Norway

3.1 General information

The city of Oslo is the capital of Norway. It is in the southeast of the country and has approximately 670.000 inhabitants. Oslo is also the biggest city of Norway. The population and urbanization are growing very fast, one of the fastest in Europe (Venkatesh and Brattebø, 2011). The city is located at the end of the Oslo fjord. The center is close to the water and expanded to the inland. During the last century the city expanded with suburbs to the northeastern part and to the south along the Oslo fjord (Venkatesh and Brattebø, 2011). The city is surrounded by mountains and forests (Google Maps), as can be seen in figure 1.

3.2 Climate

The area has a humid continental climate with cold winters and wet warm summers. During the winter the city must deal with snowfall that can stay for a long time. It is possible that all the snow is just melted in the end of May. In the months June, July, August and September,

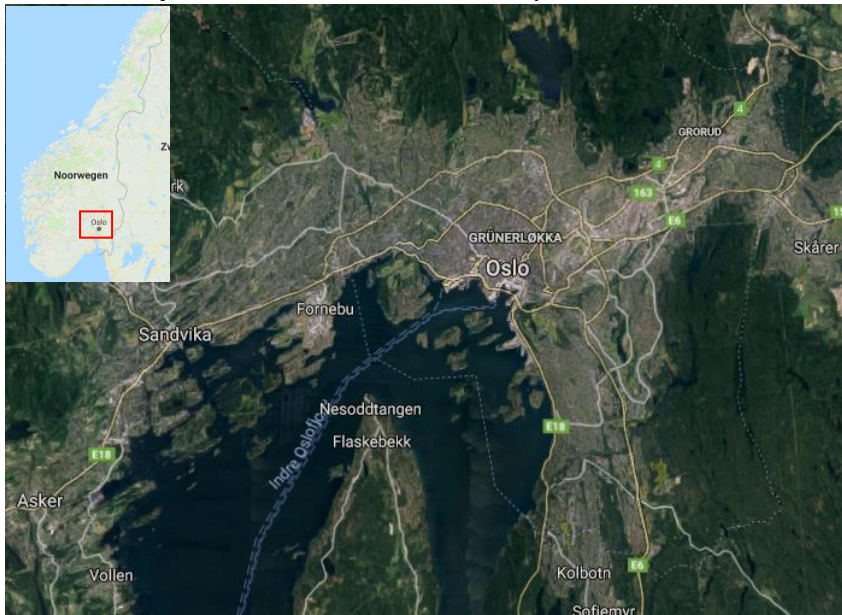


Figure 1 Location of the city of Oslo

on average most precipitation is measured. The temperatures in the winter are on average under zero degrees Celsius. In summer time there can be an average above 20 degrees Celsius and some days above 30 °C. On average the city of Oslo receives 800 mm rainfall per year.

(Departementenes sikkerhets- og serviceorganisasjon and

Informasjonsforvaltning, 2015).

3.2.1 Green Capital of Europe

In 2019, the city of Oslo will be the Green Capital of Europe, so they want to show how far the city is in the field of sustainability and environment. There are already many projects going on to improve the sustainability. Urban stormwater management will be an essential aspect during this event.

3.3 Conventional and sustainable drainage system

In the introduction the terms urban sewerage system and sustainable drainage system are already used. In most developed countries there is an underground sewerage system used which is constructed by large underground concrete pipes. In most countries sewerage and stormwater are transported by the same system; this kind of system is called a combined sewer system. There are also examples where the stormwater is separated from the sewerage, in Australia this is done more often. These conventional drainage systems catch all the water that runs off from all the impervious surfaces such as streets and buildings. The water that is caught is transported to a water treatment plant and cleaned. These large conventional systems were designed and constructed approximately 40 years ago. The design, construction and maintenance are done by engineers, municipalities, national and regional government (Brown, Farelly and Loorbach, 2013) (Fryd *et al.*, 2012).

Sustainable drainage systems focus on catching stormwater on a local scale. Vegetation is essential in the design of these systems, because it can store water much better than asphalt or concrete. Green roofs, raingardens and vegetation strips are examples of green solutions and parts of a sustainable drainage system. In figure 2 there is an example given of a green roof in Oslo. Mostly, sustainable drainage systems have a small catchment area such as roofs, parks or parts of streets. The purpose is to catch stormwater locally and let the water evaporate or infiltrate it into the soil. This process maintains the hydrological cycle. Also, there is the possibility to use the stormwater for other purposes such as garden irrigation, toilets and street cleaning. These sustainable drainage systems can be designed, implemented and maintained on a local scale by the municipality or by citizens (Cosgrove and Loucks, 2015; Hoang and Fenner, 2016;van Hattum *et al.*, 2016).

In Oslo, most stormwater is caught by the conventional drainage systems. These systems transport the sewerage together with the stormwater to the water treatment plant. At this moment the concrete underground piped system is still the foremost system, but due to recent floods sustainable drainage systems get more attention. The municipality of Oslo (Oslo kommune) is promoting green solutions and catch stormwater locally. Together with the nomination of Green Capital of Europe 2019, stormwater will be an important spearhead on the agenda. There are already streets where they built raingardens and more people are building green roofs. The planning of the municipality is to reduce the number of cars in the city and transform busy roads in small streets with vegetation strips (Departementenes sikkerhets- og serviceorganisasjon and Informasjonsforvaltning, 2015; Norwegian Ministry of Climate and Environment, 2013).



Figure 2 Green roof in Oslo

4 Literature study about the financing of urban stormwater management

This literature review is about how the management of urban stormwater is financed. The purpose is to see which mechanisms are used and if there is a difference between the conventional and sustainable way of management. The financing aspect is very important, because without financing the drainage system cannot be maintained and will not optimally function anymore. Also, there are different ways of financing and the type of financing mechanism can depend on the scale of application. For this literature study different countries are compared with each other. This is done, because there is not enough information about Norway alone and some mechanisms in other countries can be applied in Norway in the future. Financing of stormwater management is quite a new area for research, so it was hard to find literature only about this subject. So, there is also literature used about the financing of climate change adaptation. There is only literature used about the financing of climate change adaptation if the financing mechanism is feasible for stormwater. The feasibility of the measure is determined by the scale and purpose of the measure.

For this literature study the following research question is formulated: *How is the financing of urban stormwater management done?*

This specific research question concerning the financing of stormwater management is divided in three parts. In the end, there is a conclusion to answer the whole question.

4.1 Policy instruments used to finance urban stormwater management

4.1.1 Monthly fee and stormwater tax

The financing of urban stormwater management is quite a new subject where not a lot of research is done until now. In cities where a conventional drainage system is used with a large concrete infrastructure, users already have to pay a monthly fee which is a payment that users connected to the drainage system have to pay for their discharges and the maintenance of the system. This is relatively not a large amount of money. Recently, there are discussions that this fee must be raised to keep up with the stormwater amounts expected in the future (van Hattum *et al.*, 2016). Another policy instrument that is used is taxing of stormwater produced per household. The tax can be determined by the amount in cubic meters or by the quality of the stormwater. Furthermore, for every area the tax can be different. This instrument is not often used, sometimes in the United States. The purpose of this policy instrument is that users connected to the urban drainage system pay a tax for the stormwater produced based on the total impervious area. The advantage of this policy

instrument is that people who produce more runoff also have to pay more tax than people who produce less (Cameron *et al.*, 1999) (Keeley, 2007).

4.1.2 No financing mechanism

In general, there are not many policy instruments used to finance urban stormwater management. The reason for this is that most governments and countries see it as a right to be connected to the urban drainage system and have the possibility to drain their wastewater. This mindset can change in the future because it is probable that the current drainage systems cannot handle the expected amounts of stormwater in the future. These expected amounts of stormwater require the current drainage system to change and adapt which costs a lot of money. Some countries are already supporting the implementation of sustainable measures by giving subsidies. For example in the Netherlands there are subsidies for green roofs and for the disconnection of rainwater (Brown and Farelly, 2009) (Roy *et al.*, 2008) (Brown, Keath and Wong, 2009).

4.1.3 Norway

In Norway they have the same policy instruments as most other countries. People must pay a monthly fee to be connected to the urban drainage system and discharge the produced wastewater. This is a relatively small amount compared to the total costs of the maintenance of the urban drainage system that is paid by the state. The amount of the monthly fee paid differs per city or region. Although, cities such as Oslo pay nowadays more and more attention to urban stormwater. Recent urban floods caused large damage and costs in the infrastructure together with the expected climate change, Oslo kommune wants to change the current way of management to be better prepared for future floods (Norwegian Ministry of Climate and Environment, 2013; Departementenes sikkerhets- og serviceorganisasjon and Informasjonsforvaltning, 2015).

4.2 Difference in financing between sorts of measures

4.2.1 Financing mechanism dependent on measure

During the literature review there is also searched if there is a difference in financing, taking the type of measure into account. The results are that there are no specific financing mechanisms attached to the type of measure used. Furthermore, there are not so many different types of measures used yet, because in most countries there is still a preference for large end-of-pipe systems, especially in developed countries. Another reason mentioned earlier is that most countries see it as a right to be connected to the urban drainage system (Brown and Farelly, 2009). In the literature found about financing climate change adaptation there were already more kinds of financing used. Even though there is no relation found between the type of measure and the way how it is financed. The financing mechanism used

depends more on the preference of the stakeholders in the area (Banhalimi-Zakar *et al.*, 2016).

4.2.2 Difference between conventional and sustainable

There is a difference in financing between the conventional urban stormwater management and sustainable stormwater management. One reason for this is the difference in scale between the two ways of management, because generally the sustainable measures are designed for a smaller scale than the large underground piped systems used now. Figure 3 shows an example of a sustainable measure. For the sustainable measures there is a possibility to use a financing mechanism that can be controlled on a smaller scale by the local water authorities. The use of financing mechanism on a small scale gives the opportunity to adapt the mechanism to the local circumstances which makes the mechanism more efficient. Also, the control on local scale gives municipalities more responsibility which probably has a positive effect on the development of the drainage system (Nickel *et al.*, 2014). Another reason is that sustainable stormwater management is not so common nowadays, so to spread this way of management there are mechanisms needed to involve more people and to show the advantages of sustainable stormwater management. The appropriate mechanisms depend on the local situation and the preferences of the stakeholders. It is essential that the stakeholders work together and collaborate with other sectors (Bos, Brown and Farely, 2015).

4.3 Difference between countries

4.3.1 United Kingdom and United States

There are some differences in the financing of urban stormwater management between countries. As mentioned earlier, the developed countries that use large concrete underground piped systems use mostly a monthly fee to compensate the costs of the maintenance and the discharges of the wastewater. The amounts of the monthly fee depend on the country and region. Although, generally the costs are quite low based on the total costs of the whole drainage system (van Hattum *et al.*, 2016). Countries such as the United States and the United Kingdom have a different way of financing. Both countries use also large concrete drainage systems, but here the people must pay for their own risk. For example, the government of the United Kingdom installs the drainage systems, but the insurance against floods is market based and regulated by private companies. People in the UK must pay a certain amount for insurance to protect themselves against floods. So mostly, households that live in high-risk areas must pay more for insurance than households in low-risk areas (Hanger *et al.*, 2018).



Figure 3 Raingarden and green roof in Oslo

In the literature there are also examples found about mechanisms where people in the United States must pay tax for stormwater produced. There are also examples in the United States that people must do everything on their own to protect themselves against floods (Bisaro and Hinkel, 2018).

4.3.2 Developing countries

Furthermore, there is literature found about financing mechanisms in developing countries. In these articles, mechanisms such as microfinancing are more familiar to improve the urban stormwater management or even start to build a drainage system, because there is not a system yet that collects all the waste- and stormwater (Torvanger *et al.*, 2016). These mechanisms are not so relevant during this thesis, because most of the time these are mechanisms used in countries that do not have so much money to spend in this sector. This makes most mechanism not applicable for Norway, because Norway is a rich country, but still there are some financing mechanisms that even can be used in rich countries such as Norway.

4.4 Conclusion

The financing of urban stormwater management is an important aspect of the whole process, because people are always interested in the costs. In countries where large underground piped systems are used, households already have to pay monthly fees to discharge their wastewater and for the maintenance of the system. This mechanism is used already for many years, but there is a discussion nowadays that this amount of money is too less to keep up with the expected amounts of stormwater and the climate change. There are already some examples that use other financing mechanisms to get more money available to invest in urban stormwater management (van Hattum *et al.*, 2016). The other point is that sustainable stormwater management is upcoming, but requires another way of financing than the current stormwater management (Ernst *et al.*, 2016) (Brown, Fareilly and Loorbach, 2013). The reason is that sustainable stormwater management can be done on a smaller scale. Sustainable drainage systems also need more attention to become favorable over large concrete infrastructure systems to cause a transition. Taking the financing into account there is a difference between the sustainable and conventional way of stormwater management. Furthermore, the financing depends on the region, city and country. Every country has its own circumstances and preferences, which determines what kind of mechanisms will work. Finally, there is no clear relation between the use of certain financing mechanisms and the type of measures implemented. The circumstances and preferences are much more important (Banhalimi-Zakar *et al.*, 2016) (Hanger *et al.*, 2018).

5 Literature study about the barriers and challenges in urban stormwater management

Looking at the transition in stormwater management it is important to see what the barriers and challenges are to go from the current management to the sustainable system. In this chapter the focus will especially be on the barriers and challenges on the different levels in society.

This brings us to the following specific research question: *What are the challenges and barriers on the institutional and legislative level?*

This question will not be answered in one time, it will be subdivided in two parts. These parts will help to answer the specific research question mentioned above. During this literature study the focus was mostly on the differences between countries, framework, barriers and enablers. In this thesis the case study is about the city of Oslo in Norway, but there is not enough information available about the area to make it representative. That is why literature about other countries is used and compared. In the literature there are many case studies, and some are in the same situation as Oslo, so it is possible to a certain level to ascribe the same barriers and challenges that are experienced in the case studies in the literature also to Oslo. In the next section the two subdivided parts will lead to the answer of the specific research question.

5.1 Urban stormwater management on the institutional level

5.1.1 Transition in institutions

As explained earlier the climate is changing, together with the fast-growing cities it is probable that the current urban drainage system must change to let it work optimally in the future. Furthermore, many people say that the way of thinking about water must change. In the past water in the city had to be drained as fast as possible and it was a nuisance (Dhakal and Chevalier, 2016). Currently, there is more attention to give water more space by creating ponds and channels to make the city more attractive and livable. Cities like Rotterdam, Copenhagen and Melbourne already made a big step towards a more attractive and livable city. This is one of the first steps to even cause a transition in urban stormwater management. The change in the mindset about water is only the beginning, because institutions that manage the stormwater need to change as well (Brown, Farelly and Loorbach, 2013).

5.1.2 Centralized underground piped systems

In present time, most cities in developed countries still use an underground piped drainage system that catches all the water that comes from streets and roofs of buildings. This stormwater together with the sewerage are transported by a combined system. The management of these large infrastructure systems is done on a large scale. That means that there is a group of people, who are far away from the system, decides what must be done. The management of the current urban drainage system is very centralized. The institutions that decide what must be done are mostly the national, regional government or municipality. The advantage of these large infrastructures is that it is implemented in one time and they have a relative long lifetime. Another advantage is that there is not a good collaboration needed between all the stakeholders, because the national or regional government decides what must be done and the engineers design and implement the systems (Barbosa, Fernandes and David, 2012) (Brown and Farely, 2009) (Fryd *et al.*, 2012).

5.1.3 Change in drainage system

Nowadays, there are more and more people who say that the current drainage system needs to be renewed, because it is too old, and it does not function optimally anymore (Bettini, Brown and de Haan, 2015). Over the world many cities experience already water scarcity and floods. If climate change will worsen the situation by increasing the frequency of extreme weather events, water scarcity and floods will become even more severe problems in the future. This is a reason why many people say that a new large technical infrastructure does not solve the problems. They say that a more sustainable system is the solution. With this sustainable system water can be caught and stored to use it for other purposes. Figure 4 shows an example of a sustainable system. As explained earlier there are many changes needed to get to a sustainable urban drainage system especially on an institutional level (Bettini, Brown and de Haan, 2015) (Fryd *et al.*, 2012) (Madsen *et al.*, 2017).

5.1.4 Institutions in different countries

During the literature study there are approximately 35 articles read and reviewed. The purpose was to compare the development in sustainable stormwater management in different countries and see what the differences are in institutions. There are many articles used that Australia and especially the city of Melbourne had as a case study (Brown, Farely and Loorbach, 2013). Also, the cities Sydney, Adelaide and Perth are often mentioned (Brodnik, Brown and Cocklin, 2017) (Bos, Brown and Farely, 2015). Other countries that were often highlighted were the United States of America, the United Kingdom, the Netherlands and Denmark (Brown, Keath and Wong, 2009) (Bulkeley, Castán Broto and Maassen, 2012) (Dhakal and Chevalier, 2016) (Roy *et al.*, 2008). There were also examples of other countries, but these were the most important. As these countries were compared with each other, they are all developed countries, but have different problems. For example the cities in Australia experience water scarcity while the Netherlands, the United Kingdom and Denmark experience more floods (van der Brugge, Rotmans and Loorbach, 2005) (Ernst *et al.*, 2016) (Fryd *et al.*, 2012) (Bettini, Brown and de Haan, 2015). Taking the institutions into

account which manage the drainage systems, they are quite the same in the countries mentioned above. Most countries make use of a combined sewer system or of a separate drainage system, but all the systems are large infrastructures that have the purpose to drain the water as fast as possible. The decisions about the system are made on a national or regional scale and the system is very centralized. In most countries the management is also done by the state and it is seen as a right to be connected to the water supply and drainage system (Brown and Farely, 2009).

5.1.5 Involvement of stakeholders

The institutions are quite similar and how these institutions manage the drainage system, but there are differences between cities in how far they are in the development of sustainable stormwater management because the city of Melbourne is quite far in implementing this way of management looking at other countries and cities. Melbourne tries to involve more stakeholders in the plans and management to solve the problems (Brown, Farely and Loorbach, 2013). In one article the cities Perth and Adelaide were compared. Both cities are in Australia and experience water scarcity, but each city handles it differently. Perth stays to the conservative way with a centralized management while Adelaide involves the public and other organizations to get a more complete view about the problem (Bettini, Brown and de Haan, 2015).

5.1.6 Role of institutions

The role of the institutions differs in some countries. The United Kingdom and the United States have national governments and private companies that take care of urban stormwater management. The private companies are the biggest role player. These private companies decide what needs to be done when it is about stormwater management. Sometimes the government supports them (Bulkeley and Betsill, 2013). This is different compared to the other case studies in the literature because there the national government takes the decisions and handles the management of stormwater. In all countries it is seen as a right to be connected to the urban drainage system, but in the UK and the USA the people are more responsible for the risks of floods than in the other countries (Roy *et al.*, 2008). The costs for insurance in the United Kingdom and the United States depends per region and the severity of a hazard (Hoang and Fenner, 2016) (Dhakal and Chevalier, 2016).



Figure 4 Raingarden in Oslo

5.2 Legislation of urban stormwater management

5.2.1 Water quality

In most countries there are laws concerning urban stormwater management. Of course, the laws in each country are different, but the countries with the same urban drainage system have in general the same legislations. There are laws that control that the quality of the stormwater that reaches the surface water is good enough to prevent the decrease in quality of the surface water. For example, that stormwater cannot reach a certain amount of heavy metals or nutrients (Barbosa, Fernandes and David, 2012).

5.2.2 Return period of floods

Furthermore there are laws that say the chance that a certain part of the city can be flooded. This chance depends on the current land use and the climate. In residential areas the occurrence of a flood must be much lower than in rural areas for example. In countries with a high adaptive capacity have less damage with an occurrence of a flood with a design storm of 100 years than countries with less adaptive capacity. The chance of an occurrence of a flood depends also if a country gives much attention to floods or to other problems (van der Brugge, Rotmans and Loorbach, 2005) (Fryd *et al.*, 2012).

5.2.3 Norway

In Norway there is relatively not so much attention given to floods or stormwater compared to other Scandinavian countries such as Denmark and Sweden. Norway has laws concerning stormwater, but these are combined with other sectors. There are no laws about stormwater alone. There are laws about water contamination, floods, nature, etcetera. These laws can differ per municipality. The same counts for the costs for example for the cleaning of contaminated water. For flood occurrences, the type of area determines what the chance is that the area will be flooded. So, in residential areas there is a return period used of once in twenty years and for areas with less value a return period of 4 or 5 years is used. Norway also uses a climate factor. For measures this climate factor is multiplied with the current values to include the expected changes in the future. The climate factor differs per region and city (Departementenes sikkerhets- og serviceorganisasjon and Informasjonsforvaltning, 2015) (Norwegian Ministry of Climate and Environment, 2013).

5.3 Conclusion

5.3.1 Barriers

In almost all the articles the preference of conventional drainage systems is a barrier at every location. These technical engineering solutions are often underground piped and are a one-time investment with a long lifetime. This makes the solution very attractive, because these systems need to be maintained, but not as often as the sustainable green measures (Ernst *et al.*, 2016) (Brown, Farelly and Loorbach, 2013) (Biswas and Tortajada, 2010). Another barrier is the costs. People think that sustainable measures are more expensive than traditional drainage systems. Here also the reason is that the maintenance of the green measures cost more time and work. In some situations, this is true, but there are also studies that show the opposite (Roy *et al.*, 2008). Thirdly, uncertainty is an import obstacle to change to sustainable urban drainage systems. There are a lot of models that predict the future climate, but nothing is certain, so people say why investing in a new way of management while it is maybe not necessary to change the current system (Kamari *et al.*, 2008) (Lienert, Monstadt and Truffer, 2006).

5.3.2 City of Oslo

In the city of Oslo, the stormwater is managed by the municipality of Oslo (Oslo kommune). They have a few departments that maintain the large drainage systems in the city. Oslo has also a combined sewer system underground. Now there is change going on to go to a more sustainable way of stormwater drainage, but this goes very slowly. The barriers explained in the paragraph above can also be applied to Oslo (Departementenes sikkerhets- og serviceorganisasjon and Informasjonsforvaltning, 2015).

5.3.3 Enablers

The main enablers for transition are climate change, initiatives, visions, goals and experiences. Climate change makes people aware that something in the current management must change (Madsen *et al.*, 2017). More frequent heavy rainfall events cause more combined sewer overflows. These overflows decrease water quality and cause urban floods. People think that the current urban drainage system has not enough capacity to handle future stormwater (Wise *et al.*, 2014). Also, in countries like Australia, water scarcity becomes more and more a problem. There is a possibility that stormwater can be used as a resource for some purposes. The EU water directive and floods directive are initiatives that try to improve the water situation in the European countries. These organizations also have goals and visions taking sustainability into account (Bos, Brown and Farelly, 2015). This helps to improve the situation, because it is easier to work to a certain target then without. The last enabler is the experience with sustainable stormwater management. The last years there are more examples of the implementation of green solutions. The experience is very important to show to other countries and cities. Practical information in these cases helps more than theory (Dobbie, Brown and Farelly, 2016) (Larsen *et al.*, 2016).

6 Results online survey

6.1 Results

The online survey is sent to approximately 400 addresses to municipalities in the countries Australia, Germany, the Netherlands, Norway, Sweden, United Kingdom and United States. There are approximately 40 persons that filled in the online survey. The program Enalyzer is used to make the survey and process the results. In the survey the term open surface solutions used, but sustainable drainage system has the same meaning.

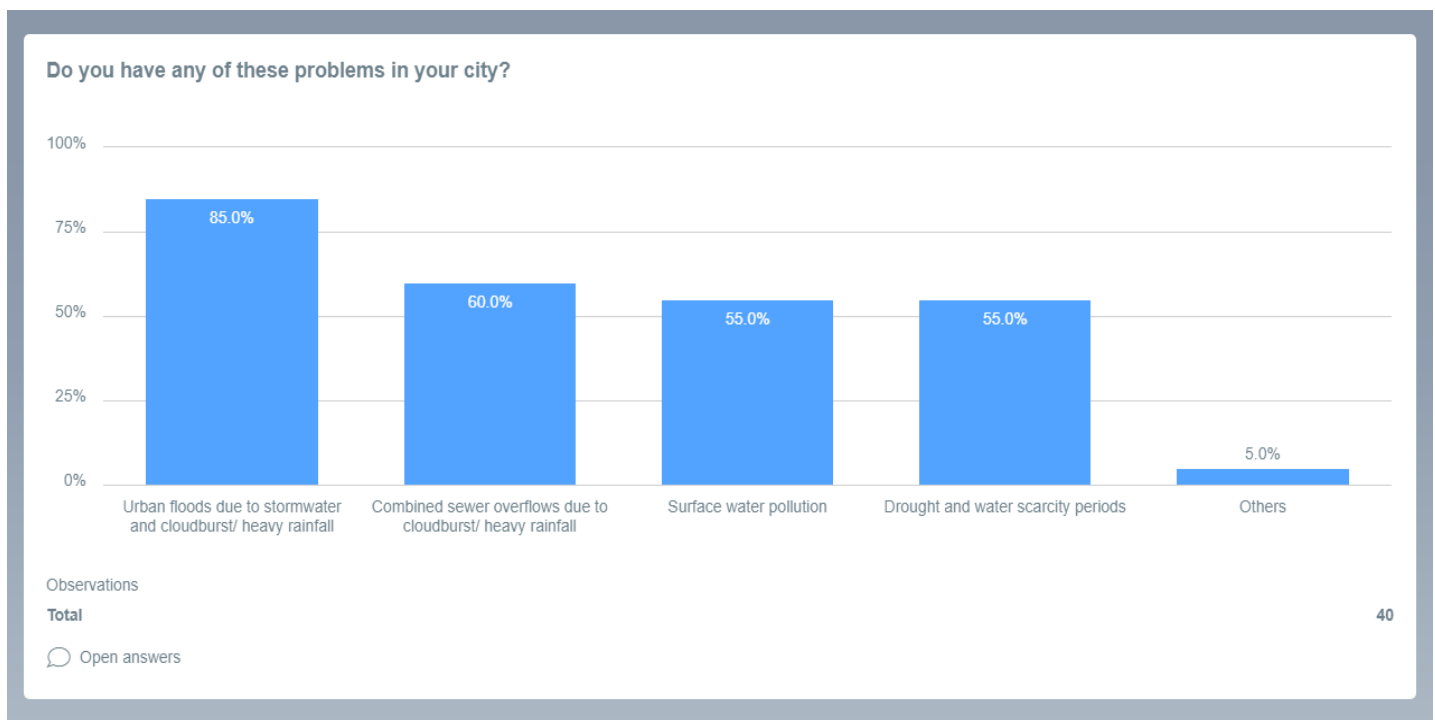


Figure 5 Question online survey: Do you have any of these problems in your city

6.1.1 Urban water challenges

In figure 5, can be seen that urban floods caused by stormwater in the form of cloudbursts and heavy rainfall is the biggest problem. This was the case for 85% of the respondents. Other problems that were experienced by the respondents were combined sewer overflows, surface water pollution, drought and water scarcity periods. These problems had almost the same weight.

6.1.2 Knowledge gaps and needs

As can be seen in figure 6, most of the respondents say knowledge is not a barrier to properly manage stormwater in the city. They say that there is enough knowledge available.

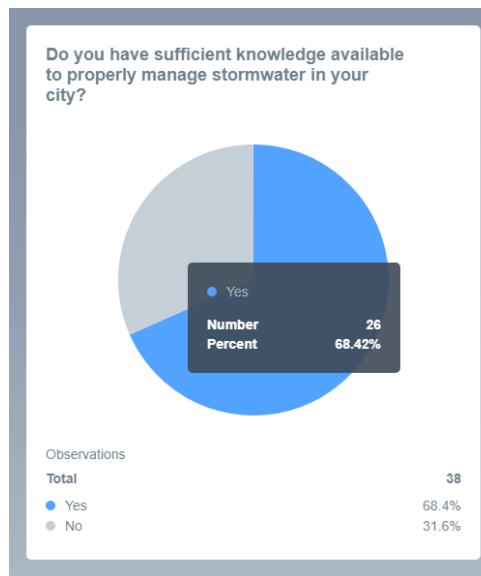


Figure 6 Question online survey: Do you have sufficient knowledge available to properly manage stormwater in your city

6.1.3 Financing

Looking at figure 7, there are big differences in the financing of stormwater management. There are three ways of financing that are used most often. 42.9% of the respondents says that in their city a national budget is used to pay for stormwater management. Waste water fees and a flat rate to pay for the maintenance of the urban drainage system are also two common financing methods. Non-compliance fees for those who do not invest in open surface solutions and rate dependent on runoff produced by total impervious area are not so often used in practice. Then there is 17% of the respondents who say that there is no financing mechanism used.

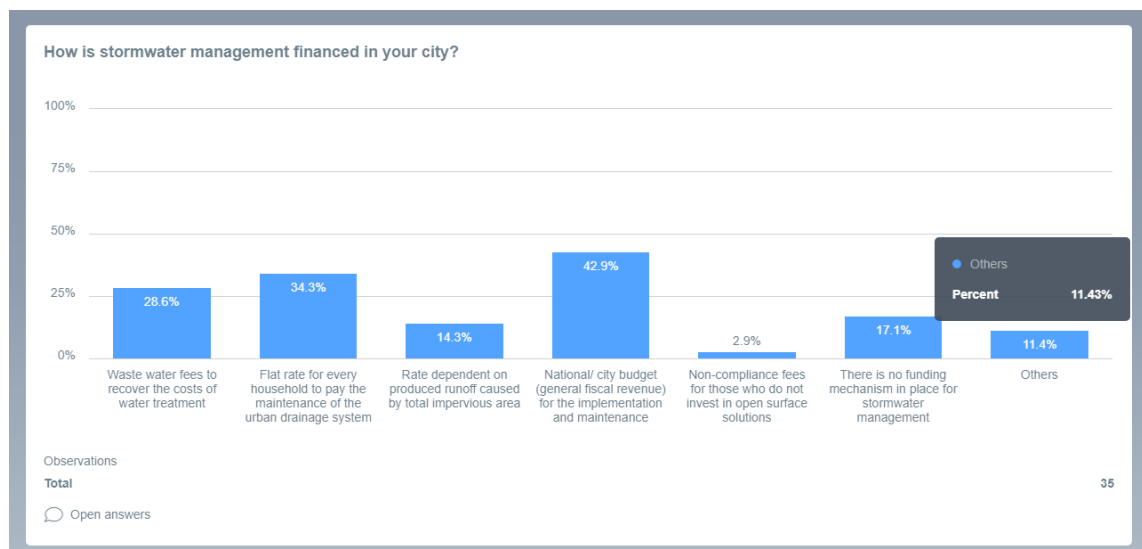


Figure 7 Question online survey: How is stormwater management financed in your city

6.1.4 Enablers and drivers

For the main enablers or drivers for the implementation of open surface solutions in the city almost all the options have the same weight, the differences are little. In figure 8, can be seen that a major historic storm event and a shared vision of several stakeholders to have open surface solutions are the two enablers with the highest percentage. The respondents think that political support, costs, regulations and showcase examples are a little bit less important.

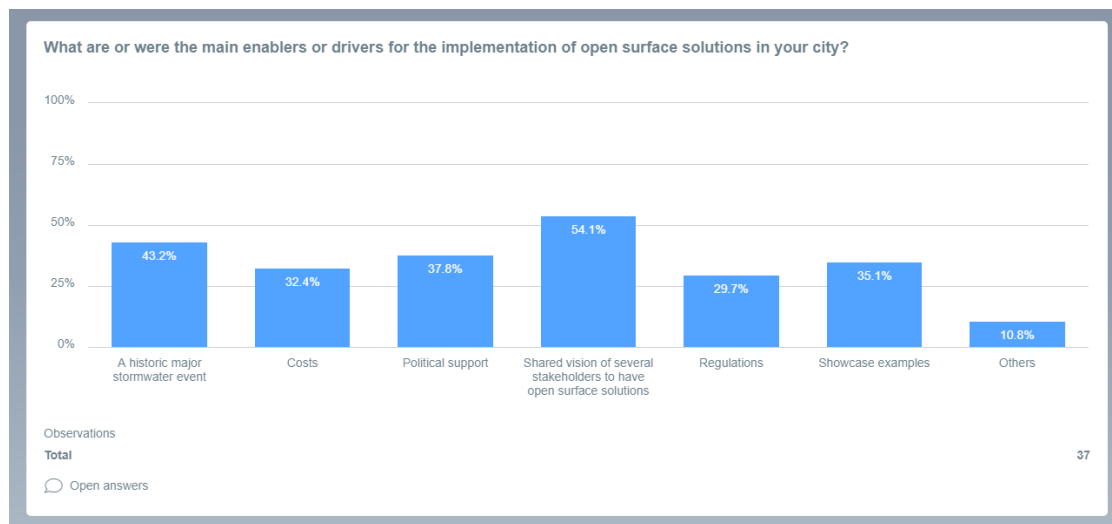


Figure 8 Question online survey: What are or were the main enablers or drivers for the implementation of open surface solutions in your city?

6.1.5 Challenges

In figure 9, can be seen that the costs are the biggest challenge for the implementation of open surface solutions. The costs are followed by the fragmented responsibilities by stakeholders, lack of collaboration between stakeholders, not enough of public spaces and bad infiltration conditions. The rest of the challenges have the same weight.

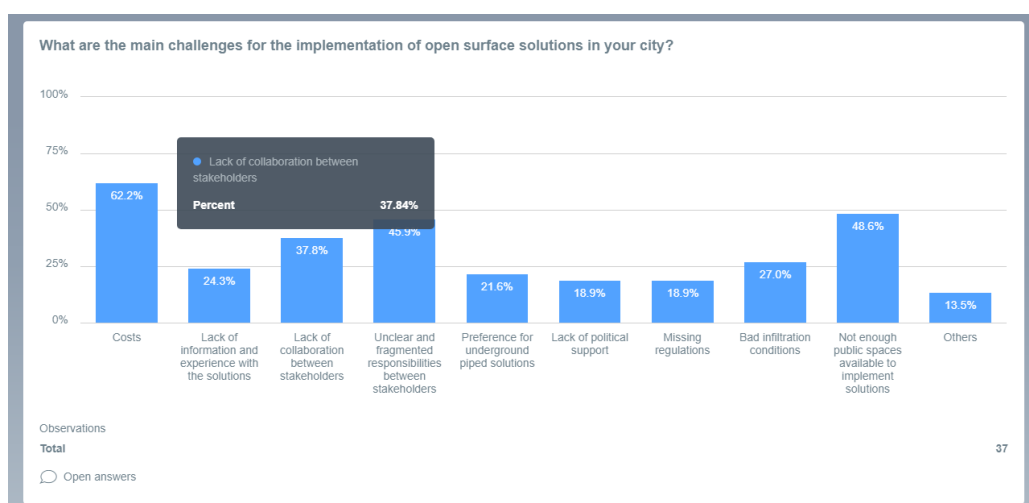


Figure 9 Question online survey: What are the main challenges for the implementation of open surface solutions in your city?

6.2 Conclusion

The results of the survey show that the respondents are quite clear what the challenges are concerning urban water issues. Cloudburst and heavy rainfall events are the biggest challenges in urban areas. Also, knowledge is not a barrier taking the properly management of stormwater into account. This is quite different than the results of the literature studies. In these literature studies, knowledge is absolutely a barrier especially with the management of sustainable drainage systems because there are not many sustainable drainage systems implemented. The weight of answers of the other questions are closer together compared with the question about urban water challenges and knowledge. This makes it difficult to say what the main enabler is, also with a low response rate. In the end, the results of the online survey are much the same as the results of the literature studies, so the online survey strengthens the conclusions of the literature reviews.

7 Discussion

Sustainable stormwater management upcoming topic

The literature studies and the online survey give a good image of the barriers and challenges in the transition from the current urban stormwater management to a sustainable stormwater management. They can answer most questions and fill most gaps, but because sustainable stormwater management is an upcoming topic it still requires a lot of research in the future. Many cities are now in the phase that water is not seen as a nuisance anymore but can make the city more attractive. Also, more and more people have the idea that the current large concrete infrastructures have reached their limit and do not have the capacity to handle the amounts of stormwater in the future. In the results of the online survey can be seen that the people are even more concerned than can be seen in the literature, so after a couple of years it is likely that this image also will be written in the literature.

Reflection about financing of stormwater management

The barriers and challenges on the institutional level are quite clear and there is also a lot of literature available about this subject. With knowing the barriers there can be sought to solutions to solve these barriers. For the financing of urban stormwater management this will be much more difficult because it is quite a new topic. In general, sustainable stormwater management is a new topic. The first step of the transition going from a conventional drainage system to a sustainable drainage system is to investigate the barriers and challenges. This research is still going on and more literature will be written. Financing is the next step and because the research about the barriers and challenges is still going on, there is almost no research done about the financing. For this thesis it was therefore difficult to find literature about the financing of stormwater management. Eventually, literature about financing of climate adaptation was used and sustainable stormwater management is a form of climate adaptation, so it is useful literature. Even though, the financing of climate adaptation is also quite a new topic, so it makes it very difficult to find relative literature study for this thesis. Recently, more research is done about the financing of stormwater management, so more and more relevant literature will become available.

Improvement for online survey

The online survey is a good addition to the two literature studies, it gives opinions of people, which is different than literature articles. The survey is now sent to more than 400 addresses which is adequate, but the response rate is not quite high. There are several reasons possible such as summer holidays, sent to the wrong addresses and unclear questions. For future research the online survey could be improved to get a higher response rate to give the survey even more value.

Relevant information about Oslo

Finally, the case study for this thesis is the city of Oslo. There are several documents found made by Oslo kommune concerning urban stormwater management, but for the next time it would be better to have more literature available about the case study to make conclusions and relations with the literature and the case study. For this thesis there is many literature used from other countries and climate change adaptation. Then the comparable and useful literature was used to make statements which is adequate if the situations are almost the same and if there is no information available about the case study itself. Even though in the future it would be better to have more information about the city of Oslo.

8 Conclusion

Urban stormwater management is an important sector in each city. Nowadays, more and more people are saying that the current way of management must change (Brown and Farelly, 2009). One plausible alternative is sustainable stormwater management which focuses more on small scale management of stormwater with green solutions (Hoang and Fenner, 2016). Most developed countries use large concrete drainage system to transport the wastewater and stormwater to the water treatment plants. This is the same for the city of Oslo (Departementenes sikkerhets- og serviceorganisasjon and Informasjonsforvaltning, 2015).

Barriers and challenges in urban stormwater management

Looking at the development of a sustainable urban drainage system there still needs a lot to be done. The city experiences the same institutional barriers as the other developed countries. The main barriers are the preference and lock-in of a large concrete drainage system, the costs, lack of collaboration between stakeholders and uncertainty. On the other hand, there are the challenges such as climate change and urbanization that the city needs to consider (Cosgrove and Loucks, 2015) (de Haan *et al.*, 2014).

Financing of urban stormwater management

For the financing of urban stormwater management, the city of Oslo uses the same mechanisms as other developed countries. Households must pay for the discharges of their wastewater and the maintenance of the system. Even though most costs are paid by the municipality itself because the government sees it as a right to be connected to the urban drainage system (Departementenes sikkerhets- og serviceorganisasjon and Informasjonsforvaltning, 2015).

Progress of sustainable stormwater management

There can be seen that the current way of urban stormwater management is changing. The way of thinking about water is changing. Water is now seen as attractive and not as a nuisance anymore (Ernst *et al.*, 2016). Furthermore, green solutions get more attention such as green roofs and rain gardens, but this is going very slowly (Hoang and Fenner, 2016). Nowadays, there are more projects going on that show how a sustainable urban drainage system can stop future urban floods and improve the situation. Also, the damages and experiences of recently floods show that the current system needs to change. All these activities help to enable and establish a sustainable urban drainage. It is a slowly process, but the city is going to a more sustainable stormwater management with a better collaboration between stakeholders, green solutions and greater resilience (Norwegian Ministry of Climate and Environment, 2013).

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10 Annex

The online survey consists in total of 36 parts and 25 questions are asked. Not all the questions in the online survey were relevant for this thesis, so only the five questions discussed in the results of the survey are used. In the figures below, the type of question and the answer options are given for the questions used for this thesis.

Do you have any of these problems in your city?

- ☐ Combined sewer overflows due to cloudburst/ heavy rainfall
- ☐ Surface water pollution
- ☐ Urban floods due to stormwater and cloudburst/ heavy rainfall
- ☐ Drought and water scarcity periods
- ☐ Others

Do you have sufficient knowledge available to properly manage stormwater in your city?

- ☐ Yes
- ☐ No

How is stormwater management financed in your city?

- ☐ Waste water fees to recover the costs of water treatment
- ☐ Flat rate for every household to pay the maintenance of the urban drainage system
- ☐ Rate dependent on produced runoff caused by total impervious area
- ☐ National/ city budget (general fiscal revenue) for the implementation and maintenance
- ☐ Non-compliance fees for those who do not invest in open surface solutions
- ☐ There is no funding mechanism in place for stormwater management
- ☐ Others

What are or were the main enablers or drivers for the implementation of open surface solutions in your city?

- ☐ Costs
- ☐ Shared vision of several stakeholders to have open surface solutions
- ☐ A historic major stormwater event
- ☐ Regulations
- ☐ Showcase examples
- ☐ Political support
- ☐ Others

What are the main challenges for the implementation of open surface solutions in your city?

- ☐ Costs
- ☐ Lack of information and experience with the solutions
- ☐ Lack of collaboration between stakeholders
- ☐ Unclear and fragmented responsibilities between stakeholders
- ☐ Preference for underground piped solutions
- ☐ Lack of political support
- ☐ Missing regulations
- ☐ Bad infiltration conditions
- ☐ Not enough public spaces available to implement solutions
- ☐ Others

These categories are used for the literature reviews to compare the articles and case studies with each other. Here below an example is given

Author, year, title	Abstract	Relevance	Country	Theoretical background/ approach	Notes	Obstacles	Enablers
Wise R.M. et al., 2014, Reconceptualising adaptation to climate change as part of pathways of change and response	In this paper the practice of adaptation decision-oriented approaches is discussed. In the beginning there is looked to the status of adaptation. In many areas there is invested in adaptation science, but this seems only true in theory. In practice there not, many approaches successfully implemented. So, in the first part the status of adaptation is discussed together with the recent developments in research adaptation. Most of the decision-oriented approaches use a certain framing. These several framings are discussed in the second part of the text. These framings try to generate ways of adaptation, but the results are not		There are four case studies mentioned: The United States, Australia, Solomon Islands and South Africa. But these case studies are only discussed in one table and there is almost not referred to the case studies in the text.	In this article adaptive pathways are used to see with the status is of adaptation and see what kind of framings the decision-oriented approaches use. Also, the results of the 'classic' pathways are discussed.	This article focusses on the status and the framing of adaptation approaches. In the first part, the status of adaptation in the society and the developments are discussed. In the second part, the different framings that approaches have are mentioned. Finally, the new framing is discussed and how new adaptive pathways can help to transform existing institutions to make them adaptive for the long-term future	The existing framings are incremental proximate, not transformative. Also, these framings cannot deal with multiple future uncertainties. There is a paradigm shift needed in the framing of adaptation research and practice	Climate change and extreme events help to implement adaptive measures. The existing decision-oriented approaches inspired the way of thinking in pathways and new approaches

	<p>there. The framings build awareness and understanding of climate change, vulnerability, adaptive capacity and the barriers, but are not enough to deal with the multiple uncertainties in the future. That is why a new framing is needed that can deal with future problems. This new framing wants to work with pathways that help to transform current institutions and make them properly for the long term future.</p>						
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