Lund University

Division of Water Resource Engineering

Sustainable Drainage and Surface Water Management in Xiamen, China

A case study in Urban Stormwater Management

Master Thesis
A Minor Field Study

Gunnar Olsson

December 2011

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Civil Engineering with focus on Water Resources

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Cover image:	Xiamen skyline, viewed from a nearby harbor (Cullinan, 2010).

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Gunnar Olsson
Xiamen, December 2011

Summary

Sustainable urban drainage systems (SUDS) is a relatively new way of handling stormwater in urban environments. Originating in the late 1980's, the concept has developed as an alternative to the traditional way of removing the urban water as quick as possible in pipes, buried underneath the ground. Sustainable urban drainage systems are open solutions, designed to regenerate nature's way of stormwater management, reducing peak flows and providing treatment of the water on its way to the recipients. Instead of only focusing on quantity, quality and amenity are of equal importance.

Situated in Southern China, Xiamen enjoys a subtropical climate with a yearly average temperature of 20.8 degrees, and an average yearly rainfall of 1347mm. The city has a population of around 2.5 million people. Being one of six special economic zones in China, Xiamen has seen an enormous development in economy and infrastructure during the last decades. This rapid development has however often come to the price of the environment. Stormwater management has had a low priority, with water seen as a burden conducted as quickly as possible in pipes to the recipients. Flooding and high levels of contaminants in the water are common issues in the city.

The main focus with this thesis is to evaluate the possibility of implementing sustainable urban drainage solutions in the central parts of Xiamen to achieve a better qualitative and quantitative control of the stormwater. Current situation in the city, concerning administration and legislations is investigated, followed by an evaluation of feasible solutions of implementation. A chapter is dedicated to the conditions in Sweden, a country which has developed the concept of SUDS during several decades. This chapter is meant to give readers the possibility of comparing differences between the two countries.

The stormwater administration in Xiamen involves a large number of departments, which often complicates and delays important decision making. Chinese national quality standards for pollution control are used as guidelines in the recipients in Xiamen.

The main recipients of Xiamen Island are either the sea, or Yuan Dang Lake. Formerly an open harbor, Yuan Dang Lake has been created through a series of land-reclamation projects, and has today the size of 1.5 km^2. The lake is under constant observation, and the condition of the lake has improved significantly during the last decades.

The area investigated in this report is a heavily urbanized district of central Xiamen, and a part of the Yuan Dang Lake catchment. The area evaluated should be considered a typical urbanized district of central Xiamen, and the solutions evaluated are meant to be applicable for other, similar areas of the city.

Since all the land in central Xiamen is already developed, the implementation of stormwater solutions will be through retrofitting. Area-demanding solutions like wetlands and green filter strips are therefore difficult to realize in Xiamen. The same applies to swales, which also due to lack of space will be hard to implement.

Evaluations in this report show that green roofs will be the most feasible solution to implement on rooftops. Recreational ponds and open recreational areas like football fields located in central Xiamen may be converted to better detain stormwater, releasing it with an even flow, to mitigate

downstream stress at the event of a storm. Green areas in central Xiamen are relatively abundant, and have the potential be redesigned to bioretention areas. Though often small in size, the multitude of installations will add up to a significant improvement in the total stormwater control. Other Infiltration devices such as permeable paving, soakaways and infiltration basins may be installed where space is available. Because of the risk of groundwater contamination, infiltration devices should be installed with an underdrain.

The stormwater is conducted downstream through the investigated area in concrete canals. Though not the optimal sustainable urban stormwater solution, a pragmatic approach has been used in the evaluation, eliminating other non-feasible alternatives. In the area of investigation, water from storms will be conducted to Yuan Dang Lake, which is regarded as the final downstream recipient, before released in the sea.

This evaluation shows that if the suggested solutions are implemented, the stormwater will be intercepted by several stormwater management solutions on its way downstream, which will contribute to notable improvements in Xiamen's urban drainage situation. Evaluations show that the maximum runoff during a 24-hour flow is reduced to less than half of the flow quantity before the improvements were implemented. A management train is favorable, in order to achieve highest potential level of qualitative and quantitative improvement.

Keywords: sustainable urban drainage systems, SUDS, Xiamen, China, stormwater

摘要

可持续发展的城市排水系统(SUDS)是一项在城市化的环境中处理暴雨水的新型技术手段。起源于20世纪80年代，不同于传统快速排放和掩埋的方式，SUDS为处理城市暴雨水提供了一套全新的思维模式。SUDS是一个开放式的解决方案，以模拟和利用自然为设计理念，目的在于减少高峰期水流量，同时在排放过程中同步净化水质。因此，暴雨水的质量和美观度被赋予了同流量相当的重要性。

厦门坐落在中国的东南部，属于亚热带气候，全年平均气温保持在20.8度左右，年平均降水量为1347毫米。厦门拥有常驻居民约250万。作为中国六大经济特区之一，厦门在过去的几十年里，经济和城市基础设施建设都经历了长足的发展。然而，如此迅猛的改变往往都是以巨大的环境破坏为代价的。由于暴雨水通常被视作需尽快排放掉的负担，暴雨水的管理从未引起有关部门的足够重视。频繁的内涝和严重的雨水污染在厦门屡见不鲜。

本论文的研究重点即为衡量在厦门中心城区实施SUDS管理的可能性。在充分调查研究厦门市现状，相关政府管理体系和法律法规的基础上，不同SUDS实施方式将被讨论和验证。由于瑞典在发展SUDS领域已有数十年的经验和显著的成果，论文的其中一章将重点关注瑞典典型的管理模式，以提供给读者比较思考的空间。

在厦门，暴雨水的管理涉及到众多的行政部门，这样通常会影响关键决策制定的速度。厦门采用是国家级的质量标准作为雨水排放终端污染管理的指标。

厦门岛内主要的雨水排放终端为海洋和芜党湖。从最初的港口，经过一系列土地改造，才有了今天占地1.5平方公里的芜党湖。湖的情况和水质长期得到密切关注，湖的整体质量也在近几十年得到明显的改善。

本文主要关注和调查的区域是厦门高度都市化的中心城区和一部分芜党湖集水区，因此本文的研究成果也同样适用于其他相同类型的城市。

由于厦门中心城区土地的开发利用已接近饱和，暴雨水的管理将需要通过对现有设施的改造来实现。某些对土地面积要求过高的方案，比如沼泽地，绿色过滤带和洼地将难以在厦门开展。

本文的调查结果表明绿色屋顶是为雨水管理改造房顶最有效的方式。公共娱乐区域，如厦门市中心的足球场可被改造为临时储水凹地，使水可以更平稳地排出，以减少雨水集中排放的压力。厦门市区拥有相当面积的绿化用地，这些都有可能被改造成为生物积水区。即使这些措施都局限在较小的规模，但多层次，多样化的手段综合起来，将对整体暴雨水的控制起到至关重要的帮助。其他的渗透装置，例如可渗透地表，污水渗透坑和渗透洼地都可以在空间允许的前提下采用。考虑到地下水被污染的风险，以上的渗透装置都应配有阴沟。

在被调查的区域，雨水是通过现有的混泥土管道进行排放的。根据本文的评定，尽管管道并非SUDS的首选方案，但对于厦门而言，这是目前最为合适和可行的方式。在此区域的雨水，在最终被排进海洋之前，都汇集在芜党湖。

这项研究表明，如果以上建议的方式能得以实施，暴雨水在排放的过程可受到若干设施的阻截。暴雨水的管理应该形成链条模式，如此才能在最大程度上改进水量和水质。

LUNDS TEKNISKA HÖGSKOLA
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The MFS Scholarship Programme offers Swedish university students an opportunity to carry out two months' field work in a developing country resulting in a graduation thesis work, a Master's dissertation or a similar in-depth study. These studies are primarily conducted within subject areas that are important from an international development perspective and in a country supported by Swedish international development assistance.

The main purpose of the MFS Programme is to enhance Swedish university students' knowledge and understanding of developing countries and their problems. An MFS should provide the student with initial experience of conditions in such a country. A further purpose is to widen the human resource base for recruitment into international co-operation. Further information can be reached at the following internet address: http://www.tg.lth.se/mfs .

The responsibility for the accuracy of the information presented in this MFS report rests entirely with the authors and their supervisors.

Gerhard Barmen
Local MFS Programme Officer

Abbreviations and Chinese currency exchange rate

BOD	Biological Oxygen Demand
Al	Aluminum
As	Arsenic
BMP	Best Management Practices
Cd	Cadmium
COD	Chemical Oxygen Demand
Cr	Chromium
Cu	Copper
CN^-	Cyanide
DO	Dissolved Oxygen
LID	Low Impact Development
Mn	Manganese
Hg	Mercury
Ni	Nickel
N	Nitrogen
NO_2	Nitrogen dioxide
O_3	Ozone
PM_{10}	Particulate matter less than 10 micrometer in diameter
P	Phosphorous
Sol P	Soluble Phosphorus
S^{2-}	Sulfide
SO_2	Sulfur dioxide

SS	Suspended Solids
SUDS	Sustainable Urban Drainage Systems
TN	Total Nitrogen
Nox	Total Oxides of Nitrogen
TP	Total Phosphorous
TSS	Total Suspended Solids
Zn	Zink

1 Chinese Yuan Renminbi equals : 0.12 Euro
0.16 US Dollars
1.06 Swedish Krona

(Currency exchange rate, 08-12-2011.)

Content

1 Introduction

1.1 Background

Located on the eastern shores of Southern China, the city of Xiamen is a rapidly developing city, with over 2.5 million people (Lai, 2010). Since the opening-up reforms were initiated in China around 30 years ago, Xiamen has undergone a tremendous economical and infrastructural development. In 1980 the city was selected as one of Chinas six special economic zones, meaning that certain privileges were given to companies investing in the city. That year the city's GDP (Gross Domestic Product) reached 741 million Yuan. In 2007 this number had increased to 138,8 billion Yuan, which is an increase by 187 times (People´s Daily online, 2008)! In the same time period, the built up area of the city increased from less than 20 square kilometers to around 180 square kilometers, which means the city expanded around 9 times its original size (People´s Daily online, 2008). A double-digit economic growth rate has been the standard for the city during the last decades.

Naturally, this rapid development has had its price. Economic development has often been prioritized at the cost of the environment, which has contributed to various environmental nuisances, and high levels of pollutants in the city, and its surrounding areas.

The removal of stormwater is one issue which for a long time has had a low priority, resulting in the increase of urban flooding risks, contaminants reaching the recipients and other stormwater related problems. With a rapid expansion of infrastructure, the results can be seen in hard surfaces replacing permeable soil, hence not allowing the water to infiltrate and quickly conducting it towards the pipes. The conventional way of quickly removing stormwater through an underground pipe system has often proved insufficient, and puts a lot of stress on the recipients. This situation is not unique for Xiamen, but includes a majority of the larger cities in China, all undergoing similar economic development as Xiamen and experiencing the same problems related to stormwater management.

This thesis will treat the possibilities of implementing sustainable urban drainage systems (SUDS) in central Xiamen, as a means of better controlling stormwater runoff from a quantitative, qualitative and aesthetical perspective. The district investigated is a densely urbanized area in central Xiamen, with a total area of 148 hectares. The width of the area is around 800 meters, with a length of 1850 meters. The investigated area, as well as the location of Xiamen in China is displayed in Figure 1.

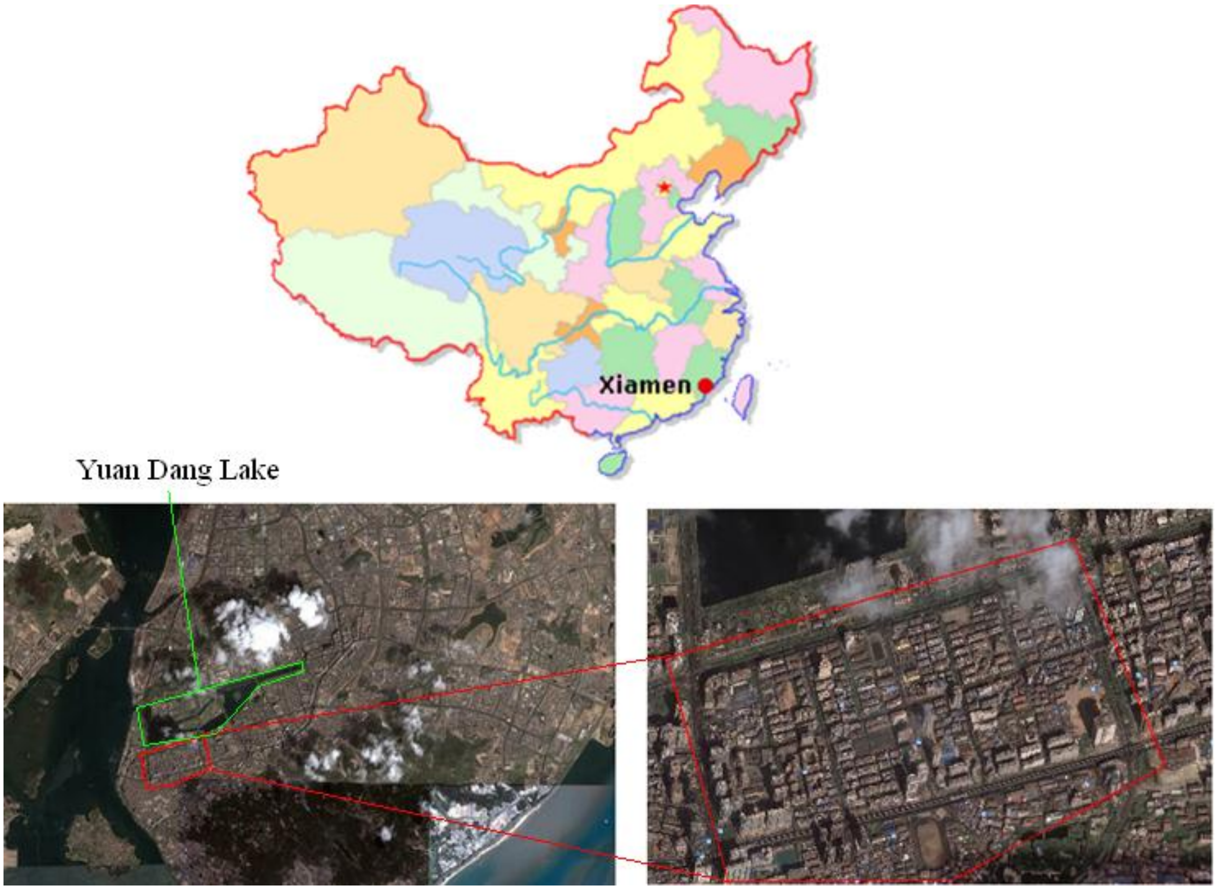


Figure 1: The location of Xiamen in China, followed by the investigated area in central Xiamen (Top China Travel, 2011; Google maps, 2011).

Though existing in western countries for several decades, the sustainable urban drainage techniques are still considered relatively new in China. Finding which sustainable urban stormwater solutions are feasible for retrofitting in Xiamen, which is the main aim with this thesis, may lay the foundation for further more detailed investigations in the field.

The paper will commence by giving a perspicuous introduction of SUDS, followed by more detailed explanations about different specific open stormwater solutions. Next part will include a mapping of legislations and active departments in the planning and implementation of stormwater solutions in Sweden, a country where the development in the field of SUDS has progressed relatively far. Case-studies from two Swedish cities will be included. After this section, there will be a presentation of Xiamen, where local conditions will be discussed, along with an overview of the legislative and administrative roadmap of the city. When reading these chapters, conditions in Sweden and Xiamen may be compared for the reader to get an understanding about the similarities and differences between the two different systems. The chapter threating the conditions in Xiamen is followed by calculations and examples of which stormwater solutions that are feasible to construct for retrofitting purposes in Xiamen. The final chapter discusses the impact the evaluated solutions will have in the area of investigation.

1.2 Objectives

The main objective of this study is to investigate which sustainable urban drainage solutions are possible to implement in central Xiamen through retrofitting, and estimate how these implementations will affect the current stormwater situation in the city. More specifically, the objectives with this study can be divided into following parts:

- Introduce the concept of SUDS, and describe different possible solutions.
- Investigate the current situation in Xiamen, China concerning storm water handling and SUDS
- Analyze which sustainable urban drainage methods are most suitable in Xiamen, and their impact in the city.
- Highlight the situation of SUDS in Sweden, and review some successfully implemented examples.

1.3 Method

Chapters 2 - 4 of this study are based on literature studies, which have taken place during spring, summer and early fall. Collected information from authors and institutions of various nations has been reviewed to find pertinent information for the study, and to gain further understanding in the field of sustainable urban drainage systems. Additional information has in some cases been retrieved through mail conversations with people having expertise in the field of investigation.

Local information about Xiamen has been obtained through direct observations in the investigated area, through conversations with my tutor and other professors, and through local sources mainly provided by assistant professor Hu at Xiamen University, College of Oceanography and Environmental Science.

Based on the local conditions and evaluations of compiled information, examples and calculations have been realized. In cases when data was not available, or when the limited time of the study constrained the possibility to obtain information, relevant approximations derived from existing data have been made.

2 Sustainable Urban Drainage Systems

2.1 Historical overview

Along with the development of towns and cities, naturally vegetated areas have successively been replaced with hard-surfaced areas as the urbanization proceeded (Environment Agency, 2003). For a long time, the highest priority was to get rid of the stormwater without considering the consequences. The book Urban Drainage by LaBranche et al (2007). describes archeological evidences which prove the romans and other early civilizations to have drainage provided to specific buildings and certain urbanized areas. Czemiel Berndtsson (2004) continues the historical review by describing the development of transporting stormwater away from the city to the recipients. Some of the early means of the 17th century was through the usage of simple open ditches. With the development of cities, these primitive systems were to support an ever increasing amount of water. With problems like garbage ending up in the open dikes, clogging of the drainage system and increasing sanitary problems were frequent issues. The solution in the beginning of the 20th century was a combined sewer system, where foul water and stormwater were lead away from the city in combined pipes. The decision with combined pipes instead of a separate system for stormwater and wastewater was in many cases economically oriented, since it was cheaper to connect the different sources of water to the same pipe, instead of the alternative, which was to construct more pipes (Czemiel Berndtsson, 2004). In the second half of the same century the praxis was changing towards separate systems for the different waters, which meant that the wastewater was transferred to wastewater treatment plants, while the stormwater was transferred directly to the recipient. Though this solution was the primarily used one during the last half century, countries like England and France still have about 70% of their pipes as combined sewer-systems (Butler & Davies, 2004). By implementing separate sewer systems, the unpredictable burden of extra stormwater at the treatment plant could be avoided. The problems connected to particles brought to the recipient by the stormwater, as well as flooding due to overburdening of the pipe system when a heavy storm arrived, remained though. Leading the water though pipes means that the natural effects of nature like buffering, infiltration and evapotranspiration is bypassed (Falu Energi & Vatten AB et al., 2008). To cope with these problems, the concept of local management of stormwater and open solutions won ground, and has been increasingly propagated in many countries during the last decades. While the purpose still remains the same, removing the stormwater, focus has now shifted towards a more holistic approach of handling stormwater. More focus is put on possible treatment processes during the transport of the stormwater, as well as the situation at the recipients (Persson et al., 2009).

2.2 The concept of sustainable urban drainage systems

The idea with SUDS is that in the best possible way regenerate the natural system of stormwater handling, in order to reduce peak flows and provide treatment for the stormwater on its way to the recipients. With the urbanization follows an increase in hard surfaces, where the water is unable to penetrate. This means that stormwater runs on the hardened surfaces without any retardation. The consequences are high peak flows, which arrive quickly after the storm commences. Since the traditional pipe-systems in the cities normally aren´t designed to handle these occasional peak flows, flooding is often the results. With the introduction of Sustainable Urban Drainage Systems, the water will be delayed on its’ way downstream, in resemblance with nature’s way of handling stormwater runoff (Environment Agency, 2003). The difference in peak-flows for pre and post-urban conditions can be seen in Figure 2.

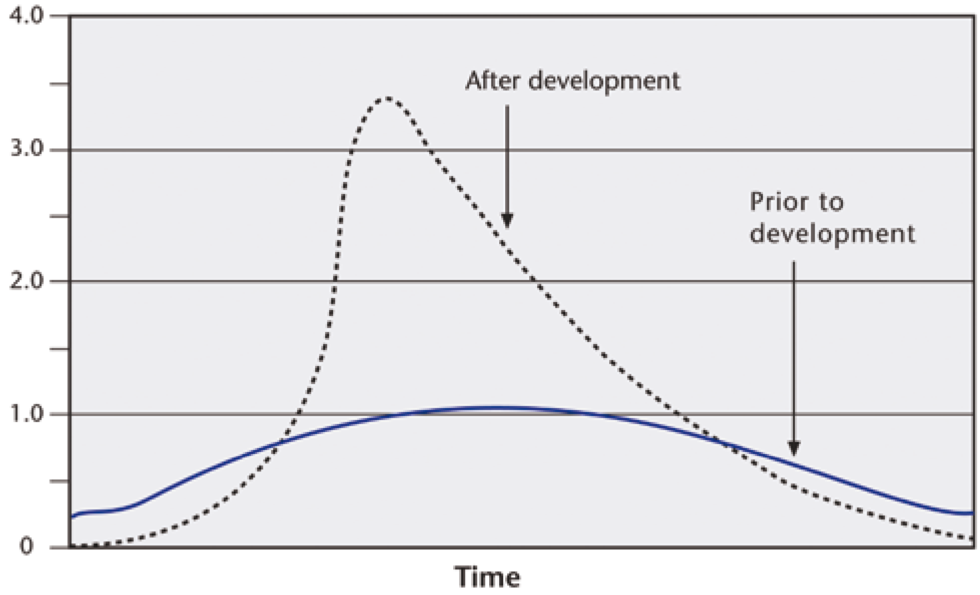


Figure 2: Impact of urbanization on runoff quantity (Environment Agency, 2003).

As seen in the figure, there is a significant increase in peak-flows after a storm in urbanized areas.

Handling the stormwater in urban environments by mimicking the natural effect goes by many different names, depending on in which country you are situated. Some of the most commonly used terms and places of usage are:

• Sustainable (Urban) Drainage Systems – SUDS	United Kingdom
• Low Impact Development – LID	United States
• Best Management Practice – BMP	Canada and United States
• Water Sensitive Urban Design – WSUD	Australia

(Jönsson, 2011; Butler & Davies, 2004)

These methods are basically the same, and in this thesis the technique will be referred to as Sustainable Urban Drainage Systems (SUDS). As written before, these systems provide an important contribution in the development towards a holistic way of taking care of the water, where amenity values and the quality of the water play an equally important role as the actual removal of the water (Ciria, 2011a). If possible, the solutions should be implemented as landscape features, to increasing the aesthetics and recreational values of the area (SEPA, 2011). The philosophy of sustainable urban drainage approach is shown in Figure 3.

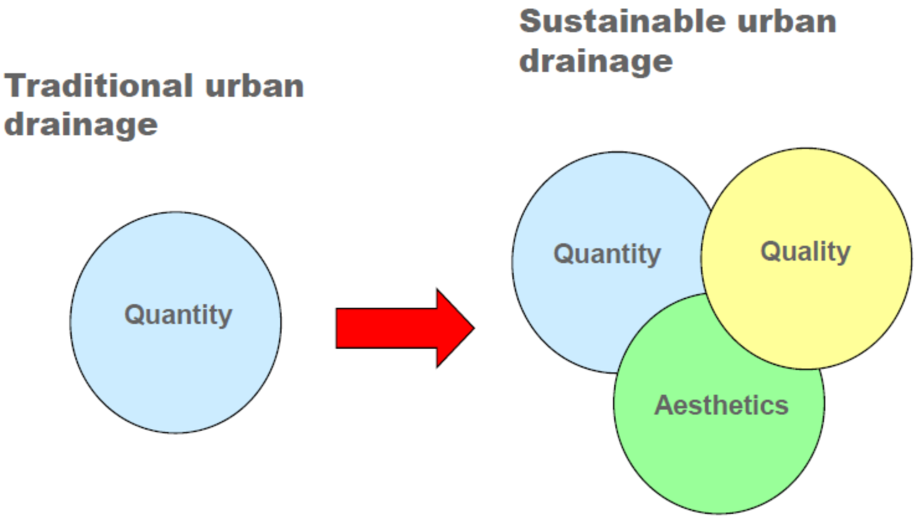


Figure 3: The SUDS approach of handling stormwater (Jönsson, 2011).

As displayed in Figure 3, the objectives with sustainable urban drainage are to minimize the effects of urbanization by improving the biodiversity and quality of the stormwater in its way to the recipient. There are many of possible solutions in the field of SUDS. Different techniques enjoy various potentials of pollutant removal, and elements like level of urbanization, climate and soil conditions play a vital role in deciding the most suitable SUDS-technique for a location (Falkirk Council, 2009). Descriptions about different SUDS- techniques will be presented further down in this document, in Chapter 3.

The idea with SUDS is to handle the stormwater as close to the source as possible and not convey it through pipes directly to the recipients, which often is the case today. The solutions are flexible, and different measures can be taken depending on the characteristics in the area of implementation (NSWG, 2004). There are different coherent steps in the scheme of handling stormwater on its way to the recipient. The objective is to maximize the effects of reduced flow rates, flow volumes and achieve an as big as possible reduction of pollutants reaching the recipient (NSWG, 2004). Best results are obtained if a series of sustainable drainage techniques are used coherently, before the water reaches the recipient (SEPA, 2011). Flow between the solutions should preferably be regulated through slow conveyance (Persson et al., 2009). To facilitate the process, the water should to an as big extent as possible follow the natural drainage pattern (NSWG, 2004). A scheme of the different steps in the stormwater treatment-train can be seen in Figure 4.

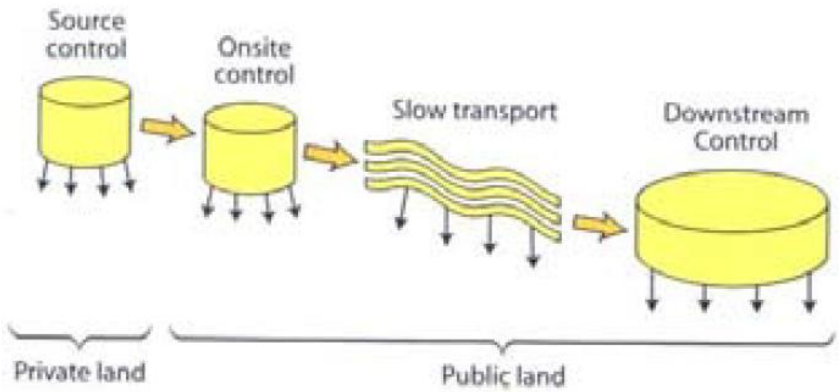


Figure 4: Different steps in the stormwater management train (Lidström, 2010).

The general idea is to handle the water as early as possible (SEPA, 2011). The different steps of implementation in a sustainable stormwater drainage showed in the figure above will briefly be explained below.

1. **Prevention:**
   To handle the pollution or take care of the rainwater before it enters the system, this is the first action. If the contaminants don't enter the system, then there is no need to remove them. Measures of prevention include the sweeping of roads and car-parks from dust and detritus (SEPA, 2011). Another way of achieving the goals of less pollutants in the stormwater is to raise people's awareness concerning polluting. By doing this, governments hope there will be a reduced burden on the stormwater drainage systems, and a reduced stress for the recipients (LaBranche et al., 2007).
2. **Source control:**
   As the name explains, stormwater is taken care of near its source. The closer to the source the water is taken care of, the less is needed to be taken care of further down the flow path. These measures are often realized on private ground, with examples such as green areas, permeable pavements, green roofs or rainwater harvesting (Falkirk Council, 2009).
3. **Onsite control:**
   Water from adjacent areas like roofs, car parks or local squares are conducted to infiltration or detention basins, where the outlets often are regulated. This makes it possible to retain the water temporarily, reducing the worst peak-flows (SEPA, 2011).
4. **Slow transport:**
   Stormwater running along the flow path towards the next sustainable urban drainage solution should be slowed down, in order to mitigate the stress on downstream solutions and recipients. This can be realized by letting the surface water run through a vegetated strip or a dike (Persson et al., 2009).
5. **Downstream control:**
   The last step in this scheme is the downstream control, with common solutions such as ponds or wetlands. Water from a vast area is retained in these solutions for a period of time, further contributing to creating a more controlled flow, and removing contaminants from the stormwater (SEPA, 2011).

Except quantity and quality control of stormwater, there are also several other benefits connected to the implementation of SUDS. Some of the most important benefits are:

- Less stress from surface water in the pipe systems
- Benefits from flood risk management
- Groundwater recharge through infiltration (where suitable)
- Improves the aesthetic values in the area
- Provides sanctuaries for animals in urban environments
- Improves the water quality and thereby protects recipients

(Dublin City Council, 2005a)

When developing SUDS it is important to consider the fact that many of the downstream solutions are relatively space-demanding. There is also a need for regular maintenance of the open drainage systems, for them to work properly (Dublin City Council, 2005a). If not constructed or maintained in a correct manner, the advantages related to sustainable urban drainage systems may default, and the solutions may rather be seen as a burden for the area. In the book Sustainability in urban storm drainage by Stahre (2006), the author stresses the importance of early agreements among involved partners of how to divide the responsibility for the construction, and establish well defined agreements of future maintenance work and its costs.

2.3 Pollutants

There is a wide variety of contaminants affecting stormwater and recipients. The problem with pollutants in urban stormwater is complex, and the subject to further research. In a literature study by Ledin et al., (2001), it is concluded that a total of 63 metals, 119 general physical and organic compounds, 40 xenobiotic organic compounds and 33 microbiological parameters may be found in stormwater pollution.

This report will be limited to reviewing the main categories of pollutants, and will not go further in to details. For a more comprehensive view on stormwater pollutants, Ledin et al., (2001) is a good source of information. Different studies categorize the main pollutants in urban stormwater differently, even though the involved compounds are the same. For different perspectives on categorizations of pollutants, information can be found in Jacobs et al., (2009) or EPA Victoria, (2006). According to Dublin City Council, (2005b), the pollutants and their sources can broadly be categorized in the following manner:

- Organic and inorganic compounds (N & P)
  - Common sources: Fertilizers & pesticides, Industrial effluents, Traffic and Atmospheric deposition
- Hydrocarbons
  - Common sources: Oil spills, Road runoff and Industrial runoff
- Trace metals (Pb, Cu, Zn, Cd, Cr, Ni, Hg etc.)
  - Common sources: Urban runoff, Atmospheric deposition, Roads & car parks and Industrial effluents
- Microbial pollutants
  - Common sources: Wastewater discharge, Leaking sewers and Animal faeces

- Sediments, Suspended Solids
  - Common sources: Land erosion, Construction sites and Urban runoff
- Litter
  - Common sources: Urban areas in general
- Chemical pollutants
  - Common sources: Mainly from industries

(Dublin City Council, 2005b)

The amount of contaminants reaching the recipients depends on several factors. Duration since last rain, percentage of impermeable area, level of vegetation, condition of the urban environment and local laws and praxis are features which may affect the level of urban contaminants in an area (NSW Government, 2011a).

As explained above, there are vast numbers of pollutants in the stormwater, originating from urban areas. The implementation of SUDS is a natural and sustainable way of using nature's own ways of reducing the levels of pollutants in the water. The quality of the water is ameliorated through different processes along the chain of steps. The main processes of treatment are biodegradation, sedimentation, filtration and uptake by plants (NSWG, 2004).

When discussing the pollution in urban stormwater it is important to consider the phenomenon of first flush. During dry periods, pollutants cumulate in urban areas. In the initial stages of a storm, these compounds are swept away from hard surfaces and transported to the recipients (NSW Government, 2011b). Dublin City Council (2005b) highlights that the first flush contaminants often arrives with the first water reaching the recipients, which in many cases are rivers. This means the water level of the river is still low with yet no additional stormwater, meaning no further dilution of the contaminants in the water will occur. At a later stage in the storm-cycle, when the water level of the river has been raised, the river is better prepared to respond to the pollutants and the nuisances are less comprehensive (Dublin City Council, 2005b). The first flush phenomenon highlights the importance of the quality and quantity control of sustainable urban drainage systems, to mitigate mentioned impacts. NSW Government (2011b) gives further suggestions of techniques how to prevent the contaminants from the first flush to reach the recipients.

3 Sustainable urban drainage techniques

3.1 Stormwater ponds

3.1.1 Quick summary

Top Picture: Ingsbergssjön, Nässjö
Bottom Picture: (Nilsson, 2008)

Key considerations:

- **Design variation:**
  Wet ponds
  Dry Ponds
- **Drainage area:**
  Minimum: 10 hectares
- **Areal requirements:**
  2-3% of drainage area
- **Stormwater management:**
  - Quality control: High
  - Quantity control: High
- **Pollutant removal (wet ponds):**
  TSS: 65-80%
  TP: 50%
  TN: 30%
  Heavy metals: 25-65%
  Pollutant removal (dry ponds):
  TSS: 60%
  TP: 20%
  TN: 30%
  Heavy metals: 0-55%
- **Treatment processes:**
  Sedimentation, biological, physical and chemical processes

General information: Stormwater ponds are manmade features, designed to mimic the ecological function of naturally occurring ponds and wetlands. Stormwater ponds can consist of a single pond, or include a multiple pond system.

Advantages:

- Increased biodiversity for the area
- Amenity is increased
- Creates recreational opportunities
- Possible to reuse water in the ponds
- Often increases adjacent property-values
- May be used for research and education

Disadvantages:

- Poor construction may lead to
  - Erosion
  -High water levels and flooding
  -Low water levels and harming of biota
- Possible upstream and downstream degradation of habitats
- Potential hazard for children
- May suffer from algae growth and odors

3.1.2 Introduction

Stormwater ponds go by many different names, of where some of the most common are wet ponds, retention ponds, SUDS ponds and wet extended detention ponds (Stormwater Center, 2011a; Heal, 2000). The design may vary, and it can consist of a single wet pond, or include a multiple pond system (Brown et al., 2001a).

Stormwater ponds are manmade features, designed to mimic the ecological function of naturally occurring ponds and wetlands. In rare cases, existing ponds have been remodeled to serve as SUDS pond (Heal, 2000). In earlier days, the ponds were designed with the purpose of slowing down the flow, thereby minimizing the risk of flooding further downstream. Nowadays the ponds have other functions as well, of which treating the water is one of the most important feature (SWFRP, 2004).

The two main purposes of the wet pond are, as written above, to improve the quality and control the quantity of the stormwater discharge. An important aspect is to construct the system so it works in both rainy and dry weather (Ciria, 2011b).

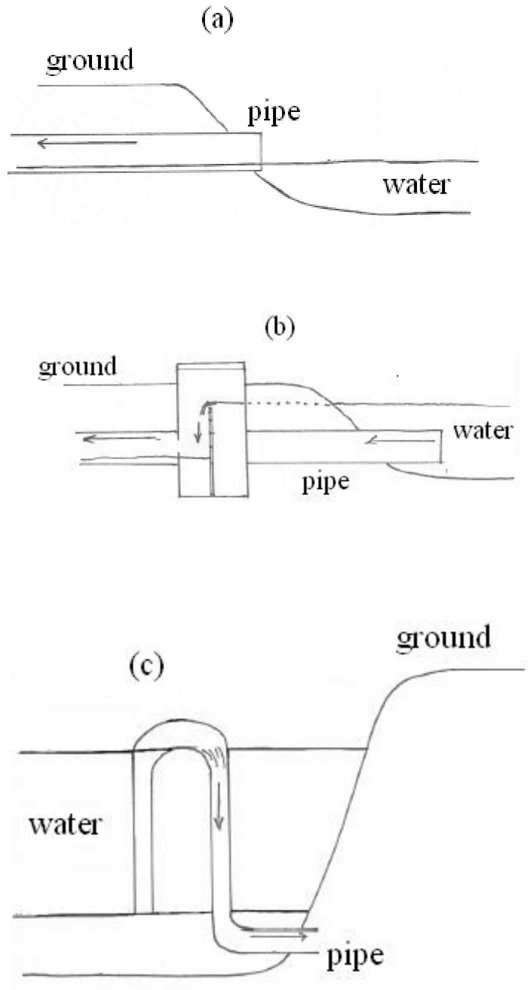
Even though wet ponds occupy a rather large area, it is only around two to three percent of the total drainage area (USEPA, 2006g). The area needs however to be connected, which makes it, as explained above, hard for retrofitting in densely urbanized areas. The maintenance cost of wet ponds, calculated on a yearly basis, is estimated to be around 3-5 percent of the construction costs (USEPA, 2006g). It is important to have clear directions of who will be responsible for maintaining the pond, and how the costs for construction and maintenance will be divided (Stahre, 2006).

3.1.3 Applicability and design

Because of an increase in recreational values, ponds are often popular additions to the landscape features at locations like company headquarters (Heal, 2000). Because of its rather big area of coverage, stormwater ponds are often incorporated into new developments, rather than retrofitted into an existing urbanized area (Heal, 2000). Stormwater Center (2011a) however states in a review about wet ponds that it is a common to use this solution for stormwater retrofitting when space is available.

The flow rate is controlled by detention of the water in the pond. The outlet is releasing a regulated amount of water, thereby creating a controlled flow and mitigating the stress for downstream recipients (Ciria, 2011b). To protect downstream ecosystems, most stormwater management policies require the outlet from the pond to be no higher than the pre-development peak flow (Akan & Yen, 1999).

To regulate the outlet, there are several different solutions. Nilsson (2008) describes in a degree project several solutions of how to regulate the outflow. Some of the most important solutions, which are also exercised on other stormwater solutions are mentioned below:



Dip-pipe
A pipe with the right dimensions for the amount of water in the outlet is a common solution to regulating the downstream flow (Figure 3:a).

Munk
In this solution the outflow is regulated by adjusting the central board in **a** vertical direction as seen in the picture, thereby regulating the water level of the pond (Figure 3:b).

Siphon
Using this solution means the water is first allowed to rise to a certain level before the outflow is initiated. This continues until the water level is down on a low level again. The quickness of the emptying of the pool is decided by the dimension of the pipe. Since the water isn´t drained from the pond until reaching a certain level, there may be a higher level of the water between the storms, something that promotes biodiversity and regeneration of the vegetation in the pond (Figure 3:c).

Figure 5: Variations in design to control stormwater outlet (Nilsson, 2008).

For further information regarding solutions of water outflow, Nilsson (2008) is a good source of information.

Apart from a regulated outflow, all ponds should also have a flooding path. When a heavy storm occurs, the capacity of the retention volume of the pond may not be sufficient to retain all arriving stormwater. For these occasions a flooding path should be used. In case of a flooding event there are different ways of handling the problem. Strutler Jr (1986) highlights the possibility of leading the water to additional temporary storage areas, e.g. parking lots or playgrounds, where the water can be stored for a limited amount of time, in order to avoid peak flows and flooding further down the flow path. Another option suggested in the text is the possibility to lead the water to the existing pipe-network, and thereby temporarily lowering the burden from the stormwater in the pond (Strutler Jr, 1986).

When it comes to cost effectiveness, wet ponds are preferably constructed in a larger scale (Brown, Stein, Warner, 2001). Wet Ponds are constructed to have a permanent pool of water, in dry weather as well, though significantly less than in rainy weather (ibid.). The water in a wet pond is divided into permanent volume and detention volume. The latter is the difference in volume between the normal level and the maximum level of the water in the pond (Nilsson, 2008). For obvious reasons the usage of the detention volume requires a larger inlet than outlet. In the decision-making of the required detention volume, factors like runoff area, hardened surfaces, maximum outflow and dimensioning precipitation are considered (ibid.). According to Brown et al., (2001b), the minimum drainage area for a wet pond should be 10 hectares.

The design lifetime of SUDS ponds is normally approximated to 25-30 years, but available information about limiting factors like accumulation of contaminants and sediment or how regular maintenance will change the lifespan of the ponds are today insufficient (Heal, 2000).

In colder climates, the performance of wet ponds decreases notably during the frigid months. USEPA (2006g) treats this topic, and emphasizes the fact that an ice layer on the pond severely affects the performance of contaminant removal. With ice layers sometimes occupying as much as half of the retention volume, the pressured and turbulent conditions in the water often lead to re-suspension of solid sediment (USEPA, 2006g). Often the water has no possibility to enter the pond, but simply runs on top of the ice layer, receiving no treatment or quantity equilibration whatsoever before continuing downstream. The cold temperature also affects biological processes in the pond, reducing them to a minimum (Oberts, 1994). When thawing occurs, a high concentration of pollutants, which have gathered during a long period of time quickly is released in the pond. Ice barriers are also commonly formed, which disturb the normal flow of water through the conveyance system (USEPA, 2006g). For a comprehensive review concerning this topic, Oberts (1994) is a good source of information.

3.1.4 Treatment

Whilst in the pond, the water is treated through chemical processes like precipitation and destruction of pathogens by UV in sunlight, biological processes like plant uptake of nutrients and microbial decomposition as well as physical processes like sedimentation and adsorption to sediment (Heal, 2000). If designed correctly, wet ponds can achieve a high degree of contaminant removal from the stormwater. Pollutants removed include sediments, BOD, trace metals, organic nutrients and soluble nutrients (nitrate and phosphorus) (Brown, Stein, Warner, 2001).

There are several features which can enhance the performance of stormwater ponds. A detrimental factor for the treatment processes to be able to function correctly is the detention time of the water in the pond (Stormwater Center, 2011a). Solutions like increasing the volume of the pool or regulating the outlet orifice are ways of regulating the detention time in the pond, which also will be the time for sedimentation and other treating features (Strutler Jr, 1986). In the article Stormwater detention ponds: An evaluation using frequency distributions for detention times, Strutler Jr, (1986) summarizes studies done by Metropolitan Washington Council of Governments, Northern Virginia Planning District Commission and Occoquan Watershed Monitoring laboratory. The results show that 70-90% of sediments were removed, when the average detention of the water in the pond approached 50 hours.

Another way to enhance the performance is to create a multiple pool system, meaning that the water successively gets cleaner the further it gets on its way through the different pools (Brown et al., 2001b). Sometimes, if the downstream recipient is sensitive to certain pollutants, the treatment time of the water may be decided by a critical factor, for example nitrogen removal (Stormwater Center, 2011a). An important aspect when designing wet ponds is to ensure that all parts of the pond are used for its purpose, which means that the water must flow through the entire pond, and no dead pockets are allowed to be created. By utilizing the full potential of the pond, a longer distance from the inlet to the outlet is created, thence making more time for treatment. Measures of achieving this are through lengthening of the pond, or the installation of underwater berms, designed to alter the flow path in the pond (ibid.).

The percentage of reduction regarding different contaminants is fairly good in wet ponds. Results deviate from different studies (Winer, 2000). USEPA (2006g) highlights that some of the reasons why there are relatively significant differences in the performances of different ponds are due to differences in the areal characteristics, the design and the maintenance of the pond. There are several studies on this topic, and this paper will include results from two reports in this field. The first report, found in National Pollutant Removal Performance Database for Stormwater Treatment Practices, 2nd Edition by Winer (2000) summarizes the result of a multitude of studies in the field during a time-span of 19 years. In the second report, found in the journal Watershed Protection Techniques, Schueler (1997) summarizes some of the research in the field. The values of the latter source are the average values from Wet extended Detention Ponds, Multiple Pond Systems and Wet Ponds (ibid.). The results are shown in Table 1:

Table 1: Pollutant removal for stormwater ponds. Study 1: (Winer, 2000) Study 2: (Schueler, 1997)

	Pollutant removal(%)							
Study	**TSS**	**TP**	**Sol P**	**TN**	**NOx**	**Cu**	**Zn**	**Bacteria**
1	80	51	66	33	43	57	66	70
2	67	48	--	31	24	25	25	65

For further information about the pollutant removal of stormwater ponds, there is information to be found in USEPA (2006g) or Schueler & Holland (2000).

3.1.5 Additional benefits

Apart from flooding control and reduction of contaminants there are other benefits gained from using wet ponds. One palpable benefit is the increased biodiversity deriving from a correctly constructed stormwater pond. To maximize the ecological potential for a pond with a rich variety of flora and fauna is an important aspect in today’s planning of stormwater ponds (Heal, 2000). A well-constructed stormwater pond has a high amenity value, with areas potentially used for sports, recreation or the observing of wildlife (Ciria, 2011b).

Correctly constructed ponds with appurtenant aesthetical features often create a raise in the adjacent property values, according to studies in the field. USEPA (2006g) reviews studies showing how the property values increased 10 – 25% when located near a wet pond. Stormwater ponds may also have an educational value, and be a part in raising people’s awareness of environmental issues, in particular stormwater related ones (Heal, 2000).

Another potential benefit is the possibility of reusing the stormwater in the pond. Water is then pumped back into irrigated pervious areas in the watershed for the pond. The result, except from the economical winnings of not having to transport water from far away, is an even greater pollutant removal than normal, and an increase of groundwater recharge. The latter is especially important in coastal areas, where seawater intrusion will occur if the groundwater level isn´t sufficiently recharged (Wanielista & Yousef, 1993). Limiting factors for a water reuse pond are the fact that there needs to be an area to irrigate nearby and possible damage on the downstream flow from the pond, since the amount of water reaching these areas will decrease a lot (ibid.).

3.1.6 Limitations

To avoid complications regarding performance, it is important that stormwater ponds are constructed correctly. Some of the most common deficiencies associated with a poorly constructed stormwater pond are erosion, flooding caused by high water levels, the killing of aquatic plant and wildlife due to low water levels, too short retention time in the pond leading to insufficient treatment or that sediments fill up the pond faster than calculated (SWFRP, 2004).

Brown, Stein, Warner (2001) lists further potential negative impacts with stormwater ponds, like upstream and downstream degradation of habitats, potential safety hazards for children, and occasional complications concerning algae, odor or debris.

Brown et al (2001b). echoes the earlier statement, and adds that the water may get heated in the wet pond, which may affect a sensitive biota subsequent to the pond.

3.1.7 Dry ponds

Since the characteristics differ quite substantially between wet and dry ponds, the latter mentioned will have a separate part in this presentation about ponds.

Dry ponds, also called dry extended detention ponds, have the purpose of detaining the water after a storm for a limited amount of time, in order to reduce peak flows and to allow partial sedimentation. There are few geographical limits of implementing these systems (USEPA, 2006a). The normal depth of dry ponds is between one and two meters, with a dimensioned retention time of the water depending on the area, for example 24 hours (IDAQ, 2005). When constructed, the site is often landscaped to blend in with the rest of the environment. At dry periods, other functions can be derived from the installation, and it may be used as recreational areas such as picnic areas or playgrounds (ibid.). These additional functions are most applicable in arid climates, where the time-span is greater between the storms. To maintain the recreational value in dry areas it is important to consider which vegetation to use, to make sure that it sustains dry periods (USEPA, 2006a).

The drainage area for this kind of pond should be no less than 4 hectares, since the flow otherwise will be too small. To control a limited flow from a small drainage area, a small orifice diameter at the outlet will be constructed, leading to frequent clogging, and an aggravated control of the channel and water quality (USEPA, 2006a). Problems with clogging may be mitigated by pretreating the stormwater in a sediment forebay, where a lot of particles can be removed before it reaches the larger permanent pool (ibid.).

Removal rates for dry extended detention ponds, as reported by Winer (2000) and Schueler (1997) in Table 2 are the following:

Table 2: Pollutant removal for dry ponds. Study 1: (Winer, 2000) Study 2: (Schueler, 1997)

Pollutant removal(%)							
Study:	**TSS**	**TP**	**Sol P**	**TN**	**Nox**	**Cu**	**Zn**
1	61	20	-11	31	-2	29	29
2	61	19	--	31	9	26-54	26-54

As seen when compared to wet ponds, dry extended detention ponds doesn´t give the same treatment and removal of contaminants. In some of the columns even negative numbers are observed. Some of values are based on less than five data points, which is a source of contingency (Winer, 2000). The deviation varies between 8 - 35% (ibid.).

Apart from the moderate pollutant removal, other negative aspects of dry ponds are their potential of breeding mosquitoes if wet puddles remain for a long time, and soluble pollutants aren´t removed effectively (USEPA, 2006a). Some studies also point at the fact that property values actually decrease when located close to a dry pond (ibid.).

3.2 Stormwater wetlands

3.2.1 Quick Summary

Top Picture: (Brown et al., 2001b)
Bottom Picture: (Brown et al., 2001b)

Key considerations:

- **Design Variations:**
  Shallow wetland /Extended Detention Shallow Wetland
  Pond/Wetland Systems
  Pocket Wetland
- **Drainage area:**
  Minimum: 10 hectares
- **Areal requirements:**
  3-5% of drainage area
- **Stormwater management:**
  - Quality control: High
  - Quantity control: High
- **Pollutant removal:**
  TSS: 80%
  TP: 40-50%
  TN: 20-30%
  Heavy metals: 40-70%
- **Treatment processes:**
  Sedimentation, biological, physical and chemical processes

General information: Stormwater wetlands are shallow pools of water, working in a similar way of stormwater ponds, designed to mimic the ecological function of retention and treatment.

Advantages:

- Increased biodiversity for the area
- Amenity is increased
- Creates recreational opportunities
- Reduces the need for conventional pipe-systems
- Often increases adjacent property-values
- May be used for research and education
- Potential usage for aquaculture.

Disadvantages:

- Relatively high areal demands
- Possible downstream degradation of habitats Due to bigger heat fluxes of the water in the wetland
- Release of nutrients in the fall
- May suffer from algae growth and odors
- Reduced capacity in cold temperatures

3.2.2 Introduction

Stormwater wetlands, also referred to as constructed wetlands, are in structural practice similar to wet ponds, and the principals of treatment and retention are comparable in several aspects. Just like stormwater ponds, the water enters the wetland area and receives treatment during the retention time. The distance between the inlet and the outlet is favorably as long as possible, allowing more time for detention and treatment of the water (NCDENR, 2007a). Though occupying a larger area than stormwater detention ponds, wetlands are often easier to integrate in the surrounding environment, because of its rich vegetation and aesthetic values (NCDENR, 2007a). The minimum drainage area connected to a wetland should according to Brown et al., (2001b) be 10 hectares.

Depending on location and purpose, there are several different designs of wetlands. According to Akan & Yen (1999) different design variants of wetlands include:

- Shallow wetland
- Extended Detention Shallow Wetland
- Pond/Wetland Systems
- Pocket Wetland

The first two variants listed above enjoy similar construction. The main area is a shallow marsh with a low depth, and it is in this area where treatment occurs. There are deeper sections located at the inlet and at the outlet respectively, called micropools (Brown et al., 2001b). The micropool at the outlet should contain at least 10% of the total treatment volume, with the main purpose of preventing clogging in the outlet (Anderson et al., 2001a). What differs the shallow wetland and the extended detention shallow wetland is that in the latter, a part of the water treatment is provided as an extended detention above the marshes, and released during a period of 24 hours. The consequence is that less area compared to a normal shallow wetland is needed for treating the water. Limitations on the vegetation, which has to sustain both wet and dry periods, supervene though (Brown et al., 2001b).

The pond/wetland system is a wetland with a coherent pond upstream. Sedimentation and reduction of the runoff are processes occurring in the pond, reducing the burden of the wetland, hence allowing the water to get additional treatment (ibid.).

The last variant, the pocket wetland, is a smaller element than the other solutions mentioned above, with a drainage area of around 2 – 4 hectares. To have a functional wetland with such a small drainage area often requires a construction at groundwater level, to assure the constant availability of sufficient amounts of water (Brown et al., 2001b).

3.2.3 Applicability and design

The applicability of stormwater wetlands is diverse, and they can generally be applied wherever there is a concern for contaminated stormwater. Residential areas, commercial areas or areas for agriculture and industry are suitable for implementation. Recently there has been an increase in constructing wetlands in the vicinity of highways to reduce the road- contaminants in the adjacent recipients (Czemiel Berndtsson, 2004). There exist some restrictions to where the system is applicable though. One limit is the large area required for wetlands, making it hard to utilize this solution in highly urbanized areas. It is however possible to apply this solution further downstream, if there is space available. The matter of size may also pose a serious problem in the question of retrofitting. If there is space available however, wetlands are often a welcomed solution, with the increase in vegetation and aesthetic values that it brings (USEPA, 2006b).

Even though occupying a somewhat large space, the stormwater wetland only requires a few percent of the tributary drainage area, meaning it can handle the stormwater from a relatively vast area. Brown et al., (2001b) suggests the wetland to occupy 3-5% of the drainage area, while Anderson et al., (2001a) and USEPA (2006b) states that an area of 1-2% is sufficient. Other constraints of where suitable to build are soil type, topography and groundwater table. If the soil is of a sandy character with high permeability, it is important to construct the wetland at a level where the groundwater may help to retain a constant water level (Doll & Hunt, 2000). At sites where the groundwater level is lower than the projected wetland, Anderson et al., (2001a) suggests an impermeable linear to prevent the water from infiltrating the ground too quickly, and drying out the wetland. At sites with a high pollutant level where there is an impending risk of contaminating the groundwater, Anderson et al., (2001a) implies that an impermeable linear should be required. When it comes to soil types such as loam and silt loam with low permeability, less consideration needs to be taken to the permeability issues mentioned above (Doll & Hunt, 2000). Since wetlands contain a constant pool of water, areas with high aridity may not be suitable for constructed wetlands (USEPA, 2006b).

When it comes to performance in colder climates, wetlands suffer the same deficiencies as wet ponds. The performance decreases drastically during the cold months, and the total efficiency may drop even more than what is the case with wet ponds. Reasons explaining this are the shallow water in the system is sensitive to ice-layers, the high amount of detritus available for re-suspension and the fact that the biological processes, which are detrimental for the water treatment in wetlands are dormant in cold weather (Oberts, 1994). Ice forming at the outlet may also create a plug, preventing the water from following its normal flow path. Snowmelt, when the flow is high and pollutants accumulated during the winter months quickly are released, also poses a problem for wetlands (Ibid.). High levels of salt from road maintenance may also pose a problem, especially in wetlands constructed adjacent to highways. It is important to choose vegetation after the predominate circumstances, in this case plants that can tolerates both high salt levels and frigid temperatures (USEPA, 2006b).

Even though there is a limited amount of available data, wetlands are considered relatively cheap to construct. The annual maintenance cost is estimated to lie between 3 - 5 % of the construction cost (USEPA, 2006b). Measures like inspection of vegetation are particularly important during the first years after the construction, before the plants have fully adapted to the local conditions. Other arrangements like removing sediments or excessive vegetation can be considered in certain types of wetlands, but should be done with caution in order to avoid harming the biological harmony of the area (Anderson et al., 2001a).

3.2.4 Treatment

The performance in treating polluted water is generally a function of the retention time and the quantity of the inlet flow (Carleton, 1997). Apart from controlling runoff volumes, the water is being treated through pollutant removal mechanisms such as sedimentation, bio-degradation of organic compounds and petroleum hydrocarbons, nitrogen reduction, and sequestration of metals in the form of chelated compounds (Stormwater Center, 2011b; NSI, 2011). The treatment of the water is preferably to be done by specially constructed wetlands. In many places, like the United Kingdom, it is generally not accepted to lead stormwater to already existing wetland areas (SuDS Wales, 2011). These standards vary however, and in a report from the United States by Carleton (1997), case studies from both natural and constructed wetlands receiving stormwater from urbanized areas are summarized. The results show similar contaminant removals rates with slight advantage to the constructed wetlands (Carleton, 1997). This may be due to the possibility with the constructed wetland to design an appropriate size, suitable the drainage area. Vegetation may also be chosen for specific treatment purposes and create good results with a limited variability, if done correctly (ibid.).

It is important maintaining healthy vegetation, since a lot of the treatment processes are impeded if the plants are not in a good condition. Healthy vegetation entails processes like the decomposition of compounds, nutrients like nitrogen and phosphorus being used in the creation of new biomass, and nitrate transformation to nitrate gas by microorganisms adhering to plants. The plants also physically trap pollutants and slow down the water flow, allowing solids to settle. Last but not least, abundant vegetation provides a habitat for a number of animals and insects (NCDENR, 2007a). Many of the treatment processes for pollutants are feasible in both aerobic and anaerobic conditions (ibid.).

Wetlands are considered to be a highly efficient method of treating stormwater from urban areas and roads, before it continues to the recipient. Doll & Hunt (2000) highlights a study from North Carolina, which, in line with United States nationwide research in the field, indicates that stormwater wetlands in average are the most efficient SUDS-solution when it comes to pollutant removal (Doll & Hunt, 2000). If constructed and maintained in accordance to the recommended specifications, the rates of pollutant removal is considered high in wetlands (Brown et al., 2001b). The best result is achieved when a detention pond is created upstream from the wetland. By doing this, the larger particles will have time to settle before the water enters the wetland, thereby mitigating additional nuisances on the vegetation and the soil (Stormwater Center, 2011a). The removal rates of different contaminants are shown in Table 3.

Table 3: Pollutant removal for stormwater wetlands. Study 1: (Brown et al., 2001b), Study 2: (Winer, 2000), Study 3: (Doll & Hunt, 2000)

			Pollutant removal(%)				
Study:	**TSS**	**TP**	**Sol P**	**TN**	**Nox**	**Cu**	**Zn**
1	80	40	--	30	--	50	50
2	76	49	35	30	67	40	44
3	78	51	--	21	67	39.5	53.5

There is a big variation in the margin of difference, which in Winer (2000) and Doll & Hunt (2000) for some pollutants reach well over 50%. As written before; differences in construction, maintenance and location characteristics are important contributing factors to a diverse result (Doll & Hunt, 2000).

3.2.5 Additional benefits

Except from treating the stormwater runoff and reducing peak flows, there are several other benefits connected to stormwater wetlands. An abundant biodiversity and prosperous vegetation is the result of a successful implementation. These consequences further enhance the amenity of the area. This increased concinnity of the area creates new opportunities for relaxation and recreation (CRWA, 2008).

Another benefit derived from the construction of a well-functioning stormwater wetland is highlighted by USEPA (2006b). According to studies made in the field, the property value of land adjacent to wetlands may rise between 10-25%, creating an economic incentive for implementing these solutions (USEPA, 2006b).

The construction of wetlands may also replace the construction of a conventional pipe-system in the selected area. In Toftanäs Wetland Park, calculations showed that the cost of constructing the wetland and the calculated costs for a pipe system removing the same amount of water were didn´t differ much. If the water from the area had to be transported through pipes to the closest recipient, about a kilometer away, that would have resulted in an additional cost of about 30% for the pipe system (Stahre, 2008).

Czemiel Berndtsson (2004) writes about the possibility to use stormwater wetlands for certain types of aquaculture, when the surrounding conditions are suitable. Some examples of limited amplitude are discussed, but the author points out that there are yet no reports where crops in stormwater wetlands have been harvested on a regular basis.

3.2.6 Limitations

As with all SUDS-solutions there are some negative aspects with stormwater wetlands. As brought up earlier in this paper, the space requirements are often seen as a limit of the implementation possibilities. In climates with distinct seasons there is often a release of nutrients in the fall, due to the decrease and decaying of vegetation. The colder temperature also makes the processes less effective (Anderson et al., 2001a). Further elaborations about the consequences in temperatures below zero are evaluated earlier in this text.

In some cases the wetland may have an impact on the subsequent recipients. If the biota in recipients preceded by the wetland is sensitive to heat fluxes, it may be negatively affected due to the fact that the shallow pools of the wetlands make the temperature of the water shift quicker than it would have done in a deeper pool (Anderson et al., 2001a).

3.3 Infiltration devices

3.3.1 Quick summary

Top Picture: (TRCA et al., 2010)
Bottom Picture: (TRCA et al., 2010)

Key considerations:

- **Design Variations:**
  Permeable paving
  Infiltration trenches
  Soakaways
  Infiltration basins
  Bioretention areas (Rain Gardens)

- **Drainage area:**
  Varies, normally relatively small

- **Areal requirements:**
  Varies depending on the solution

- **Stormwater management:**

- Quality control:	High
- Quantity control:	Low-Average

- **Pollutant removal:**

TSS:	90%
TP:	50-80%
TN:	45-50%
Heavy metals:	40-95%

- **Treatment processes:**
  Mainly filtration. Sorption and microbial uptake on a limited basis.

General information: Infiltration devices work by relocating surface water to areas with permeable soil, and retaining it there until the water has time to percolate through the ground to the underlying soil.

Advantages:

- Good for retrofitting.
- Some solutions may be constructed under existing installments, e.g. parking areas
- May provide groundwater recharge where suitable
- Diverse solutions applicable in different conditions
- The infiltration mechanism prevents puddeling of water

Disadvantages:

- No additional recreational values (Bioretention areas not included)
- Limitations of implication due to soil conditions
- High rate of failure

3.3.2 Introduction

In the context of SUDS, infiltration refers to when groundwater is penetrating the soil. Infiltration devices work by relocating surface water to areas with permeable soil, and retaining it there until the water has time to percolate through the ground to the underlying soil (NCDENR, 2007b). Infiltration devices works through reducing stormwater flow and the amount of pollutants reaching the recipients. The techniques are established methods of handling stormwater, and are particularly popular in Europe and Japan (Hatt, Fletcher, Deletic, 2007).

The natural ability for the soil to drain water from the ground is often enhanced by infiltration devices. Due to an often large contact area with the soil, the water has an easier way percolating into the ground (Ciria, 2011c). In many urban areas around the world, over-abstraction of groundwater is a common problem. An extended usage of infiltration devices may increase the stormwater contribution to the recovery of stressed aquifers. The potential benefits of recharging the aquifer must be balanced with the possible threat of groundwater contamination, as a result when pollutants are not sufficiently removed from the stormwater before infiltration (Ellis, 2000). It is also important to find a balance in the recharge. If the permeability of the applied infiltration device and the soil is particularly high, there will be large fluctuations in the groundwater table connected to storms. If the recharge is too extensive, the underground waterways can alter, and polluted stormwater may be transported to abstraction zones (Ellis, 2000). Another consequence of altered levels of groundwater is mentioned by NCDENR (2007) bringing up the possibility of groundwater seeping into foundations and basements, if the infiltration devices aren´t sited correctly. The performance of infiltration devices is somewhat erratic, and the rate of failures is high. According to Ellis (2000), within a 5-year time-span, between 50-75% of some solutions will not work as designed. Infiltration rates decrease significantly due to clogging by fine materials in the infiltration pores (ibid.). Inappropriately big drainage areas often create a stress and results in a reduced performance. No maintenance or insufficient pretreatment, like removal of sediments and litter, are some other common concerns leading to reduced infiltration capacity (Ellis, 2000). According to Hatt, Fletcher, Deletic (2007), the full effects of the infiltration and treatment processes aren´t fully understood yet. Results from tests and studies are often “snapshots” of temporary performance, while the long run outcomes may be very inconsistent. Knowledge about accumulated pollutants and their impacts on the devices are yet limited (ibid.).

Infiltration systems are easy to integrate in different environments, and solutions may be used in areas ranging from parking lots to public parks (Ciria, 2011c). With such a diverse applicability, Hatt, Fletcher, Deletic (2007) urges for further research in the area of pollutant-removal for infiltration devices, to better understand which results to expect.

3.3.3 Treatment

The mechanisms primarily contributing to the treatment are mechanical and physic-chemical filtration taking place in in the device´s infiltration system. Chemical and biological processes contribute to the treatment of the water, however on a limited basis (Hatt, Fletcher, Deletic, 2007). The removal rate of contaminants for a well-functioning infiltration device is relatively high. Studies summarized by Winer (2000) and experiments made by Hatt, Fletcher, Deletic (2007) show the levels of pollutant removal presented in Table 4.

Table 4: Pollutant removal for infiltration devices. Study 1: (Winer, 2000), Study 2: (Hatt, Fletcher, Deletic, 2007)

			Pollutant removal(%)					
Study:	**TSS**	**TP**	**Sol P**	**TN**	**Nox**	**Cu**	**Zn**	**Pb**
1	95	80	85	51	82	--	99	--
2	92	53	--	44	12	62	38	80

As seen from the results, values tend to vary quite significantly. This variation in performance may be due to the area characteristics, climate and the different set of techniques assembled under the name of infiltration devices, reviewed below.

There is a miscellaneous selection of infiltration devices. The fundamental technique of operation is the same, though the implementation varies a lot. In this paper a perspicuous review of the different methods will be presented. Some of the commonly used infiltration devices are:

1. **Permeable paving**
2. **Infiltration trenches**
3. **Soakways**
4. **Infiltration basins**
5. **Bioretention areas (Rain Gardens)**

(Ciria, 2011c; Hinman, 2005)

Following is a shorter explanation of each of these five techniques.

3.3.4 Permeable paving

Permeable paving is an alternative to the normal impermeable alternative, commonly used in urbanized areas. Infiltration and treatment is mainly conducted through the filtering process. The mechanisms and general removal rates are as explained above in the description of infiltration devices. Permeable paving is commonly used for low traffic roads, parking lots, driveways, pedestrian plazas and walkways (TRCA et al., 2010). According to Hinman (2005), high traffic roads such as highways have not been considered suitable for these solutions, much due to the heavy load these are subjects to.

When constructing permeable paving, there is a wide range of solutions to choose from. The most commonly used pavers are pervious concrete, permeable interlocking concrete pavers, plastic or concrete grid systems, and porous asphalt (Hinman, 2005). Compacted gravel is however not considered a permeable pavement (NCDENR, 2007c).

Where to implement this solution is highly dependent on the soil conditions and the level of groundwater. The base of the permeable paving should be, according to TRCA et al., (2010), at least one meter above the seasonally high groundwater level. The soil characteristics are important in deciding if sufficient infiltration to the ground is possible for the devices to function properly. The United States Department of Agriculture – Natural Resources Conservation Service (USDA-NRCS) has defined that no finer texture than Loamy Very Fine Sand is acceptable beneath a permeable paving (NCDENR, 2007c). One big pro with permeable paving is the area-requirements. For retrofitting purposes or at sites with limited areas, there may not be space for implementing many of the SUDS-techniques, which often are relatively area-demanding. Here permeable paving is ideal, since no additional space needs to be accounted for, but the solution can be realized on an already urbanized area (TRCA et al., 2010). The main concern for these devices is often the risk of clogging in the infiltration canals, leading to a reduced capacity or a total failure in performance. To avoid clogging TRCA et al., (2010) suggests measures like ensuring sufficient vegetation in adjacent areas for removal of sediments before reaching the permeable paving, regular maintenance such as sweeping, and a specific maintenance plan for colder climates which does not include sanding. It is important not to have a too big drainage area for the permeable paving (Hinman, 2005). The impermeable drainage area shouldn´t exceed 1.2 times the permeable paving receiving the water (TRCA et al., 2010). Since most pollutants are removed before infiltrating the ground, there is little risk of underlying soil or groundwater contamination, according to TRCA (2008).

Constructing permeable paving contributes with other benefits, apart from reduction of flow and contaminant removal. Since the thermal conductivity is lower in porous materials, the urban heat effect is reduced when comparing to areas with normal pavement. In colder climates, the rapid drainage from thawing snow reduces the creation of puddles and flooding in parking lots. To some extent, noise levels are also reduced, since porous materials absorb more of the sound energy (TRCA et al., 2010). For more detailed information, Hinman (2005) or TRCA et al., (2010) are good sources of information.

3.3.5 Infiltration trenches

Infiltration trenches are of a rectangular shape. Lined with geotextile fabric and filled with a void-creating material such as clean granular stones, these devices work through, as the name explains, infiltration and temporary detention of the stormwater (TRCA et al., 2010). These devices are designed to receive water from a small drainage area, no bigger than 2 hectares according to , MAPC (2011a). A larger area increases the risk of clogging, and often results in more extensive maintenance work (USEPA, 2006c). To prevent clogging and a failure of the system, pretreatment of the water before entering the infiltration trench is often recommended. Filter strips, swales with a check dam or sediment basins are some suitable pretreatment devices (CCSWMD, 2004).

During construction of the trench, it is important that preemptive treatment techniques mentioned above are implemented before installing the infiltration trench, to make sure sediments and particles are taken care of, and not get the opportunity to reach the trench during the installation (USEPA, 1999a).

In the infiltration trenches, water is stored in the voids of the ballast before infiltrating the ground. Using this solution is a good way of recharging groundwater, thus mitigating conditions of the natural biota in the area (MAPC, 2011a). As for any infiltration device, the risk of groundwater contamination must be carefully analyzed before the installment. TRCA et al., (2010) writes that the infiltration practice normally prevents most of the stormwater pollutants from reaching the groundwater, estimating the contamination potential to small or moderate. The same review refers to studies concluding that the risk of contaminating the surrounding soil also is small, even after 10 years of practice (TRCA et al., 2010). The soil characteristics must, like for all infiltration devices, be suitable for infiltration, meaning a reasonable permeability of the soil. Same preconditions as for other infiltration devices regarding the groundwater table apply for infiltration trenches as well. To put it simple, groundwater table must be on a lower level than the trench, for the infiltration to function correctly (USEPA, 1999a).

To be able to perform without complications, the slope of the adjacent catchment area shouldn't exceed 12%. A steeper gradient will increase the possibility of seepage from the subgrade to the ground surface at lower elevations. Another important consideration is to make sure that the bottom, where much of the infiltration will take place is totally flat. This allows the water to percolate the ground at all parts of the device, thence creating an as large as possible infiltration area (USKH Inc., 2008).
When maintained properly, these devices are expected to have longevity of some decades, where after the ballast may need to be changed (Stahre, 2006).

In highly urbanized areas Infiltration trenches are not recommended, due to the often compacted, impermeable soil in cities, and because of the required separation from foundations (MAPC, 2011a). The risk of contaminated infiltration from e.g. gas stations is another reason to consider before installing infiltration trenches in urban areas (USEPA, 2006c). In cold climates, these trenches may function well if properly constructed. Considerations that need to be taken to have a well-functioning device in the winter are the removal of snow and ice from the trench surface, and installing the device at a depth deeper than the frost line to preserve the percolation during the colder months (MAPC, 2011a).

Infiltration trenches are often used where there is a limit of space, or when the available area is of a narrow shape (CCSWMD, 2004). The device normally covers around 2-3% of the drainage area, which is to be considered as relatively small space requirements (USEPA, 2006c). The maintenance cost of infiltration trenches are generally around 5-10% of the installation cost on a yearly basis, according to CCSWMD (2004). Unlike many other SUDS, infiltration trenches give no extra recreational values and do not contribute to the amenity of the area (MAPC, 2011a). There is little specific data available about the treatment efficiency when it comes to infiltration trenches. Because none of the rainwater entering the trench remains on the surface, a high level of pollutant removal is assumed (USEPA, 2006c).

3.3.6 Soakaways

Soakaways are very similar in construction to infiltration trenches. Just like with preceding device, a void-creating material such as granular stones is put in a trench lined with geotextile fibers (TRCA et al., 2010). What is different between two solutions are mainly the means by which the water reaches the devices, but there are also some structural and positional differences (USKH Inc., 2008). While Infiltration trenches get the water from an adjacent drainage area, soakaways receive it by an inlet pipe, offering an alternative when it isn´t possible to divert the stormwater runoff directly from an infiltration area (Stahre, 2006). Soakaways do not need to have the shape of rectangular trenches, but may be designed with different shapes and are commonly constructed as rectangular or circular excavations (STEP, 2009). USKH Inc. (2008) writes that soakaways are often designed to receive stormwater from roofs, and that the device will occupy around 4% of the contributing area (USKH Inc., 2008).

Because of its great similarities, functional characteristics are very similar for soakaways and infiltration trenches. Many guides to SUDS, including TRCA et al., (2010), put the two structures in the same chapter when revising its properties. So for a perspicuous review about collective abilities, limits and considerations, viewers are asked to read preceding section about infiltration trenches.

3.3.7 Infiltration basins

Sharing similar characteristics as previously mentioned techniques, infiltration basins enjoy many characteristics of the infiltration trenches and soakaways. TRCA et al., (2010) describes the infiltration basin as a variation of soakaways. The design properties differ quite substantially though. While the two techniques mentioned above handle limited amounts of water, Infiltration basins are designed to handle large amounts of stormwater, stored in underground void-spaces (STEP, 2009). An infiltration basin consists of an underground modular system with perforated walls and an optional underlying granular stone reservoir, where water is temporarily stored before percolating into the underlying soil (TRCA et al., 2010). These underground basins can be installed separately or in coherent series, allowing the construction of very large voids (ibid.). Provided there is some pretreatment to remove sediments, infiltration basins can receive water from roofs, parking lots, walkways and roads (STEP, 2009). The solutions are typically constructed under parking lots and landscaped areas, where there is no space available for other SUDS, and where there is a desire to have a minimal footprint of the installation (TRCA et al., 2010). Because of palpable similarities in functional characteristics to the techniques mentioned above, a review about collective abilities, limits and considerations is to be found in preceding section about infiltration trenches.

3.3.8 Bioretention areas

Also called Rain Gardens, bioretention areas originate from Prince George’s County in Maryland in the 1990’s (Andoh, 2011). A bioretention area consists of a depression in the ground, filled with soil and various types of vegetation (NCDENR, 2007d). These are often small-scale facilities, dispersed over an area, as integrated parts of the ambient environment (Hinman, 2005). These SUDS solutions are engineered to intimately mimic the natural conditions and often bringing amenity values to the site of implementation. Over time, the bioretention solutions have developed, and there are today a number of different designs. Some areas where these solutions are commonly applied are parking lot islands, median strips and traffic islands (MAPC, 2011b).

When evaluating infiltration devices, bioretention areas are the only solution increasing the recreational value in the area of implementation. The vegetation is an important feature, not only because of esthetic reasons, but also for the plants abilities to ameliorate the performance of contaminant removal. The spreading of the root system promotes percolation into the soil, and the vegetation will provide treatment for the water by biological uptake of pollutants and nutrients from the stormwater (USKH Inc., 2008). As for all infiltration devices, bioretention areas operate through storage and infiltration, reducing peak flows and partially treating the stormwater. Bioretention areas may be constructed as an isolated feature, but best results are achieved when part of a SUDS management train (ibid.). The best results in bioretention areas are achieved when the stormwater gets some pretreatment before entering. Pretreatment may be conducted by swales or narrow filter strips, which help removing some of the sediments reducing the possibly of clogging the system and reducing the drainage capacity (MAPC, 2011b). The construction is very versatile, and depending on the characteristics of the soil, the systems may be designed with or without underdrains. An impermeable linear may also be installed under the system, if percolation into the soil isn´t possible (TRCA et al., 2010). When constructed with an underdrain, Hinman (2005) writes that there is less retention of flow rates and less reduction of peak flows. If designed in highly urbanized areas with a space limitation, the constructions may have vertical sides, while gentle slopes often are adapted in areas with pre-urbanized conditions (TRCA et al., 2010). Regarding retrofitting, bioretention areas are one of few SUDS which are possible to implement in highly urbanized areas. USEPA (2006d) warns however that even though there is a possibility to implement these solutions, the cost of using small-scale solutions like bioretention areas for treating a large watershed may be very expensive (MAPC, 2011b).

Bioretention areas are designed to retain water particularly from small storm events. The amount of water a device can receive is limited. TRCA et al., (2010) underlines the necessity of having an overflow bypass, for heavy storms. The contributing drainage area shouldn't exceed 2 hectares for a single bioretention area, according to USKH Inc. (2008). The review however continues by concluding that the water from a significantly larger area may be treated, if multiple rain gardens are connected, or if these solutions are a part in a coherent SUDS chain of multiple solutions.

Being an infiltration device, bioretention areas may provide some help in recharging groundwater levels where appropriate. When designing the bioretention pond, a gentle slope is preferably incorporated in the design. This is to make sure that the water, whilst detained, also has a gentle flow over the surface (LIDC, 2007c). USEPA (2006d) continues the reasoning and establishes that parking lots and landscaped areas often are constructed with a small slope, which is yet another reason why bioretention areas are popular solutions in these areas. The ponding time of the water shouldn´t exceed four days, according to F. X. Browne, Inc. (2007). Many design manuals, including TRCA et al., (2010) suggests however that the drawdown time of the surface pool shouldn´t exceed 24 hours. 24 hours is less than the breeding cycle for mosquitos. By implementing the limit of a day, inconveniences with mosquitos will be avoided (TRCA et al., 2010). When constructed on a slope steeper than 20%, terraces may be required to avoid water entering the design with too high velocity, which may result in the removal of soil from the area and an inadequate contaminant removal (MAPC, 2011b). Infiltration devices, including this technique, are commonly seen as good at removing pollutants from the stormwater, hence only contributing to a low or moderate risk of groundwater and soil contamination even after a decade of running (TRCA et al., 2010). There are several mechanisms working to treat the water. These active treatment mechanisms include filtration, adsorption to soil particles and biological uptake by plants (F. X. Browne, Inc., 2007). With the specific case of bioretention areas, there is only a limited amount of studies, which makes the results somewhat uncertain (USEPA, 2006d). There are some studies done though. LIDC (2007c) refers to laboratory and field studies from the University of Maryland, indicating excellent results in removing heavy metals such as Pb, Zn and Cu. The efficiency rate of removal was here well over 90%, with small deviations in the results (ibid.).

In colder climates, Bioretention areas may provide a conveniently located area for snow storage and subsequently also treatment of the melt water (TRCA et al., 2010).

3.4 Swales

3.4.1 Quick summary

Top Picture: (TRCA et al., 2010)
Bottom Picture: (Brown et al., 2001b)

Key considerations:

- **Design variations:**
  Grassed channels
  Wet Swales
  Dry Swales
  Enhanced Swales

- **Drainage area:**
  Maximum: 2 hectares

- **Areal requirements:**
  1-15% of drainage area

- **Stormwater management:**
  - Quality control: Medium
  - Quantity control: Runoff slowdown

- **Pollutant removal:**

TSS:	80%
TP:	10-35%
TN:	80%
Heavy metals:	15-70%

- **Treatment processes:**
  Settling, infiltration and biofiltration

General information: The term swale refers to a number of different vegetated, open channels designed to attenuate and treat stormwater runoff on its way downstream. These systems work both as transport systems and infiltration devices for stormwater.

Advantages:

- Partially increase the amenity values of an area
- Mitigates groundwater conditions through infiltration
- Low installation costs
- Relatively low maintenance costs
- Adjacent to roads, it may provide a valuable habitat for the biota

Disadvantages:

- Often contributes to an increase in bacteria
- Puddles may be created, being a breeding ground for mosquitos and creating odor-problems
- Sensible to high flow rates, which may create increased erosion and a re-suspension of sediments.

3.4.2 Introduction

The term swale refers to a number of different vegetated, open channels designed to attenuate and treat stormwater runoff on its way down the flow path (Stormwater Center, 2011c). Stahre (2006) describes swales as a grassed shallow drainage ditch with flat side slopes. These systems work both as transport systems and infiltration devices for stormwater (Stahre, 2006).

According to Stormwater Center (2011c), all swales can be seen as improvements of traditional ditches. There are a number of different variations when it comes to the design of swales. Some of the most common variants are the following:

Grassed channel

Grassed channels enjoy most similarities to a normal ditch among the different types of swales. What distinguish the grassed channel from a ditch are the small longitudinal slope and the flat sides, designed to attenuate the flow velocity of the water, hence increasing the retention time and treatment processes. An important difference between grassed swales and other SUDS is the fact that with swales, designs are based on a flow rate, while usually a quantity of water decides the design limitations. The average time for water to pass through the grassed channel should be around ten minutes (Stormwater Center, 2011c).

Dry swales

Dry swales have great similarities in design to bioretention areas. Here, the entire quantity of water from a rainfall is temporarily stored in a pool, or a series of pools (Anderson et al., 2001c). Soil or sand with the right requirements for permeability is put on top of an underdrain system. A perforated pipe leads the water, treated by the soil layer above, from the dry swale to the subsequent step in the drainage system (Stormwater Center, 2011c).

Wet swales

A wet swale has many similarities in performance to a wetland. A wet swale is created when the installation is located close to, or at the same altitude as the groundwater surface. Unlike dry swales, the top soil layer isn´t changed, the swale is constructed directly in the existing soil. The wet swale basically works as a long and linear shallow wetland. As with dry swales, the entire quantity of the water from a rainfall is temporarily stored in a pool, or a series of pools (Anderson et al., 2001b).

Enhanced swales

Enhanced swales incorporate the design of a grassed channel, with the addition of heavier vegetation and check dams, which both has the function to attenuate the water flow, and enhance the treatment processes. These solutions are constructed on existing soil, and no improvements are normally made to enhance its permeability. This lack of permeable soil layers in certain areas makes this technique unable to provide the same consistency in water quality and water balance benefits as dry swales (TRCA et al., 2010).

3.4.3 Applicability and design

Swales are successfully applicable adjacent to parking areas, commercial and light industrial facilities, roads and highways, residential developments, and are often implemented as an alternative to curbs/gutters and storm sewers (Cahill Associates Inc., 2006). Normally, swales are located along the impervious area it is to drain, and runoff may enter the swale all along its length (Stahre, 2006). To increase the storage capacity of the swale, a feasible solution is to design a soakaway under the bottom of the swale (ibid.). Brown et al., (2001b) indicates that the side slopes should be maximum 3:1 to ensure as large a wetted perimeter as possible, thereby contributing to a high efficiency of the solution.

Normally, swales take a parabolic or a trapezoidal design (Cahill Associates Inc., 2006). The longitudinal slope should not exceed 4%, and should preferably be around 1-2%, according to TRCA et al., (2010). If the slope is too steep, water velocities become too high, which may result in erosion and inadequate infiltration to the soil (Stormwater Center, 2011c). If dimensioning for the biggest estimated flow with a recurrence time of two years, VADCR (1999) writes that the maximum flow should be 1,2m/s, and if dimensioning for a rain with an estimated return period of ten years, the largest flow should be 2,1m/s. To get a good treatment of the water, KCDEPW (2008) suggests a flow velocity of 0.3 m/s as a maximal limit. However, if the longitudinal slope is too flat, ponding may occur. To help reduce the risk of ponding water, an underdrain below the swale may be constructed (NCDENR, 2007e). To mitigate the flow of the water, the natural drainage patterns should be followed to an as big extent as possible (NCDENR, 2007e). Important questions where further studies are being conducted are how the slope affects the infiltration rate, how the performance changes over time and the effects of e.g. check dams in enhanced swales (USEPA, 1999b).

Though often used as an isolated SUDS-technique, the best results are achieved if Swales are put in conjunction with other SUDS, such as wetlands, ponds or filter strips (USEPA, 1999b). KCDEPW (2008) also suggests swales as a pretreatment measure for bioretention areas and other infiltration devices. Swales may be suitable for retrofitting in some cases, especially when it comes to converting traditional dikes or gutters (Stormwater Center, 2011c).

Of importance is the precondition that the entire structure of the swale (with the exception of wet swales) is constructed above the groundwater level, in similarity to all techniques utilizing infiltration processes (Stahre, 2006). By doing this, a moist bottom is avoided, and the risk of groundwater contamination is reduced. The swales should be located at least 0.6 meters above the groundwater surface (TRCA et al., 2010). When infiltrating water to the ground, swales can also provide a certain groundwater recharge. Debris and settled sediments on the bottom of the swale can however obstruct water from infiltrating the ground, and need to be removed on a regular basis ensure a high performance (USEPA, 2006e).

When designing swales, size can be decided through the usage of Manning’s Equation, but a rule of thumb to facilitate the procedure is to install swales on at least 1% of the drainage area (USEPA, 1999b). TRCA et al., (2010) on the other hand writes that a suitable size for the swale is about 5-15% of the contributing drainage area. This area for swales is normally smaller than 2 hectares (Stormwater Center, 2011c). The efficiency in performance is often directly proportional to the maintenance frequency. Maintenance includes keeping a thick grass cover, removing excess sediments, repairing damaged areas and handling possible puddles created (USEPA, 1999b).

In cold climates swales may be used as snow storage areas (TRCA et al., 2010). Plants able to sustain cold temperatures should be selected. When close to roads, it is important to consider using vegetation not sensitive to high amounts of salt (Stormwater Center, 2011c).

3.4.4 Treatment

Swales remove pollutants from the stormwater by settling, infiltration and biofiltration (NCDENR, 2007e). The water is treated by these techniques while slowly running through the swale (ibid.).
According to Stormwater Center (2011c) there are few studies available regarding the treatment capacity of swales. There are significant variations between the removal of different contaminants, and in some cases there may even be an increase. Table 5 summarizes some data available from studies in the field:

Table 5: Pollutant removal for Swales. Study 1: (Winer, 2000), Study 2: (USEPA, 1999b), Study 3: (Schueler, 1997)

Pollutant removal(%)								
Study:	**TSS**	**TP**	**Sol P**	**TN**	**Nox**	**Cu**	**Zn**	**Bacteria**
1	81	34	38	84	31	51	71	--
2	81	9	--	--	38	51	71	--
3	81	29	--	--	38	14 -55	14 - 44	-50

The results from Winer (2000), is collected from National Pollutant Removal database, summarizing several existing studies in the field. Information from USEPA (1999b) also summarizes a number studies. The third study performance is found in a review by Schueler (1997). As seen in Table 5, many figures from different studies correspond very closely to each other. This may be because, as written above, there are only a limited number of studies in the field, which may lead to the conclusion that the summaries above in some cases may have used values from coherent studies.

In general, grassed channels have a poorer removal rate than wet and dry swales (USEPA, 2006e). To improve removal rates, check dams may be added to the construction, just like in the case of enhanced swales. This is done to decrease the flow velocity, hence maximizing the retention time and promoting biological treatment and the settling of sediments (USEPA, 1999b). For more extensive data about performance for different types of swales in the United States, USEPA (2006e) has collected information from a number of studies.

Regarding bacteria, studies actually show an increase in growth. USEPA (2006e) writes that the reasons for this growth are not fully understood yet. A possible reason suggested in the review is that the warm swale soils provide a favorable environment for bacteria. Other mentioned reasons are inputs from animals reaching the swales, or excrements from dogs being walked next to the swales (USEPA, 2006e).

3.4.5 Additional benefits

Swales can to some extent provide an increase in the amenity values of an area. Additional vegetation may contribute in enhancing the esthetical values of the swale (NCDENR, 2007e). The flow retardation provided by swales may be valuable in some residential areas, and may in some cases mitigate or prevent e.g. flooding of basements, due to a peak flow reduction (Stahre, 2008). As written earlier, infiltration from swales may also help mitigate groundwater conditions in certain areas (Brown et al., 2001b).

Economically, swales may be beneficial to construct, since the installation costs are lower than for e.g. curbs and gutters (NCDENR, 2007e). Compared to other SUDS, the maintenance costs are considered to be relatively low (KCDEPW, 2008). If the vegetation is not cut, swales adjacent to roads may provide a valuable habitat for the biota, similar to the ones in wet meadows (NCDENR, 2007e).

3.4.6 Limitations

Some limitations, like the increase of bacteria have been discussed earlier in this text. Other negative aspects connected to the installation of swales may be that when swales do not drain properly, puddles are created. These puddles may lead to an infestation of mosquitoes and problems with odor, if not taken care of immediately (USEPA, 1999b).

High flow rates in the swales may also create increased erosion and a re-suspension of sediments (KCDEPW, 2008; USEPA, 1999b).

3.5 Filter strips

3.5.1 Quick summary

Top Picture: (Brown et al., 2001b)
Bottom Picture: (TRCA et al., 2010)

- **Length of contributing area:**
  Impermeable surface: 23 meters
  Permeable surface: 46 meters

- **Areal requirements:**
  Often 50% of drainage area

- **Slope of adjacent drainage area:**
  Preferably 2-6%,

- **Stormwater management:**

- Quality control:	Low-Medium
- Quantity control:	Low

- **Pollutant removal:**

TSS:	50-85%
TP:	-25-40%
TN:	20%
Heavy metals:	-30-55%

- **Treatment processes:**
  Sedimentation, biological, physical and chemical processes

General information: Filter strips are areas of grass or other vegetation with a gentle slope, designed to receive water from impervious areas. For a filter strip to work successfully, it must receive the stormwater as a sheet flow.

Advantages:

- Provides some increase in biodiversity
- Low installation costs
- Low maintenance costs
- Mitigates groundwater conditions through infiltration
- Can serve as a visual barrier to eyesores like industries, parking lots or roads.
- May intercept blowing dust from e.g. construction sites

Disadvantages:

- Limited removal rates with high variations
- Limited flow reduction
- Needs a sheet flow to function, which leads to areal limitations of implementation
- Space-requiring
- Difficult to monitor

3.5.2 Introduction

Filter strips are also known as vegetated filter strips, grassed filters strips and grassed filters (Stormwater Center, 2011d). In general terms, filter strips are areas of grass or other vegetation with a gentle slope, designed to receive water from impervious areas (TRCA et al., 2010). Filter strips were earlier mainly used for agricultural treatment purposes, planted strategically between fields and the receiving recipients to reduce contaminants from field runoff. Today however, the potential of filter strips are being recognized by urban developers, and is now frequently used as a Sustainable Urban Drainage method (USEPA, 2006f).

This solution is often built adjacent to parking lots, driveways, roof downspouts or roads (TRCA et al., 2010). The design works through decelerating the runoff, allowing infiltration, and particles to settle on its way to the recipient (Belan & Otto, 2004). The deceleration is however modest, writes USKH Inc. (2008), and the level of retardation in the filter strip depends on characteristics such as available area, slope, vegetation and soil type.

For a filter strip to work successfully, it must receive the stormwater as a sheet flow. This means that there must be an equal amount of water running over all parts of the strip, and not concentrating to certain parts. To achieve this, the drainage area supplying the water must be relatively uniformly graded, and have a horizontal downstream edge where it meets the filter strip (Blick, Kelly, Skupien, 2004). The strip itself must also have a uniform, mild slope in order to keep the sheet flow. These features make the filter strips inappropriate for receiving concentrated flows from e.g. canals or swales (ibid.). Though not succeeding these installations, filter strips may instead serve as a pre-treatment step for stormwater, before subsequently entering into canals or swales (Axler et al., 2009). Filter strips treat the water from small drainage areas, normally not larger than 0.4 hectares. A larger area can be accepted, if multiple filter strips are used in combination (USKH Inc., 2008).

3.5.3 Applicability

Filter strips should be around 6 meters wide and about 15 – 23 meters long. For these solutions it is not the runoff area that is the most important, but the length of the water flow before it reaches the stip. The contributing area shouldn´t be longer than 23 meters if it is impermeable surfaces, and 46 meters for permeable surfaces (Stormwater Center, 2011d). Maintenance of a filter strip includes removing excess debris and sediments accumulated, especially after storms. Providing regular maintenance of the vegetation in the strip and repairing possible damages of the system are other measures which ought to be done on a regular basis (Blick, Kelly, Skupien, 2004). When nutrients and sediments build up in the vegetation, the treatment potential of the filter strip decreases writes Brown et al., (1994), an observation which attests the need of regular maintenance. Sometimes fertilizers or pesticides are used to enhance the vegetation of the filter strip. This is somewhat contradictory to the fact that these installments are implemented to remove redundant nutrients and harmful substances from the stormwater. Blick, Kelly, Skupien (2004) writes that any use of substances to enhance the vegetation cannot compromise the function of the system, and should only be considered in rare exceptions.

To prevent erosion, the top and bottom parts of the filter strips should be flatter than the rest of the strip (TRCA et al., 2010). Adding a layer of topsoil should be avoided or done with great caution, since this soil erodes easily in the event of a storm. Healthy vegetation and a soil with an adequate permeability are coveted features for filter strips (Belan & Otto, 2004). It is important to have a bypass system available when heavy storms occur, in order to prevent washout damage. Overflows may occur relatively frequent, since filter strips aren´t designed to handle events bigger than a two- or three-year storm (Axler et al., 2009). Filter strips should be placed at least 0.6 – 1.2 meters above the groundwater table, in order to minimize the risk of groundwater contamination, and to make sure the strips dry up between storm events (Stormwater Center, 2011d). According to Belan & Otto (2004), a filter strip can reduce the annual runoff with up to 40%. Plants used in filter strips should be able to deal with extremes in water supply, withstand water flows and preferably have a texture that enhances the filtration of pollutants (Axler et al., 2009).

To ensure good performance from a filter strip, the drainage area shouldn´t slope more than 10% (USKH Inc., 2008). The best results are attained with a slope of 2-6%, but Belan & Otto (2004) writes in their review that the treatment processes may function for slopes with up to 15% tilting. Deletic, & Fletcher (2006) echoes the statement and even brings it further, writing about a study showing excellent suspended solids performance in a filter strip with a 23% tilt. Variations in performance indicate significant difference in local conditions.

To assure an adequate contaminant removal, design criteria like maximum flow rate may be used. USKH Inc. (2008) writes that limits often used for maximum velocity of the water in the filter strip is set to 0.27 meters per second, and the maximum depth of the designed flow is 1.25 cm (USKH Inc., 2008). A higher velocity may cause erosion and re-depositing of sediments (Deletic, & Fletcher, 2006).

In cold climates, filter strips are convenient for storage of snow and treatment of melt-water. In regard to the cold weather, it is important to consider using salt-tolerant vegetation and having a management plan for removing sand and other sediment, released by the snow when thawing occurs (Stormwater Center, 2011d).

3.5.4 Treatment

The processes through which the filter strips treat the water from pollutants are sedimentation, adsorption, filtration, biological uptake, infiltration and microbial activity. Through these processes stormwater pollutants like sediments, heavy metals, hydrocarbons and nutrients are removed (Blick, Kelly, Skupien, 2004).

The effect of removing sediments is greatest the first 2.4 – 3.7 meters. After this distance, most of the sand and silt particles are sedimented, whilst finer medium like clay particles often need a longer filter width to efficiently settle (Brown et al., 1994). This result is underlined by Deletic, & Fletcher (2006), reviewing the results from a field study in Aberdeen. Only a very limited amount of small particles (>57 μm) were trapped in the entire filter strip. The length of the strip needed to trap particles larger than this size above, was dependent of the flow rate. A slower velocity of the stormwater results in a better treatment, since the particles have an easier time to settle (Deletic, & Fletcher, 2006).

Blick, Kelly, Skupien (2004) suggests in their report a simplified perspicuous way of determining the removal rates of TSS. Here, the vegetated cover of the filter strip will decide the level of sediment reduction. According to the source, turf grass gives a 60% reduction, native grasses, meadows and planted woods give a reduction of 70%, and indigenous woods give a TSS reduction of 80% (Blick, Kelly, Skupien, 2004).

There is a very limited amount of monitoring and field studies when it comes to filter strips in urban environments. Most developed models are done for agricultural environments, and are not fully applicable when studying urban environments (Deletic, & Fletcher, 2006). USEPA (2006f) writes that only few studies have investigated the effectiveness of pollutant removal for these kinds of filter strips, e.g. adjacent to parking lots. A study from Yu, Barnes, Gerde (1993) reported in Stormwater Center (2011d) investigates however removal rates near parking lots, in a 23-meter and a 46-meter filter strip. Another summary of average contaminant reduction concluded from sampling data, modeling and professional judgment is published in a report from Brown et al., (2001b). Table 6 shows a summary of the results in contaminant removal from mentioned sources:

Table 6: Pollutant removal for filter strips. Study 1: (Stormwater center, 2010d), 23 m filter strip, Study 2: (Stormwater center, 2010d), 46 m filter strip,, Study 3: (Brown et al., 2001b)

	Pollutant removal(%)					
Study:	**TSS**	**TP**	**TN**	**NOx**	**Pb**	**Zn**
1	54	-25	--	-27	-16	47
2	84	40	--	20	50	55
3	50	20	20	--	40	40

Like with all SUDS-devices, variations in performance depend on the design features of the strip and local circumstances. As seen in Table 6, pollutant removal varies significantly depending on the length of the water flow in the stormwater in the strip. While enjoying the same preconditions apart from the flow length, the results of study 1 and 2 vary a lot. In the narrow strip, the pollution removal was moderate, even exporting some contaminants like nutrients, phosphorus and lead while the broader strip showed relatively good results in contaminant removal. Unfortunately the document gives no further explanation of possible reasons for the exportation of pollutants in the narrow filter strip.

Studies about agricultural runoff, evaluating removal of nitrogen, phosphorous and sediments, display better results than what is observed from filter strips installed in urban environments. In a report from Brown et al., (1994), studies from agricultural runoff in Indiana, Iowa, Maryland, and Virginia are summarized. The vegetation in these strips consisted of grass, and the flow length of the water in the strip varied from 4.5 to 9 meters. Removal rates attained were: sediments 56-95%, nitrogen 27-87% and phosphorous 0-83% (Brown et al., 1994).

3.5.5 Additional benefits

Even though the removal rates of filter strips are moderate, there are some additional benefits connected to its implementation. Economically, there are some pros related to using this technique. Installation costs are low, the installation is easy and the solutions have a relatively low maintenance cost (Belan & Otto, 2004).

Since this solution includes infiltration, it may partially help to recharge the groundwater in the area, restoring the natural balance. In line with most SUDS-techniques, filter strips may also to some extent enhance the amenity values of the area. At periods between storms the strips may be used for recreational activities (MAPC, 2011c).

The vegetation provides a habitat for animals, and if higher vegetation is installed, it can serve as a visual barrier to eyesores like industries, parking lots or roads. Dense vegetation may also intercept blowing dust from e.g. construction sites (ibid.).

3.5.6 Limitations

The fact that the removal rates are moderate, with a high fluctuation, is an uncertainty when considering filter strips (USEPA, 2006f). Since the treatment process only function when a sheet flow runs over a flat slope, there are areal limitations of implementation. Hilly landscapes and areas with a high percentage of impermeability aren´t suitable, since the velocity of the runoff in these conditions often is too great for the treatment process to function without complications. Due to the landscape characteristics mentioned above, or due to poorly constructed filter strips, the necessary sheet flow may not be working correctly. Channeling of the stormwater may occur, severely reducing the treatment capacity (MAPC, 2011c).

Filter strips require a lot of space. Anderson et al., (2001b) highlights the fact that the strip itself often must have almost the same area as the impermeable area, making it one of the most area consuming solutions in relation to the area it receives water from (USEPA, 2006f). MAPC (2011c) continues the reasoning and writes that because of the great demand of area, filter strips aren’t suitable neither where land is scarce/expensive nor for retrofitting purposes. The same source also mentions that monitoring these systems is rather difficult, resulting in a scarce number of available data regarding the water treatment processes (MAPC, 2011c).

3.6 Green roofs

3.6.1 Quick summary

Top Picture: (TRCA et al., 2010)
Bottom Picture: (TRCA et al., 2010)

Key considerations:

- **Design variations:**
  Extensive (thin soil layer)
  Intensive (thick soil layer)

- **Stormwater Management:**
  - Quality control: Medium
  - Quantity control Medium

- **Average water retention:**
  50-70%

- **Treatment processes:**
  Contaminant removal in air and stormwater through biological, physical and chemical processes

- **Applicability:**
  Rooftops

- **Areal demands:**
  No new areas needed

General information: Green roofs consist of a vegetative layer situated on a rooftop, designed to mimic many hydrological processes of natural terrain. This is a popular solution, especially in Europe which may be implemented on everything from warehouses to residential buildings.

Advantages:

- Increased amenity of the area
- Shelter for flora and fauna in urban environments
- Reduced heat-flux from buildings
- Prolonged life-expectancy of the roof
- Reduces heat- island effect in urban environments
- May be used for research and education

Disadvantages:

- May be expensive to install if roof needs extra support to handle the additional weight
- The extra weight on roofs may limit the possibility for retrofitting
- Climate may limit possibilities to implement, as well as the range of vegetation
- Vegetation may not survive, or may need extensive maintenance if not properly constructed

3.6.2 Introduction

Green roofs, also called vegetated roofs, eco-roofs and nature roofs consist of a vegetative layer situated on a rooftop (LIDC, 2007a). The idea with green roofs is not a new one. For centuries, green roofs have been used to isolate and protect houses from the forces of nature. What differ the green roofs of today from earlier variants is the purpose of usage, which are met with new construction techniques. Apart from the conventional purpose of protecting and isolating, the green roofs of today are also designed for environmental, economic and aesthetic reasons (ABRG, 2011).

When it comes to implementing this technique, there are two main versions. Green roofs can be designed as either extensive or intensive, with soil-layers ranging from a few centimeters for the former, and a layer around 30 cm and thicker for the latter (Czemiel Berndtsson, 2004). The thin layer of soil on the extensive roof is often vegetated by draught tolerant plant requiring a minimum of maintenance (ABRG, 2011). Normally there is no access allowed on extensive roofs (Hinman, 2005). The vegetation on these roofs often consists of a mixture of sedum species (Stahre, 2006). These are normally installed from mats, simply rolled out on the roof when installed, making the installation quick and convenient (Becks et al., 2010). Plants should be native, and well adapted to the area of usage (Hinman, 2005). The variety of plants possible to grow on intensive roofs is far more diverse. With a thick soil layer, it is possible to choose between different bushes and trees, suitable for the area´s local condition (ABRG, 2011). A diversity of plants and vegetation is favorable in many aspects. It provides better plant uptake, increased friction leading to less erosion and more water retained on the roof. The soil layer also traps sediments, leaves and other particles, and is of great importance for the contaminant-removal results (LIDC, 2007b). GVSDD (2005) warns however from using plants with aggressive root-systems, such as bamboo or cough grass. The intensive solution demands far more maintenance, and can only be constructed on roofs able to withstand heavy weights. In between these extremes there is also a third solution, called semi-intensive roofs (ABRG, 2011).

3.6.3 Applicability and design

Vegetated roofs should preferably be constructed on flat or gently sloped surfaces. In a publication by Belan & Otto (2004), some innovative European techniques have managed to grow vegetation on roofs with a 45 degrees of tilting are discussed. The best results are achieved when the slope of the roof is between 5 and 20 degrees, since the water then can be drained by gravity (Hinman, 2005). For flat roofs, a drainage layer able to remove the water from the root zone and the impermeable membrane must be installed (Belan & Otto, 2004). Green roofs are suitable on a number of buildings, ranging from industries, warehouses, office complexes, hospitals, schools, garages to residential buildings (GVSDD, 2005).

Results by Miller, (2001b) and FLL (2002) found in GVSDD (2005) indicate that green roofs with about 75 mm of growing media have the capacity of removing around 50% of the annual rainfall volume through retention and evapotranspiration. Best results were achieved during storm events when the soil was not fully saturated (GVSDD, 2005). TRCA et al., (2010) states that the reduction percentage is a function of the depth of the soil, the roof slope and climatic conditions of the area. The review presents a number of monitored results on extensive green roofs, all varying between 50-85% reductions of stormwater (TRCA et al., 2010). LIDC (2007b) highlights similar results with removal rates of water varying from 58% to 71%, depending on the thickness of the soil and the characteristics of the vegetation. The removal of water summarized in the text was far from consistent during the different seasons in a year. In dry months, almost 95% of the rain was retained, while less than 20% was retained during the rainy months (Berghage, et al, 2009). The amount of water that is not removed is still detained, contributing to delaying peak flows and reducing the impact of runoff volumes (LIDC, 2007b).

Plant free zones should be provided on the roofs to facilitate maintenance and inspections of the vegetation. These strips should be at least 50 cm wide and located along the perimeters of the roof. Additional benefits from these zones are potential measures against fire and wind-uplift (GVSDD, 2005).

The main concerns when implementing green roofs are the weight of the installation, the drainage properties and slope of the roof (Belan & Otto, 2004). Green roofs can be constructed in many different ways. Designs generally include a waterproof membrane, a protective layer, a root barrier, insulation, a moisture retention layer, a drainage system, geotextile filter fabric followed by a soil medium and finally vegetation (USKH Inc., 2008). The different layers may be seen in Figure 6.

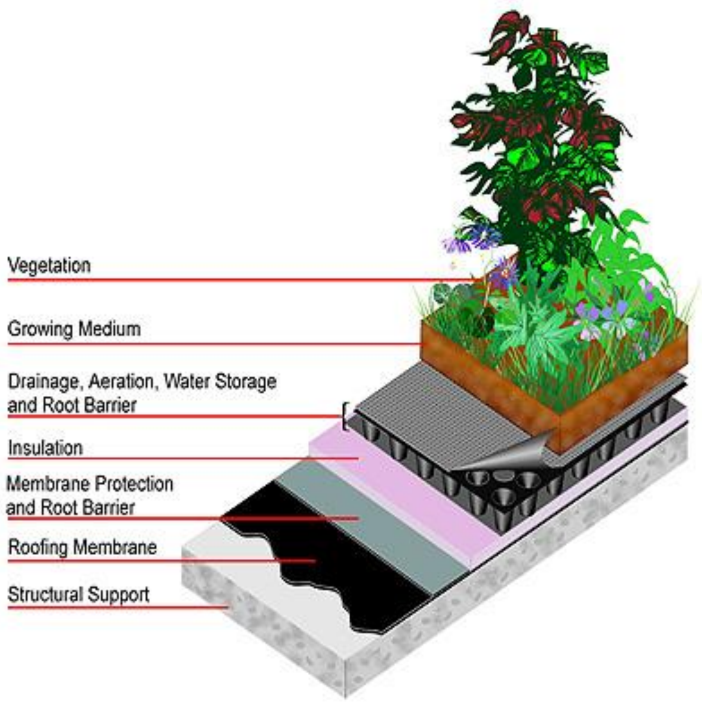


Figure 6: Different layers in a green roof construction (LIDC, 2007a).

Green roofs are popular sustainable urban drainage solutions, and the market is growing rapidly. According to roofing trade associations, the market for green roofs has grown by 16%, while the rest of the market has remained flat, reports McLean (2011) in an article in Cascadia weekly. The article also states that green roofs are popular solutions in Europe. Stuttgart is a city that is highlighted, having as much as 10% of its rooftops covered in vegetation (McLean, 2011). In Europe, the dominant type of green roof implemented is the cost-effective extensive type. Becks et al., (2010) establishes that around 80% of the green roofs in Germany are roofs of this kind.

Green roofs can be implemented on new buildings as well as a retrofitted on existing structures (Stahre, 2006). In the article by Becks et al., (2010), the potential for retrofitting is investigated. The article enlightens the importance of retrofitting for green roofs. The United Kingdom is taken as an example. As for today, over 80% of the building stock for 2025 is already constructed, and if there is to be an increase in the usage of vegetated roods, retrofitting is an important aspect. The potential of retrofitting is not yet established, but different studies in the field highlighted in the article Becks et al., (2010), gave a varied estimations of 16-61% of the roofs in urban areas potentially can be used for green roofs. Local conditions and load capacity are important aspects when considering the possibility to retrofit green roofs. Unfavorable positioning like being overshadowed by other buildings was also considered when estimations were done. Referring to a study by Stovin et al., (2007), Becks et al., (2010) concludes that buildings older than 30 years oftentimes are more suitable for retrofitting green roofs, since these buildings normally have more reserve capacity than new buildings, due to recent improvements in construction efficiency (Becks et al., 2010).

In cold climates, green roofs are feasible to implement without special adjustments, apart from choosing plants suitable for the climate. Snow will protect the vegetation, and when thawing, the water will infiltrate the soil, and is either drained away or absorbed (TRCA et al., 2010).

Bianchini & Hewage (2011) investigates the usage of green roof using a holistic approach. In the article "How "green" are the green roofs? Lifecycle analysis of green roof materials", the lifecycle of a green roof is investigated. The article states that the production of polymers used for underlying layers will create air-pollutants which will take 13-32 years for the green roofs to compensate for (Bianchini & Hewage, 2011). Other negative impacts on the environment apart from air-pollutants are also found. The article concludes however that the many positive aspects of green roofs outweigh the negative sides. Bianchini & Hewage (2011) stresses that though it is seen as advantageous to install green roofs in the long run, it is important to continue research about how to make the production more sustainable for the environment, whence even more gains for the environment will be obtained.

3.6.4 Treatment

Apart from the mitigating functions for succeeding steps in the stormwater treatment chain, the soil and vegetation on the roofs also helps treating the air in between rainfalls. Through biological, physical and chemical processes, airborne particles are removed before it has the possibility to dissolve in the stormwater. In a study from Chicago, made by Gong, Yang , Yu, (2008), green roofs on an area of 19.8ha removed 1675 kg of air pollutants during one year of operation. The main pollutants removed, categorized by parts of total weight removed were:

- O_3 (52%),
- NO_2 (27%),
- PM_{10} (14%),
- SO_2 (7%)

(Gong, Yang, Yu, 2008)

Rowe (2011) elaborates by referring to estimations by Johnson and Newton (1996) stating that 2000m^2 of uncut grass may remove up to 4000kg of particulate matter annually. By extending the reasoning using these figures, Rowe (2011) estimates that one square meter of uncut grass can offset the emissions for one car in a yearly basis (Rowe, 2011). The article continues by giving another example of estimated pollutant removal in the air from a study by Clark et al., (2005), claiming that if

20% of the industrial roofs in Detroit were to be green roofs, 889 tons of NO_2 equal to 0.5% of the emissions of the area would be removed from the air annually (Rowe, 2011).

TRCA et al., (2010) writes in that there are few studies monitoring the pollutant removal capacity of green roofs. The paper refers however to a study made in Toronto, where runoff from a black roof was compared with the same volume from a green roof. Due to the lack of similar studies, TRCA et al., (2010) suggests that the values should only be considered as an initial estimate, until further research in the field has been done. The results from the study are presented in Table 7.

Table 7: Pollutant removal for filter strips. Study 1: (TRCA et al., 2010)

			Pollutant removal(%)				
Study:	**TSS**	**TP**	**Nox**	**Al**	**Cu**	**Zn**	**Bacteria (E. Coli)**
1	89	-248	91	69	86	69	11

Other studies have reported a higher concentrations of nutrients in the stormwater runoff, where leaching from the growing medium may be the source (TRCA et al., 2010). Similar increases in phosphorous addition as shown in Table 7 are presented in a study by Berghage, et al., (2009), where an increase of 300% is registered. As a conclusion of the same study, the source states that green roofs will perform best in conjunction with other SUDS, e.g. bioretention areas (Berghage, et al, 2009). There may be a significant variety in released pollutants between small and heavy rainfalls. During small storms, basically no water leaves the green roof, meaning that all pollutants are contained with the water in the soil and vegetation. When a more extensive rainfall occurs, some loose pollutants from earlier events may follow the rainwater leaving the roof, leading to misguidance in pollutant removal rates from the roofs (Rowe, 2011).

3.6.5 Additional benefits

A green roof is one of the SUDS-solutions which entail most additional benefits. There are several valuable benefits connected to the installation of green roofs.

The structures provide rare shelters for the limited fauna in the urban environment. Green rooftops can provide temporary havens or micro habitats for animals and insects, which are rare in urban areas (Bianchini & Hewage, 2011). With its vivid vegetation, the roofs also increase the amenity of the area with its aesthetic features (USKH Inc., 2008).

Green roofs contribute to the reduction of noise. Since vegetated areas absorb more noise than hard counterparts, urban sounds are dampened by the green roofs. An optimal reduction of 10 decibel may be achieved if conditions are favorable (Rowe, 2011).

Heat fluxes will be reduced when green roofs are implemented. A black roof exposed to the sun may reach 80°C in the summer, whilst the temperature for a green roof during similar conditions merely reaches 27°C (Becks et al., 2010). The plants also evaporate water leading to a cooling effect and moist in the air (ABRG, 2011). In the winter the reversed conditions occur. The vegetated roof works as insulation, preventing heat from leaving the building (ibid.). A consequence of the reduced heat fluxes is that less energy is needed to maintain a pleasant temperature in the building, thence energy use is reduced (Becks et al., 2010). The combined result of multiple green roofs in an urbanized area will also contribute to a more pleasant temperature due to the reduction of the “heat island effect”, often experienced in urban environments (Belan & Otto, 2004).

The usage of a vegetated cover may considerably prolong the life-expectancy of the roof. Studies have shown an increase from 10-15 years to up to 40 years of lifespan when vegetated roofs are used. As a direct consequence, the cost of replacement materials on the roof is reduced (USKH Inc., 2008). There is no evidence today that the installation of green roofs will increase the risk of damage due to damp (Stahre, 2006).

New techniques may be modeled with green roofs as an origin. In the article “Green roofs as a means of pollution abatement”, Rowe (2011) introduces other green techniques, implemented to achieve the same benefits as the ones obtained from green roofs. An innovative solution is the use of green walls. This is a solution which may be implemented on four sides of a building, it enjoy similar characteristics as green roofs, without adding the extra weight on top of the building. This technique is still in its´ cradle, but show promising potential for the future (Rowe, 2011). With increasing popularity, new implementations using this technique may however be seen around the world. Figure 7 shows the center of Concepción in Chile (Chino, 2009).

Figure 7: Implementation of green walls at center of Concepción, Chile (Chino, 2009).

In the same article, Rowe (2011) reviews the idea of urban rooftop agriculture. In a time when locally produced crops are of high interest, rooftops may be used to achieve this. The article states that little research has so far been done in this field, and the potential need of fertilizers may lead to trading the benefit of locally produced goods against pollutant removal of the green roofs, something that may not be beneficial for the environment in a holistic perspective (Rowe, 2011).

Research is being done on other potential benefits derived. A German study has shown a significant reduction in electromagnetic radiation entering a building due to green roofs (ABRG, 2011).

Another field of usage is for research and education. Augustenborg's Botanical Roof garden is used for this purpose by a number of Swedish Universities. Their roof garden is also open for the public in the summers, and for guided tours throughout the year (Hjerpe. & Krantz, 2002).

3.6.6 Limitations

As with all SUDS, there are some negative aspects connected to the installation of green roofs.

Retrofitting green roofs may be very costly, especially if extra roof support to handle the extra weight must be installed (Belan & Otto, 2004).

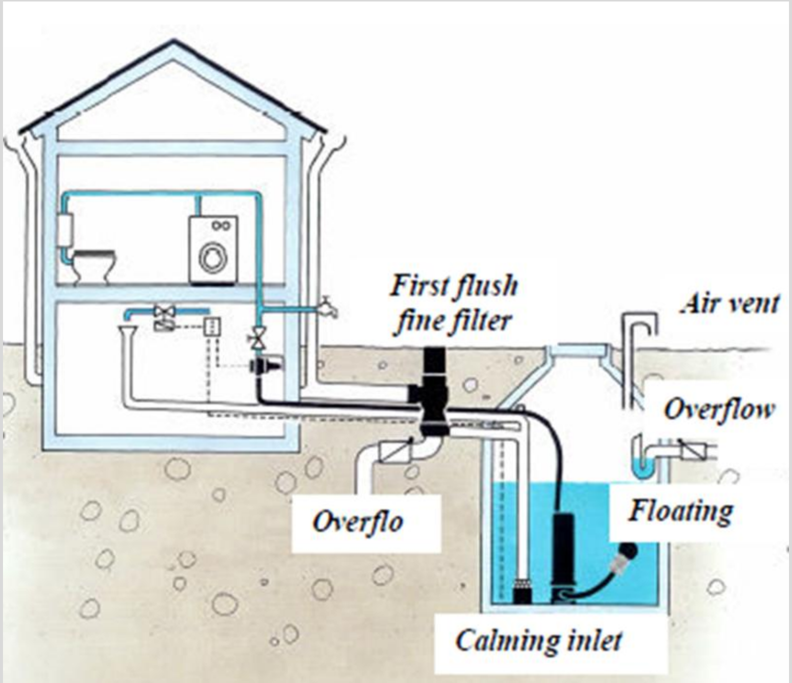
There are limits of where the installations of green roofs are possible. Arid conditions, areas often covered in shade, with windy conditions or sloping roofs may aggravate the feasibility of green roofs (Belan & Otto, 2004).

Since a lot of rainwater is detained on the roof, a crack in the waterproof membrane may cause severe damage to the interior of the building (USKH Inc., 2008).

If not properly constructed, green roofs may need more maintenance and additional watering in order for the vegetation to survive, which may cause an economical setback (USKH Inc., 2008).

3.7 Rainwater harvesting

3.7.1 Quick summary



(LaBranche et al., 2007)

Key considerations:

- **Main components:**
  - Catchment area
  - Collection and conveyance system
  - Pre-screening and first flush diverter
  - Storage tank
  - Distribution system
  - Overflow, filter path or secondary runoff reduction practice

- **Drainage Area:**
  Normally roofs

  Areal requirements:
  Normally only for storage tanks

- **Stormwater Management:**
  - Quality control: High
  - Quantity control: High

- **Treatment processes:**
  Removal of the stormwater, preventing it from continuing downstream

General information: Rainwater harvesting is a mean of intercepting, diverting and storing rainwater for future use. The water is intercepted from a catchment surface, most frequently a roof, and stored for future use.

Advantages:

- Good for retrofitting.
- Water reuse for non-potable use
- Reduced costs of water usage and distribution
- Mitigate water stress where the resources are scarce
- Modest areal demands
- No limescale, free from chlorine and often has a more balanced pH compared to normal potable tap-water

Disadvantages:

- Relatively high installation costs
- If not properly constructed, storage tanks may be a breeding ground for mosquitoes, algae and bacteria
- Placement of storage tanks may have limitations, like proximity to underground utilities for example

3.7.2 Introduction

Rainwater harvesting is a mean of intercepting, diverting and storing rainwater for future use. The water is intercepted from a catchment surface, most frequently a roof, and stored for future use (TRCA et al., 2010). The two main purposes with this technique are to conserve water for reuse, and to reduce the stormwater flow from rooftops (Hinman, 2005). The usage of stormwater helps reducing the stormwater runoff by capturing the stormwater, which consequently leads to a reduction in the amount of contaminants reaching downstream recipients. When using this technique, other SUDS further down the management-train will receive a reduced amount of water during storms, hence mitigating stress and increasing efficiency of retardation and treatment processes (NCDWQ, 2008). Rainwater harvesting is a valuable solution in places where there is a deficiency of water for non-potable purposes, or where the groundwater resources are limited (USKH Inc., 2008). The usage of rainwater harvesting is however also highly promoted in countries with an abundant access to water. Oasis (2011a) states that the United Kingdom experiences problems concerning access to water. A lack of reservoirs to meet the growing demand for water has sometime created water-deficiencies. The source states that the water debt in the UK alone is around 1billion pounds, and that the water industry is the single largest user of the court system in the country with around 250 000 cases a year (Oasis, 2011a). An increase in the usage of rainwater harvesting systems may help mitigating these problems.

A lot of the water for daily usage is for non-potable purposes. The outdoor non-potable usage requires a minimum of pretreatment before the water can be used (TRCA et al., 2010). Table 8 shows national estimates from the United States, regarding the percentage of non –potable water usage:

Table 8: Non-potable water usage in the United States. (Forasté & Hirschman, 2010)

	Total Water Use that is Non-Potable (%)
Residential	50-78
Office	86
Hotel	43

In the article "Examples of Rainwater Harvesting and Utilization Around the World" UNEP (2011) summarizes several cases around the world where rainwater harvesting has been successfully implemented. Successful implementations of rainwater harvesting systems may be seen in many capital cities. Singapore, Tokyo and Berlin are densely urbanized cities, where the usage of rainwater harvesting has won ground. The usage includes domestic non-potable use, irrigating green areas and the replenishment of ponds in commercial and residential areas (UNEP, 2011).

In cold climates, rainwater harvesting may be used, with the precondition that the storage facilities are located indoors or under the frost line in the ground, in order to avoid damages related to freezing (TRCA et al., 2010). Other sensitive parts like the distribution system should also be constructed to remain functional and not freeze in colder temperatures. If located above ground it should be insulated or heat-wrapped (VADCR, 2011).

Rainwater is conveyed and stored in tanks, located above or below the ground, for later non-potable usages. The field of usage for collected stormwater is diverse. Irrigations, flushing toilets, exterior washing, firefighting, fountains or laundry are some areas where the usage is feasible (VADCR, 2011). Rainwater harvesting is particularly applicable in medium or highly urbanized areas, where rooftops cover a high percentage of the total surface area (Hinman, 2005).

3.7.3 Main components

There are six main components required in a rainwater harvesting system:

1. Catchment area
2. Collection and conveyance system
3. Pre-screening and first flush diverter
4. Storage tank
5. Distribution system
6. Overflow, filter path or secondary runoff reduction practice

(VADCR, 2011)

A perspicuous explanation about these elements will be presented below.

1: Catchment area

It is important to choose the right material for the catchment area. In this example, just like common praxis, the catchment area consists of a roof. When installing this solution, one have to make sure it doesn´t contribute contaminants, like heavy metals or toxic chemicals to the collected water (Hinman, 2005). The material should be smooth and non-porous to ensure an efficient drainage. For the same reason, it is important to either have a well-designed drainage system, or have a sufficient slope on the roof, to ensure a quick drainage. A slow drainage leads to poor rinsing of the roof and a prolonged first flush, which will decrease the quality of the collected water (VADCR, 2011). Water collected from other catchment areas such as parking lots and driveways are generally discouraged due to the low quality of the water (ibid.).

2: Collection and conveyance system

This includes elements like gutters, downspouts and pipes. The conveyance system is constructed to conduct the stormwater to the storage tank. In residential areas, gutters and downspouts should be designed in the same manner as if no rainwater collection system was used (TRCA et al., 2010). To obtain sufficient channel and flood protection, the elements should be designed to convey the 2 and 10-year storm. The slopes conveying the water to the tank should be of a minimum of 0.5 - 1% (VADCR, 2011). If pipes are used the recommended minimum slope is 1.5% (ibid.).

3: Pre-screening and first flush diverter

Before the water enters the tank, certain pre-treatment is needed to avoid nuisances. Accumulated debris like dust and leaves must be removed, in order to prevent clogging of the system (TRCA et al., 2010). A minimum requirement for smaller systems is filters removing leaves and debris, though direct water filtration is often preferred. The main purpose of pre-filters is to prevent organic buildups in the tanks, thereby reducing the need for maintenance (VADCR, 2011). TRCA et al., (2010) writes that it is important that debris is removed from the filters. If not it may promote bacterial growth.

First flush diverters are installed to intercept the first amount of stormwater and lead it away from the storage tank. This installation will ensure that smaller particles like dust, pollen and animal-droppings accumulated on the roof during dry periods will not enter the tank (TRCA et al., 2010). It is important to design the diverters with an appropriate size, in order to remove the correct amount of water from entering the tank (VADCR, 2011). About 5% of the rainfall is normally appropriate to remove with the first flush (LaBranche et al., 2007). A common solution for a first flush device is a diversion tank, where the stormwater arrives. In the bottom of the tank there is a floating lid. When the water reaches a certain level, the lid seals the entrance to the diversion tank, conducting the water to the normal storage tank. The diversion tank has a slow outlet, allowing it to empty before next storm. The first flush diversion tank should be cleaned on a regular basis to avoid nuisances with accumulated sediments (Waterplex, 2011).

4: Storage tank

The tank is the most important, and often the most expensive component of the rainwater harvesting system. Volume of the tank can range from around one to 115 m^3, and several tanks may be connected in a system to increase the storage capacity (VADCR, 2011). Connected tanks have, according to Hinman (2005), the advantage of in general being cheaper to install than a single tank, and parts of the system can be closed down for maintenance, a feature not possible with only one tank. As written earlier, tanks can be installed above or below ground level, with the latter being the more expensive alternative. Space limitations, climatic conditions or aesthetical preferences are reasons why, though more expensive, tanks often are installed below ground (Hinman, 2005). Factors deciding the size of the tank include rainfall data, catchment area, aesthetics, budget and intended usage. The water in the tank should normally last for 10- -12 days, writes TRCA et al., (2010) To mitigate the sizing, there are tables developed by Rainwater Harvesting System Design Tools, for finding an optimal size for cisterns (TRCA et al., 2010). Tanks should have a tight cover fitting to prevent contaminants and animals from entering. If situated above ground level, sunlight shouldn´t penetrate the cistern in order to minimize algae growth (VADCR, 2011). A drainage plug should also be installed, so the tank can be completely emptied if needed (VADCR, 2011). Forasté & Hirschman (2010) gives an extensive review of design criteria and methodology for designing stormwater tanks.

5: Distribution system

The majority of distribution systems use either gravity or pumps to convey the water to its final destination (TRCA et al., 2010). When a pump is used it should be designed to produce sufficient pressure for all end-uses. For indoor use, the system normally consists of a pump which pumps out the water from the tank, a pressure tank where the water is stored for distribution and a backflow preventer, to separate harvested rainwater from the potable water pipes (VADCR, 2011).

6: Overflow, filter path or secondary runoff reduction practice

When storm events are more extensive than the system is designed for it is important to have an overflow system. Overflow pipes should have equal or greater capacity than the inflow pipes (TRCA et al., 2010). The pipes should be screened in order to prevent insects and animals from entering the tank. The excess stormwater should be released in a pervious corridor with a sufficient gradient, leading the water to the next SUDS-device, such as a swale or a channel (VADCR, 2011). In cases where overflow cannot be connected to a pervious area, the overflow pipe may have to be connected to a storm sewer system (TRCA et al., 2010).

3.7.4 Additional benefits

Except the arguments written above, there are other advantages with installing a rainwater harvesting system.

There are several financial benefits attached to this technique. One is the reduced cost for the distribution of water. Since the water is collected in situ, no expenses for transportation and distribution of this non-potable water are required. According to Forasté & Hirschman (2010), 83% of the energy in public water systems is used for transportation purposes, which makes the energy saving potential promising. The need for expanding the municipal distribution system will decrease, and the water bills get lower when some of the water demands are met with harvested rainwater (TRCA et al., 2010). The usage of rainwater harvesting in certain areas may make expensive treatment methods like desalination to get water for non-potable purposes redundant (LaBranche et al., 2007).

The areal claim for this technique is very modest. The installment of the rainwater harvesting system doesn’t need any extra space, except sometimes for the storage tank (Oasis, 2011b).

Other benefits are that rainwater doesn’t produce limescale (a white mineral deposit from hard water), is free from chlorine and often has a more balanced pH compared to normal potable tap-water (Oasis, 2011b).

3.7.5 Limitations

One aspect that may be seen as a disadvantage is the relatively high installation cost for the rainwater harvesting system (Hinman, 2005). These costs are however often compensated by the savings from usage of the water, explained earlier in the text.

If not constructed correctly, conditions in the tank may exacerbate, and it may be a breeding ground for mosquitoes, algae and bacteria (TRCA et al., 2010).

There are also some preconditions like area needed and proximity to underground utilities when installing a tank, which can be seen as a limitation (TRCA et al., 2010).

4 Conditions in Sweden

4.1 Laws and regulations

When implementing Sustainable Urban Drainage praxis in Sweden, there are several laws and regulations which need to be considered. These may be seen as control instruments, creating favorable preconditions for a correct process of implementation. The laws needed to be considered are the Planning and Building Act, the Swedish Environmental Code, the Act on public water services and the EU Water Framework Directive (Engström, personal communication, 2011). A perspicuous review of these laws will now follow:

4.1.1 The Planning and Building Act (SFS 2010:900)

The Planning and Building Act (Plan- och Bygglagen, PBL SFS 2010:900, earlier SFS 1897:10) is by many considered to be the most important control instruments when realizing SUDS- solutions (Malmö Stad, 2008). This act includes regulations about the projection of ground and water resources in Sweden, as well as information about how to implement construction work. The act includes frameworks for flow and treatment requirements, ground elevation and level of urbanization (Malmö Stad, 2008). These regulations are set to promote a holistic approach, to encourage development, good living standards and a sustainable environment today, and for future generations (PBL, 2010). The act covers everything from the comprehensive plan to the detailed planning, for public as well as private areas. Projecting the physical usage of ground and water resources should be done by the municipalities, using this law as a framework (PBL, 2010). Issues regarding water are particularly covered in chapter 5, 3 and 16 §§ about detailed planning, and chapter 8, 2 and 6 §§ about building permits (Göteborgs Stad, 2010). Stahre (2008) describes this right of physical planning of areas for the municipalities in practice to be seen almost like a monopoly. Private developers have a rather weak influence on the comprehensive planning, which is a contrast to the situation in many other countries (Stahre, 2008).

4.1.2 The Environmental Code (SFS 1998:808)

The provisions of the Environmental Code aim at promoting a sustainable environmental development through responsible administration, for this and coming generations (Miljöbalken, 1998). Various paragraphs regarding stormwater handling can be found in the Environmental Code, but the focus on questions regarding stormwater is found in chapter 11 (Göteborgs Stad, 2010). Regulations administering ground and water resources, emissions, responsibilities, environmentally hazardous activities, quantities and the protection of the environment are some of the areas covered in the code. Terms regarding the Environmental Impact Assessment (EIA) are reviewed in chapter six of the code (Miljöbalken, 1998). Standards about administration and the required quality of the municipal water environment can be found in enactment (SFS 2004:660), which is a part of the Environmental Code. If the water does not reach the requirements, there are appropriate measures of how to handle of the situation to reach the determined levels described in the code (Environmental Encatment, 2004). It is the duty of the environmental board of the municipality to assure that the environmental code is followed (Persson et al., 2009).

4.1.3 The act on public water services (SFS 2004:412)

The directions in this act aim to ensure that water resources are coordinated in a broader perspective, in consideration of the environment and of peoples' health (LOAV, 2006). The act states that the Provincial Office has the responsibility to assure that the municipalities carry out their water services in consideration of the health of the people, and the state of the environment in the vicinity (Göteborgs Stad, 2010). Water services include the areas of potable water, wastewater and stormwater (Persson et al., 2009). The law provides regulations of responsibilities, how charging related to stormwater should be executed, and how to distribute the costs between different actors involved in the process (Persson et al., 2009). Malmö Stad (2008) considers the two previous laws to be more important control instruments for the municipalities, since this act only enables local actors to raise fees in the area of stormwater handling, but there is no possibility to demand a reduction of contaminants or flow rate, referring only to this law (Malmö Stad, 2008).

4.1.4 EU Water Framework Directive (2000)

This is a framework for the water directives implemented in the European Union. Every member of the EU should organize the national water administration according to runoff districts. The districts should have an administration to establish the handling of the water (Rutberg, 2010). The objects with the directives are among others to reduce discharges and prevent further contamination of the water resources, promote a sustainable usage of water, reduce effects of floods and drought and protect recipients (Ministry of Environment (Finland), 2007). The aim with this framework is to have achieved a “good water status” for all watercourses and groundwater sources in the European Union by the year 2015 (Ministry of Environment (Finland), 2007).

4.2 Responsibilities

The responsibility of assuring that all the laws and regulations are followed, and that the implementation of open drainage systems are executed correctly is divided among several different administrations. Though different municipalities have structure of responsibilities which coincides, there may be some slight variations in administrational praxis. The aim with this text is to give an insight in the actors dividing the responsibilities. For more detailed information about specific municipality, the best way is to contact their administration for information.

In Sweden, the municipality administration has the ultimate responsibility for the handling of stormwater in cities (Malmö Stad, 2008). The responsibility is often delegated to different administrations though, of which a brief explanation now will follow:

4.2.1 Environmental administration office

Enlightens the potential environmental consequences of the stormwater treatment and supervises the handling of stormwater, in accordance to the Environmental Code and the policies of the municipality (Borlänge Energi, 2005).

4.2.2 Real estate administration office

The office ensures that matters regarding stormwater management are included in contracts for the exploitation of an area. If the area belongs to the municipality, the Real Estate Administration Office itself must pay attention to the issues regarding stormwater.

4.2.3 City planning office

This office has the responsibility of coordinating questions related to stormwater in the planning process. The city planning office should make sure the street administration office and the department for water and sewer are involved at an early stage (Tekniska Kontoret, Ängelholm, 2011). Another assignment for the office is to make sure that the stormwater handling is investigated in the beginning of the planning process, evaluate preconditions and reports about the planned area, to make sure that sustainable solutions of how to treat stormwater will be a part of the implementation plan (Malmö Stad, 2008).

4.2.4 Water and sewer department

This department should be involved at an early stage of the planning process. It should monitor the planning process, contribute with expertise in the field, with information about the stormwater situation in the area, approve the technical solutions which are to be implemented and apprize the community about the stormwater solutions. Operating information for the solutions should be introduced. The arts of the maintenance work related to the piping system are the responsibility of this department (Tekniska Kontoret, Ängelholm, 2011). The water and sewage department also answers for the operation and maintenance of the municipality's drinking water and sewage plant (Svenskt Vatten, 2011). These plants are usually owned by the municipality. In the last decade an increasing number of municipalities have started to cooperate with private companies in the running of the plants (Svenskt Vatten, 2006).

About one third of the employees at the water and sewer department are technicians at the treatment plants, one third work with the pipe-system and the rest are employed as engineers, economists, assistants or other positions required for running the department (ibid.).

4.2.5 Street administration office

This office is responsible for the choice of material, and the design criteria for the hardened surfaces in the project (Tekniska Kontoret, Ängelholm, 2011). In many cases the Street Administration Office is responsible for the public areas in the municipality, which means this office oftentimes projects, builds and maintains big parts of the stormwater solutions (Malmö Stad, 2008).

4.2.6 Park administration office

Stormwater devices are often constructed in parks, or in adjacent areas. Here it is the responsibility of the Park Administration Office to make sure the materials chosen and the design criteria are correct, and that the solutions are correctly maintained. Another responsibility is to contribute with design criterions to the planned stormwater solutions (Tekniska Kontoret, Ängelholm, 2011).

4.2.7 Documentation

It is the combined responsibility for all departments to document and evaluate the entire process, in order to be able to use this information for future projects (Malmö Stad, 2008).

4.3 The planning and implementation process

The planning process is the basis for a municipality to create a sustainable urban drainage environment. Since these solutions are relatively new, old routines often have to be put aside in order to implement sustainable solutions. Developers and city planners are often lacking insight when it comes to these solutions, and sometimes find it hard to accept that open solutions will claim a part of the developing area, hence influencing the entire appearance of the area. The realization of an area may not be possible to implement according to the visions of the city developers, since these open solutions occupy a part of the land which otherwise could be used for other purposes (Stahre, 2006). To cope with potential problems it is important to highlight potential stormwater problems, to have a close co-operation between different departments, and to involve the question of stormwater handling at a very early stage in the planning process (Stahre, 2006).

What follows is a short explanation about the different steps in the planning process:

4.3.1 Comprehensive plan

This is the long-term strategic plan for the urban development municipality, with a foresight of about ten years. This plan normally does not specify on details like specific solutions, but rather on principles and strategies for the municipality (Stahre, 2006). These principles will work as a foundation for future planning. The decisions in the comprehensive plan are not binding (Göteborgs Stad, 2010). Area-demanding solutions, like eco-corridors or large ponds may however be included in the plan, in order to facilitate further detailed solutions in the area. Surrounding area, functions, environment, recreational values and ecological values are all important to consider in order achieving a satisfying comprehensive plan (Stahre, 2006). Some aspects of importance to enlighten during the creation of the comprehensive plan are mapping of the selected area, planned level of exploitation and stress on the environment, principles of technical solutions and an outline of future maintenance work (Göteborgs Stad, 2010).

4.3.2 Site development plan

This plan regulates the land use in the planned area. Private interests are balanced with the interests of the municipality (Stahre, 2006). The basic features of the ground and water usage in the area may be regulated, in order to counteract the usage of the land for other purposes (Naturvårdsverket & Boverket, 2006). The site development plan regulates the source control on private land and the public land reservation among other things. Drainage patterns, space requirements and design for the onsite control and for slow transport of stormwater is discussed, and all involved parts should have a say before any final decision is made. It is important that decisions about maintenance and costs are made in the planning stage, to avoid future disputes (Stahre, 2006). Necessary demands on source control should always be included in the site development plans (Stahre, 2006). The site development plan can only regulate some issues, and these plans themselves are not sufficient for a building permit (Naturvårdsverket & Boverket, 2006).

4.3.3 Detailed development plan

When a project is planned to be implemented in or in the vicinity of a city, a detailed development is required. The plan should give a clear view of the municipality's thoughts about the development of the area (Boverket, 2009).

The detailed development plan is reported as a delimited area in a map. The provisions in this plan are legally binding from the time it is accepted, until it is revoked, or replaced with a new plan (Göteborgs Stad, 2010). Descriptions about context of the plan, and the purpose of the solutions should be included. A description of measures for realizing the plan should also be included (Boverket, 2009). When establishing this plan, the suitability for the planned implementations is evaluated. Surrounding environment, soil and water conditions and the wellbeing of the local habitants are some factors included in the evaluation. Sustainable solutions are often promoted (Naturvårdsverket & Boverket, 2006).

4.3.4 Projecting and building permits

The projecting phase starts after the detailed plan is done. When covering stormwater, it applies for both piping-system and open stormwater solutions. If these solutions are situated on private ground, it is the responsibility of landlord to project, build and maintain the solutions (Malmö Stad, 2008).

The financial part is also covered by the landlords. Different departments, like the water and sewer department, contribute with valuable expertise (Falu Energi & Vatten AB et al., 2008).

Demands from the site development plan should be followed up in the building permit, to ensure a correct continuation of the planning processes. Stahre (2006) informs that there often is an absence of knowledge in the field of sustainable urban drainage systems among the inspectors, which are to follow up the implementation of the designs. This problem may be solved by cooperation between the inspector and the local drainage department in questions like source control (Stahre, 2006). The city planning office is responsible for this inspection, as well as making the final decision about approving a building permit.

The entire planning process from the initial idea to the adoption of the detailed development plan is open and democratic. Different aspects of the development are discussed. People and organizations with an interest in the project are invited to share their points of views, in order to give the municipality a broad support for their decisions (Stahre, 2006).

4.4 Pollutant regulations

As for today, there are no national guidelines of allowed discharge rates of pollutants in Sweden. Today limitations are decided according to reference values, and the vulnerability of the recipient (Jacobs et al., 2009). It is common that the Environmental Administration Office of each municipality develop a framework with guiding values with limitative discharge values for the local recipients. The local policies and guidelines are set to reduce the peak flow, and to decrease the amount of contaminants reaching the recipients. To achieve this, sustainable urban drainage systems are feasible solutions, entailing palpable ameliorations in these aspects (Jacobs et al., 2009). The source presents suggested standard values of different contaminants in a variety of recipients. The values are based on long term measures series, and since the concentration of contaminants in stormwater varies a lot depending on factors like intensity and of the rain, or the period since last storm, mean-values have been utilized. Recommended standard values are presented in Table 9.

Table 9: Suggested standards values for discharge on a yearly average for stormwater. Level 1: Discharge directly to the recipient. Level 2: Discharge inside the drainage area. Level 3: Discharge levels from private enterprises, to a connection point in the public pipe-system. M: Smaller lakes and coastal bays. S: Large lakes and the open sea. (Jacobs et al., 2009)

		Small lakes, watercourses and bays		Large lakes and the open sea		Private enterprises
Substances	**Unit**	**1M**	**2M**	**1S**	**2S**	**3**
Phosphorus (TP)	µg/l	160	175	200	250	250
Nitrogen (TN)	mg/l	2.0	2.5	2.5	3.0	3.5
Lead (Pb)	µg/l	8	10	10	15	15
Cupper (Cu)	µg/l	18	30	30	40	40
Zinc (Zn)	µg/l	75	90	90	125	150
Cadmium (Cd)	µg/l	0.4	0.5	0.45	0.5	0.5
Chrome (Cr)	µg/l	10	15	15	25	25
Nickel (Ni)	µg/l	15	30	20	30	30
Mercury (Hg)	µg/l	0.03	0.07	0.05	0.07	0.1
Suspended solids (SS)	mg/l	40	60	50	75	100
Oil index (Oil)	mg/l	0.4	0.7	0.5	0.7	1.0
Benzo(a)pyrene (BaP)	µg/l	0.03	0.07	0.05	0.07	0.1

As seen above, the suggested limits of contaminants allowed in small recipients (marked S in the table) are lower than in larger recipients (marked M in the table). This is much due to the perception that smaller recipients have a more limited exchange of water, and a less significant ability of diluting contaminants arriving in the stormwater (Jacobs et al., 2009). The document also states that these listed values may be subject to changes in the future, due to a more extensive knowledge in the field, and with the implementation of new regulations (ibid.).

4.5 Case studies

4.5.1 Växjö

4.5.1.1 Introduction

The city of Växjö is a relatively small city in European standards, with a population of about 83 000 people (Växjö Kommun, 2011a). The city is located in Southern Sweden, and may in many aspects be regarded as a typical Swedish city. What differs Växjö from most other cities is the extensive work and development that has been done here towards an increased sustainability. In Växjö, the thought of creating a sustainable city is not a new one. For decades, these objectives have been a part of the agenda. In 1996, Växjö was the first city in the world to announce the goals of being totally free from fossil fuels in 2030 (Växjö Kommun, 2011b). From the early nineties until today, the economic growth has been around 50%. At the same time the carbon-emissions have decreased around 30%, testifying that the goals set up are within reach (Törnberg, 2008).

It is not only in the aspect of carbon emissions where the city has made notable progress during the last decades. The city has a holistic environmental planning, covering everything from people's daily life to a sustainable urban environment. The sustainable goals are both short and long term, with regular evaluations of the progress. The environmental goals, and policies adapted is today included in all local decision-making. Information about the development in the field is shared with citizens and local companies of Växjö, in order to give inspiration and motivation for private actors to further consider the environment (Växjö Kommun, 2011b).

For its' environmental work, the city has received many awards. In 2007 BBC London gave Växjö the epithet "The Greenest City in Europe". Other international papers like The Independent, Frankfurter Allgemein, La Gazétta and Liberacion soon echoed this statement (Växjö kommun, 2007b). Documentaries about the sustainable development have been produced by The Independent, La Libération, La Repubblica, The Sydney Morning Herald and the news agency AP among others (Växjö Kommun, 2007a).

4.5.1.2 Stormwater management

The environmental work of the city also includes a sustainable stormwater handling. This topic has been on the agenda in the municipality since early 1990. Today, it is an obvious element in the city-planning process. Every year there are delegations from other Swedish municipalities arriving to Växjö to study their stormwater-solutions, and take part of the relatively long-term data accumulated (Engström, personal communication, 2011).

The objectives with the sustainable urban drainage systems in Växjö are to equalize the flow, reduce temporary stormwater-peaks, reduce the level of contaminants reaching the recipient and minimize the risk of floods. The aim is that the burden on the recipient shouldn´t increase with the exploitation of an area (ibid.). To be able to achieve this, it is important to implement sustainable urban drainage policies at an early stage in the planning process. Engström (2011) points out that it is important to make the solutions visible in the urban environments. When planning the solutions, landscape architects are involved in the process, enhancing the visual aspects of the elements. The solutions add recreational values, contribute to the aesthetics of the city, and increases people's awareness about the handling of stormwater. The solutions practiced in Växjö are stormwater ponds for sedimentation and retention of the water, dry ponds, canals, swales and underground retardation basins (Engström, personal communication, 2011; Swedish Association of Architects, 2002).

Figure 8: Stormwater pond in Växjö. Photo: Veg Tech AB (Vegtech, 2011).

In order to decrease the stormwater from private areas, the city plans to introduce a stormwater tariff in 2012. This means that a fee will be charged for the stormwater originating from private areas, to cover some of the stormwater-related costs for the municipality. This tariff may be an incentive for private actors to further implement measures of source-control, which will reduce the stress on the downstream system (Engström, personal communication, 2011). Engström, who is an Project Manager at Växjö Municipality explains that the city today prioritize open stormwater solutions to the conventional methods since these, apart from the positive aspects mentioned above often are both cheaper to construct and easier to maintain than conventional underground systems. The cost of maintenance for open solutions may increase a little though, Engström adds.

An area in Växjö that particularly highlights the sustainable stormwater solutions is the residential area "Kampen". In 2002, the Swedish Association of Architects awarded Kampen the price for best planning of an area, because of the successful utilization of these solutions, and the way these enhanced the urban environment (Swedish Association of Architects, 2002).

4.5.2 Malmö

4.5.2.1 Introduction

Malmö is Sweden's third largest city with about 300 000 inhabitants, located in Southern Sweden, close to the border of Denmark. In Swedish standards, Malmö is considered to be a relatively large city. For a long time, the city has put a comprehensive amount of effort into developing the city in a sustainable manner. The city is in the front edge of adapting green technologies. In 2010, it was awarded the price as the most sustainable city in Sweden by the environmental magazine "Miljöaktuellt" (Växjö stad, 2011c). The city has ambitious environmental goals set for the future. In 2020, the objective is for the energy consumption to decrease by 20% per capita, and before 2030, the consumption should have decreased another 20% (Malmö Stad, 2011a). For the administrational departments of the municipality, the objective is to be carbon neutral by 2020. In 2030, the entire city should be supplied only by renewable energy (Malmö Stad, 2011a). To an as big extent as possible, the green energy should be locally produced. Except from environmental benefits derived from the ongoing green development projects, the city also expects to benefit from reduced energy costs, and make the city better prepared for future environmental changes (Malmö Stad, 2011a).

Responsibilities to reach the goals set up are shared by the different offices of Malmö municipality, which work in close cooperation with local companies and industries. The environmental board of the municipality has a leading role in coordinating the development, making sure conflicts of interests are avoided, and assuring a good communication between all involved parts. To implement successful environmental projects, raising the public awareness and involving the citizens in the development are of significant importance (Malmö Stad, 2011b).

4.5.2.2 Stormwater management

One of the means of raising the public awareness is the implementation of sustainable urban drainage systems. The municipality of Malmö has during a long time worked with developing the sustainable drainage of urban stormwater, to reduce the negative quantitative and qualitative impacts related to the conventional way of stormwater removal. The concept of sustainable urban drainage management was first introduced in Malmö in the late 1980's (Stahre, 2008). It won a lot of acceptance in Malmö during the 1990's. From meeting resistance in the beginning of the decade, to being generally accepted around the new millennium, it took about ten years of positive cooperation and development between the different departments of the city to find the necessary understanding to proceed and effectively develop the concept of SUDS (Stahre, 2008). In the year 2000, the municipality's Technical Bureau developed a common stormwater policy for the city. The policy included basic principles of how the stormwater should be handled, and became the foundation for further development of specific strategies of how to handle stormwater (Malmö Stad, 2008). The principles and goals highlighted in the stormwater policy included:

- The urbanization shouldn't affect the natural water balance in a negative way.
- Pollutants reaching the recipients should be reduced to an as big extent as possible.
- Open solutions should be prioritized where possible to implement.
- The sustainable drainage systems should reduce the risk of flooding and flash floods considerably.

- The sustainable urban drainage systems should be constructed to increase the aesthetics and recreational values of the area.

(Malmö Stad, 2008)

To reach the defined environmental goals, a broad cooperation between experts in different departments of the city's administration is of key importance (Stahre, 2008). The policies and strategies developed are important for the environment of today, as well as creating a base for future sustainable development (Malmö Stad, 2008).

Though a lot of work has been done to improve the handling of the stormwater, the stress on coherent the recipients is still heavy. To reach a long term sustainable degree of development, it is important to struggle to reach a sustainable level of stormwater release in the recipients (Malmö Stad, 2008). Between the end of the 1980's and 2008, 18 sustainable urban drainage facilities have been constructed in Malmö. The implementations have evolved, from mainly consisting of separate ponds and wetlands towards multi-functional eco-corridors (Stahre, 2008).

Many of these successful implementations of sustainable stormwater facilities have captured the interest of both domestic and international development projects. In this review, two of these facilities will be reviewed briefly, namely Toftanäs Wetland Park and the residential area of Augustenborg.

Toftanäs Wetland Park was the first large-scale implementation of sustainable urban drainage facilities in the municipality of Malmö. The wetland park was designed and created between 1989 and 1990, as a response to the development of the surrounding area for commercial and residential purposes. The alternative was to construct a pipe, more than one km long and one meter in diameter to handle the estimated increase in flow, something that would cost a lot of money and be very harmful to nearby recipients. Instead the municipality chose to create a stormwater wetland to handle the additional stormwater (Stahre, 2008).

The implementation was a success, and the 3 hectare big wetland entailed a lot of positive qualities to the area. Retention of the stormwater, and contaminant removal worked as planned, the biological values of the entire area were improved, which in return raised the recreational values of the area around the wetland park. A better control of the in-and outflow of the water was also possible, compared to the usage of conventional pipes for removing the stormwater.

Maintenance of the wetland includes yearly control of the vegetation, and sediment-removal from the inlet with 3-4 years difference and outlet with 5-6 years difference (Stahre, 2008).

The eco-city of Augustenborg may be the most famous area with implemented sustainable urban stormwater solutions in Malmö. It was developed between 1998 and 2005, and was the first area of its kind in the city (Rolfsdotter-Jansson, 2009). Before the project was initiated, the sewer-system in the area was of the combined type, meaning that stormwater and wastewater were led away in the same pipe, often causing problems with flooding (Stahre, 2008). To counter this, the open stormwater solutions were given a prominent position in the development of Augustenborg. Today, all around the residential area, signs of sustainable stormwater solutions may be seen (Rolfsdotter-Jansson, 2009).

All houses in the area are covered with green roofs, and local infiltration is practiced through green areas and permeable parking lots. Stormwater in the area is retained in ponds and temporary storage areas for stormwater. Canals, swales and ditches provide a slow transport of the water on its way downstream (Stahre, 2008). The stormwater in Augustenborg follows a management train, passing several stormwater solutions on its way to the recipient. High aesthetical and recreational values have made this area popular among the residents, and have contributed to an increased interest of Augustenborg and its innovative solutions, both nationally and internationally (ibid.). Figure 9 shows a picture from Augustenborg.

Figure 9: The residential area of Augustenborg (Rolfsdotter-Jansson, 2009).

For a comprehensive review about different sustainable urban drainage solutions implemented in the municipality of Malmö, “Blue-green fingerprints in the city of Malmö” by Stahre (2008) is a good source of information.

5 Conditions in Xiamen

5.1 Historical overview

The city of Xiamen has a long and vivid history. It was founded during the Jin Dynasty, which lasted between 265 and 400AD. In the 17th century, Portugal, Spain and the Netherlands arrived, and began to do lucrative commerce with the city. As a consequence, the importance of Xiamen and its' port grew rapidly (Echinacities, 2011). After a failed attempt to colonize the city by the Dutch, trade relations were resumed, and the trade-related connections were kept open until the end of the Opium Wars. With the treaty of Nanjing signed, Xiamen was one of five ports in China which was to be opened to foreigners. International settlements were established on Gulang Yu Island just outside of Xiamen, where colonial traces can be seen today (UNDP, 2006). In 1939 the Japanese took control over the island, during the Second World War. Xiamen was yet again opened up in 1980, and is today one of China's six special economic zones (Echinacities, 2011).

5.2 City characteristics

Located on the eastern shores of Southern China, and being the Chinese city located closest to Taiwan, the city of Xiamen is an important logistics hub for national and international commerce. The city is one of the most important cities in the province of Fujian. The exact location of Xiamen in the Fujian province can be seen in Figure 10.

Figure 10: The location of Xiamen in the Fujian Province (XRI, 2011).

The developed area of the city of Xiamen is totally 212 km^2 (China Statistics Press, 2010), with Xiamen Island covering an area of 130 km^2 (UNDP, 2006) By the end of 2009, the permanent population in the city reached 2.52 million people (Lai, 2010). The urbanized area has 55 parks, and the total green area of the city was around 75 km^2. The green area is between 35 and 40% of the urbanized parts if the city (China Statistics Press, 2010).

The population density of Xiamen's city districts is about 11317 people per square kilometer. This figure may be compared to the capital of Sweden, Stockholm, where the population density in the central districts is 4412 people per square kilometer (China Statistics Press, 2010; Briney, 2010). As seen in these numbers, the city of Xiamen is heavily urbanized. The city hosts close to three times as many people per square kilometer as Stockholm does. The total length of the roads in the city was 1183.4 km by the end of 2009, covering a total area of 29.77km^2 (China Statistics Press, 2010) As many Chinese cities, Xiamen has a heavy traffic with a lot of cars contributing to the pollution in the city. There is a lot developed infrastructure for public transportation though, which partly mitigates some of the nuisances. In the end of 2008, Xiamen had over 3000 operating public vehicles, and a total network length of around 3200 km (China Statistics Press, 2010).

5.3 Water resources

In 2004, there was a capacity of providing 580 million m^3 of potable water per year. The water conducted to the city was collected from different sources. 140 million m^3 was collected from dams and local surface water storages in the vicinity of Xiamen, and 440 million m^3 was collected from the Jiu Long River, near Xiamen (XCMB, 2006).

As seen in the numbers above, the Jiu Long River is the most important provider of potable water for Xiamen, contributing with around three fourths of the City´s potable water.

To conduct the water to the city, there is a total of 51.2km of pipes leading the water from the river to Xiamen. Between the period 1980 – 2004, a total of 2 500 million m^3 has been extracted (XCMB, 2006). In the central parts of Xiamen, 100% of the population has access to tap water (China Statistics Press, 2010).

During the last decades, there has been a steady increase in the use of potable water in Xiamen. Between the beginning of the 1980’s to the end of 2004 the usage had increases with 83% The annual increase has been around 2.5% during this period time. This increase is likely to continue in the years to come. The prognosis for the future shows a continued increase in water usage for the coming decade. In 2020 the total water spending is estimated to 1 120 million m^3 of potable water per year, which is close to a doubled amount from the year 2004. While the agricultural usage of water is estimated to decrease slightly from 2004 to 2020, the industrial and residential usages are believed to more than triple during the same period.

The field of usage for potable water has slowly changed during the last decades, being heavily focused on agriculture, towards a more diverse usage, where the industry and the households occupy a bigger share of the resources. Data from (XCMB, 2006) presenting the distribution of potable water for different sectors during two different occasions is shown in Table 10:

Table 10: Distribution of potable water in Xiamen. (XCMB, 2006)

Distribution potable water (%)			
Year	Agriculture	Industry	Private use
1980	90	5	5
2004	50	27	23

These figures correspond to the entire municipality of the Xiamen, and not only the heavily urbanized areas. On Xiamen Island, where the majority of the area is heavily urbanized, the figures differ quite substantially. Here, the private sector stands for the biggest single user of potable water, seizing about 41.3% of the resources in 2004. Second largest user on the island was commercial enterprises (29.5%), followed by governmental installations (16.5%) and industry (12.7%) Since there is no farmland on the island, agricultural share of the potable water was equal to zero (XCMB, 2006). In 2008, the amount of tap water used in Xiamen was 294.5 million m^3 (China Statistics Press, 2010). The water usage on Xiamen Island for the different sectors is displayed in Figure 11:

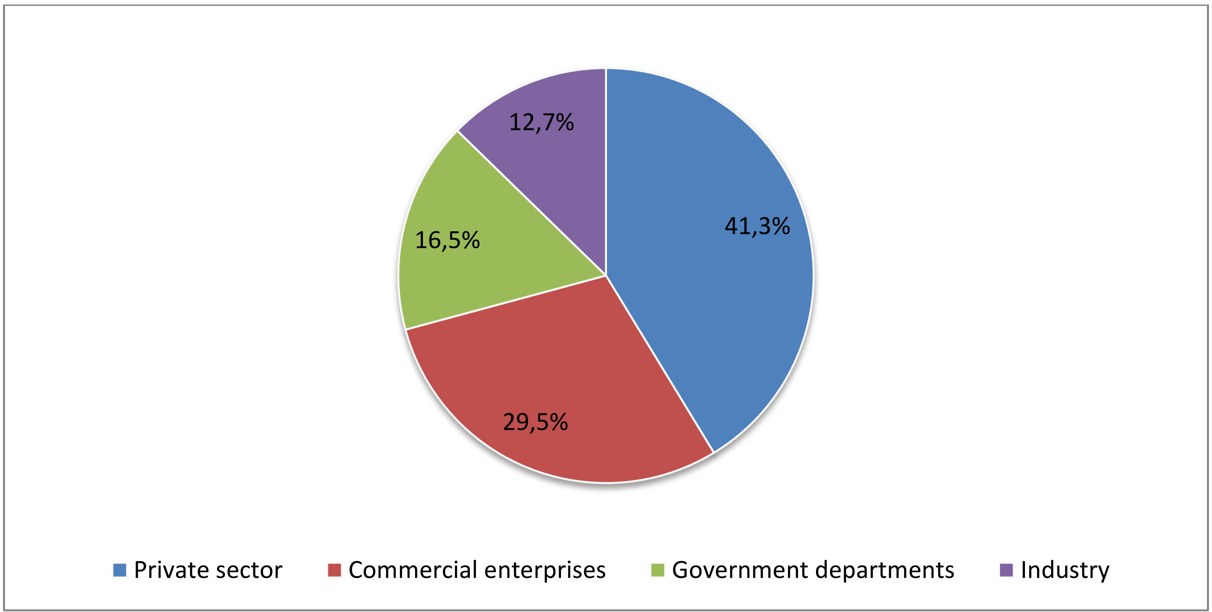


Figure 11: Potable water usage on Xiamen Island (China Statistics Press, 2010).

The per capita average usage of potable water in central Xiamen In 2004 was around 200 liters a day. Efforts have been made to assure the accessibility of fresh water to the urban residents. Though already using quite a lot of water per capita, the actual capacity of bringing potable water to the central parts of Xiamen was about twice the size of the actual usage (XCMB, 2006).

For water usage of the non-potable kind, there are other sources from where the city and its' surrounding municipality can convey water:

Groundwater

On a yearly average, the amount of groundwater used in Xiamen every year is 24 – 90 million m^3. In 2004 89 million m^3 was extracted and used mainly for agriculture on the adjacent countryside (XCMB, 2006).

Seawater

Since Xiamen is located beside the water, and the central parts of the city is situated on an island, there is an abundance of available seawater. Every year around 705 million m^3 is used for different purposes like extinguishing fires, washing roads, and to clean and keep seafood for restaurants (XCMB, 2006).

Reuse of treated wastewater

There is a limited reuse of treated sewage water. Every year around 100 000m^3 of treated wastewater is reused, mainly for irrigation, scenic spots like fountains and for cleaning purposes like washing the streets (XCMB, 2006; Xiamen Water, 2008). This only corresponds to about 1 ‰ of the total amount of wastewater produced by the city every year, indicating a big potential in the field (XCMB, 2006).

To be able to transfer large amounts of non-potable water and handle an increase in flow, an expansion of the current pipe-system is needed. This would mean a major investment, something the local government or private companies for a long time have been unwilling to make (XCMB, 2006). Recently however, 32 million Yuan has been invested in increasing the capacity of reusing treated wastewater for non-potable purposes. After implementation the estimated capacity of the system will be 24 000 m^3 reused wastewater per day, which is a considerable increase from earlier capacity. If the water is used exclusively for irrigations, the need for 725 $km^2$of green areas may be met (Xiamen Water, 2008).

In order to get an efficient organization concerning non-potable water handling, the laws and regulations must be improved. To successfully implement the correct measures and make the procedures more effective, XCMB (2006) urges that relevant information must be collected, and existing databases storing retrieved data must be developed.

As written above, there is a great potential for non-potable usage of treated wastewater. Even though the potential is high, there are several obstacles which impede an extension of this usage. One of the main reasons why the usage of non-potable water is still very limited according to XCMB (2006) is the high accessibility and low price of potable water. It is unreasonable to believe that people will invest and spend money to receive water with poorer quality, when they can get potable water for a similar price. The current price of potable water in Xiamen can be seen In Table 11.

Table 11: Water price in Xiamen. (XMG, 2011d)

Usage Classification	Water Charge (RMB Yuan/ m^3)	
	15 m^3 and less	Above 15 m^3
For Household Use	1.8	2.3
For Industrial and Constructional Use	1.8	1.8
For Commercial Use	1.8	1.8
For Hotels, Restaurants, Entertainment and businesses	2.8	2.8
Raw Water	0.8	1.0

As seen in the table, the price of tap water is relatively cheap in Xiamen. Figures from XCMB (2006) conclude that the total cost of water usage only corresponds to about 3% of the money spent in a month for an average family. The source further speculates that an increase of the water price with around 10% would give a 3-5% decrease in the usage of potable water. To make people use water in a more responsible manner, the source urges for a development of the conservation-favoring water price system, which means that the more water you use, the more expensive it will get.

This abundance of water and the very moderate pricing has led to an extensive usage of potable water among the citizens of Xiamen. Apart from mentioned factors, there are also other important aspects to consider, which contributes to the high usage of water in Xiamen. XCMB (2006) writes that there is a lack of knowledge about the need of a more economized water usage, and no knowledge of how to achieve this. For the moment many families don´t even have a meter showing the usage of water in the household, which makes it hard to keep track of the amounts used.

The fact that Xiamen is a tourist city also contributes to the high usage of water. Many restaurants and tourist facilities would rather squander the water resources in order to attract customers, than implement conservative measures, with the risk of losing their clients.

Leakages in the pipes and a lack of water saving technologies are other contributing factors mentioned as a part of the problem with high usage of water in Xiamen (XCMB, 2006).

5.4 Laws and regulations

5.4.1 The Environmental protection law

Enacted in December 1989, this law sets the framework for pollution control legislations and environmental management in China (U.S. Department of Commerce, 2005). Being the principal law for environmental protection, the law defines the rights and duties concerning environmental issues for every level of the society, from different levels of governments down to individuals (World Bank, 2006). The State Environmental Protection Agency (SEPA) is given the authority to coordinate the environmental work on a national level, and the assignment to establish national standards for different areas of the environmental quality (World Bank, 2006). The law includes the Environmental quality standard for surface water (GB 3838-2002), which defines the limits for pollutants in all useable surface water bodies within China, including rivers, lakes, canals, channels and water reservoirs (MEP China, 2002). The pollutants are graded in five levels, where level one (I) is considered to be the best, and level 5 (V) is the worst. Some of the contaminants included in the standard are displayed in Table 12:

Table 12: Environmental quality standard for surface water in China. (GB 3838-2002)

Substances		Level				
		I	II	III	IV	V
pH		6 – 9	6 – 9	6 – 9	6 – 9	6 - 9
DO (mg/l)	≥	Saturation	6	5	3	2
TN (mg/l)	≤	0.2	0.5	1.0	1.5	2.0
TP (mg/l)	≤	Rivers: 0.02 Lakes: 0.01	Rivers: 0.1 Lakes: 0.025	Rivers: 0.02 Lakes: 0.05	Rivers: 0.3 Lakes: 0.1	Rivers: 0.4 Lakes: 0.2
COD (mg/l)	≤	15	15	20	30	40
BOD_5 (mg/l)	≤	3	3	4	6	10
Cu (mg/l)	≤	0.01	1	1	1	1
Pb (mg/l)	≤	0.01	0.01	0.05	0.05	0.1
Zn (mg/l)	≤	0.05	1	1	2	2
Cd (mg/l)	≤	0.001	0.005	0.005	0.005	0.01
Petroleum (mg/l)	≤	50	50	50	500	1000
Fecal coliform (n/l)	≤	200	2000	10 000	20 000	40 000

5.4.2 The Water resource law

The law, enacted in 1988 and put in effect in October 2002 is developed to promote a sustainable development and management of the water resources. It emphasizes the need for water conservation, and prescribes that the Ministry of Water Resources (MWR) and the Water Resource Bureaus (WRB) are in charge of the administration and supervision of this aspect (World Bank, 2006;

U.S. Department of Commerce, 2005). The protection of water resources can be realized through a water quality management system, identified in the 2002 revision (U.S. Department of Commerce, 2005).

5.4.3 The Water pollution prevention and control law (WPL)

This law from 1984 is considered to be the main law for water pollution control, and applies to discharges in lakes, rivers, canals, reservoirs and groundwater. Pollution prevention, water quality and discharge standards are treated in this law. Revised in 1996, the introduced amendments further enhanced the control measurements, for a wider protection of the water bodies (U.S. Department of Commerce, 2005). A system for registering pollutant discharges at the local environmental protection bureau (EPB) was introduced, in order to charge industries for their emissions (U.S. Department of Commerce, 2005). The State Environmental Protection Agency (SEPA) and EPB are responsible for managing and supervising of the qualitative aspects of the water bodies (Berghage, et al, 2009).

5.5 Administration

There are several different departments responsible for the administration of water resources in Xiamen.

5.5.1 Xiamen municipal water conservancy bureau

This bureau responsible for the implementation of the Chinese national laws revised above, as well as stating policies and principles concerning water conservatory issues. The institution is also chargeable for developing plans and frameworks of how the water resources should be used in a sustainable way. Coordinating a unified management of the water resources, such as surface water, air water and ground water is also a part of the responsibility. Annual, short term and long term plans for the water in the city are developed by the bureau (XMG, 2011a).

5.5.2 Environmental protection bureau

Monitoring the quality of the potable water and making sure it is acceptable are responsibilities of this bureau. Another area of responsibility is the planning and implementing measures of how to prevent contamination of the water resources. To ensure a high quality of the water, the bureau also develops laws regulating emissions of contaminants (XMG, 2011a).

5.5.3 Water resource department

This department has a number of different offices:

- **Water resource management office**
  Assessments about the resources needed for water resource management protection are made here. The office also compiles supply investigations, plans the price of the water and surveys the water quality.
- **Water resource construction office**
  Responsibility for water resources to agricultural use at the countryside is given to the Water resource construction office, as well as the development of the applied irrigation techniques.
- **Park and gardening administration office**
  In charge of the water supply, as well as finding means to implement saving policies. The office handles questions regarding water treatment and the usage of non-potable water.

- **City planning administration office**
  Responsible for the planning and implementation of the infrastructure connected to the water administration. Another function of the office is to promote and facilitate the construction of water saving facilities in the city.

(XCMB, 2006)

5.5.4 Quality technology supervision department

This department monitors the quality of water saving facilities in the city. Facilities and vendors with poor quality or bad performance may be prohibited. For facilities with good performances, the department may give a state of approval. Water saving facilities may include public bathrooms, showers, taps or car washes.

5.5.5 Summary

According to XCMB (2006), there are too many departments involved in the water administration of Xiamen. This comprehensive structure of administration makes it hard to say who has the final responsibility in different questions, hence impeding processes to make progress in many important questions. Problems may be transferred between different offices or fall between the chairs, instead of getting a solution. The source further states that the administrational parts of governing water resources are relatively new and not fully developed yet, hence obstructing optimal results (XCMB, 2006).

A suggested solution to the administrational contingency by XCMB (2006) is to divide the administration of Xiamen in a three-layer hierarchy, where the private actors answers to the district government, who further on answers to the city's government.

Currently there are no laws, but only policies and regulations regulating water resources in Xiamen. Some important regulations to follow in Xiamen are:

- Xiamen water saving management method
- Xiamen city water supply management method
- Xiamen water resource management regulation
- Xiamen drinking water and 2nd water supply hygiene management method

5.6 Wastewater treatment in Xiamen

By the end of the year 2008, Xiamen had 11 sewage treatment plants. Altogether these treat around 817 000m^3 a day. When comparing this number to many developed countries there is a significant difference. In average, Xiamen has one treatment for every 260 000 people (Xiamen Water, 2008). In the city of Malmö in Sweden, there are about half the amount of people on every wastewater treatment plant (VA Syd, 2011).

The treatment plants in Xiamen treated around 80% of the wastewater by the end of 2007. This means that there is still quite a lot of wastewater being released directly to the recipients without receiving any kind of treatment. This number is high in Chinese standards though, where the average rate of treated wastewater lies around 59% (Xiamen Water, 2008). The increase in the percentage of treated water in Xiamen for the time period 2004 to 2007 can be seen in Figure 12:

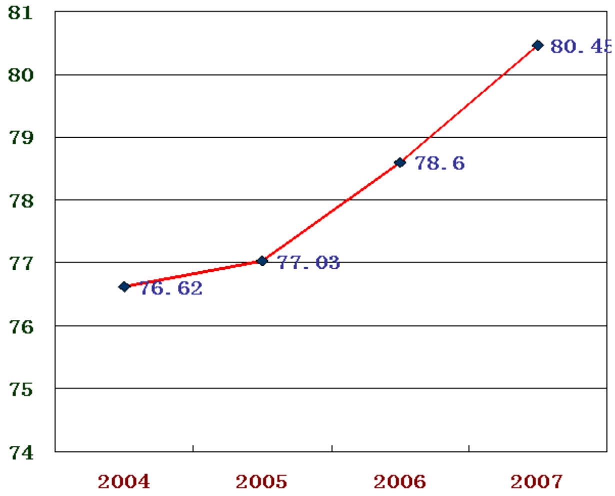


Figure 12: Increase in Sewage treatment percentage in Xiamen between 2004 and 2007 (Xiamen Water, 2008).

The recipients for the treated water of Xiamen Island are either Yuan Dang Lake, or the surrounding ocean (Xiamen Water, 2008). There are today 36 larger pipes and underground canals conducting sewage water and stormwater in combined systems to Yuan Dang Lake. Smaller pipes conducting sewage and stormwater converge to these larger pipes, with an average cross-sectional area of around 2.5-3m^2 (Chai & Hu, 2003).

In 2007, the treatment plants of Xiamen received 164 830 000m^3 of wastewater. A large amount of pollutants were removed from the arriving wastewater. In the same year, 47 089 tons of COD (90,1%), 20 408 tons of BOD (94,5%) and 28740 tons of SS (92.2%) were removed from the wastewater (Xiamen Water, 2008).

Xiamen is working on further reducing the amount of pollutants reaching the recipients. Between 2005 and 2010 the objectives were set to reduce the COD reaching the recipients with 6200 tons, from 55 600 tons to 49 400tons every year. This reduction stands for a decrease of around 11%, and may be seen as one step further in the right direction (Xiamen Water, 2008).

About the reduction of COD, Xiamen planned to reduce the values with 650 tons by the end of 2008, compared to the figures from 2005. During this period there was an estimated increase of COD by 3775 tons, eventuating in a total decrease of 4425 tons (ibid.).

The mud created by the treatment plants are used for different purposes. Recently, a factory developing fertilizers from the mud was constructed on Xiamen Island, and by the end of 2008 the plant produced 10 000 tons of fertilizers every year, from mud from wastewater treatment plants. Other areas where the mud is used is for landfills, and to a limited extent in the making of bricks (China Statistics Press, 2010).

5.7 Climate

Xiamen is situated in a sub-tropical zone, enjoying a yearly average temperature of around 20.8 °C. The warmest temperatures in Xiamen are reached in June to September, with an average daily temperature of about 31 °C. The coldest month is February, which has an average temperature of about 16 °C. The temperature rarely drops under 10 °C (XMG, 2011c). Last time a snowfall was registered in the city was 1893 (Wikipedia, 2011). There is a yearly abundance of sunshine, averaging at 2276 hours annually. The mild climate makes it possible for plants to grow all year long, and there is no time when the vegetation decreases. Average yearly rainfall between 1961 and 1990 was around 1140mm, with an average potential evapotranspiration of 1650mm. For the last ten years (2001 – 2010), the data shows an increase in the yearly average of rainfall. During this decade, the average rainfall was about 1347 mm in a year, with an average potential evapotranspiration of 1391mm (Xiamen Statistics Bureau, 2001-2010). Rainfall data for Xiamen is displayed in Appendix A. There is a big fluctuation between the annual values of rainfall between 2001 and 2010, ranging from around 1000 mm to about the double, which may be seen in the appendix. Changes in rainfall and evaporation may be due to ongoing climate changes, and to get the most accurate and up-to date values for the calculations and evaluations, the average values between 2001 and 2010 will be used in the examples. Average monthly rainfall and evapotranspiration during the last decade is displayed in Figure 13. As seen in the figure, the vast majority of the rain falls during the summer months.

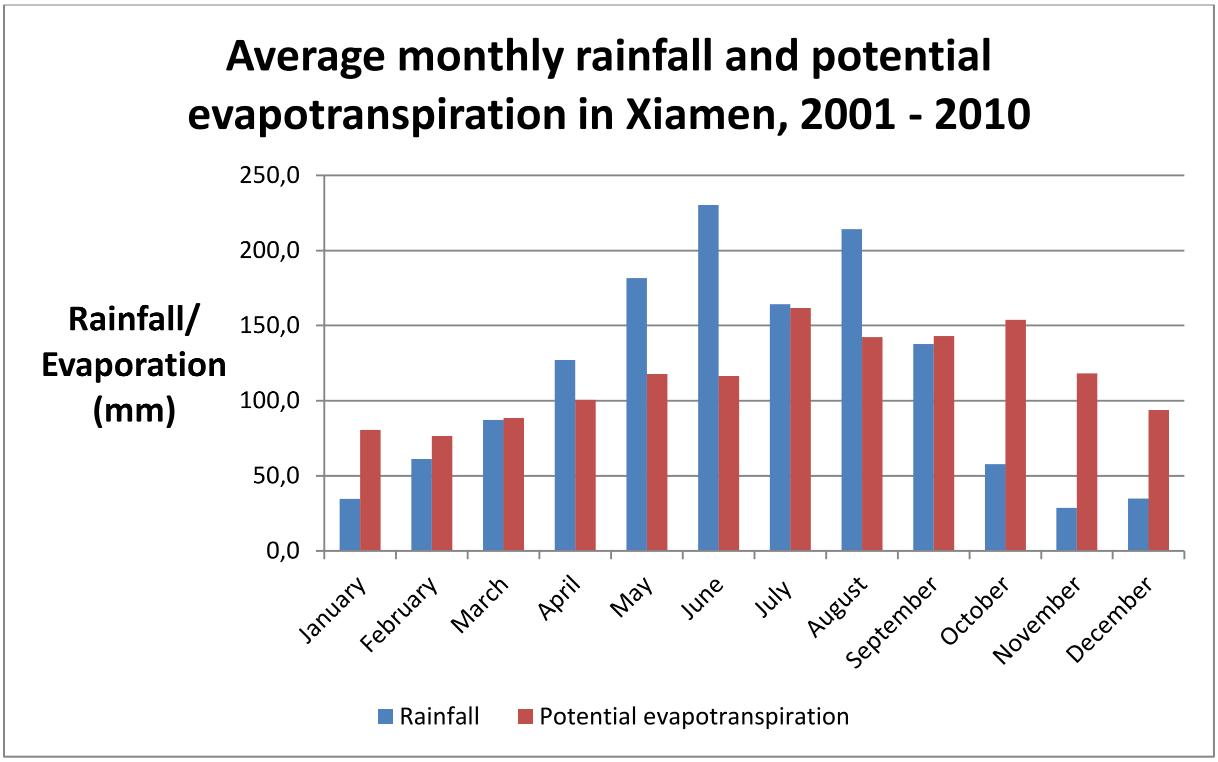


Figure 13: Average monthly Rainfall and potential evapotranspiration in Xiamen, 2001 – 2010 (Xiamen Statistics Bureau, 2001-2010).

5.8 Green areas

The natural landscape of the city includes mountains, flat lands and the ocean. On Xiamen Island, mountains cover about 40% of the area. With the development of green areas, different elements like the sea, mountains and the vegetation are combined in the planning to make an as beautiful overall impression of the city as possible. A lot of resources are spent on creating this beautiful scenery (XMG, 2011b).

The climate in Xiamen is favorable for a vast number of plants and different kinds of vegetation. Xiamen has made big effort to enhance and expand the green areas in the urbanized areas. A systematic planning of the green areas in the city was initiated in 1994. The goal was to become a

"Garden City". Objective set up was to have around 40% of green areas in Xiamen, something the city today is close to realizing. Xiamen is a tourist city, and the planning of the green areas often focuses on scenic impressions, to maximize the aesthetics of the city. Many of the larger roads in Xiamen are also "Decorated with green belts" (XMG, 2011b). The hills of Xiamen Island are fully afforested, to increase its scenic views and amenity. Information about the afforestation and the enhancement of the green areas are often promoted in local TV and in newspapers, to raise people's awareness (ibid.). Aesthetics is heavily prioritized. In the information about green areas on Xiamen Municipality´s homepage, nothing is mentioned about the green areas abilities to mitigate nuisances related to stormwater.

5.9 Rainwater management in Xiamen

On Xiamen Island like in many other cities in China, there has been a rapid urbanization, entailing a rapid increase in impermeable surfaces. Since the amount of rain hasn´t changed drastically, the consequence is that larger volumes of water are quickly conducted towards the recipients. This creates the usual problems connected to urban drainage, like flooding and poor water quality. So far the strategy of Xiamen has been the old fashion way of handling stormwater, basically to directly conduct it to the recipient. Since there is an increasing need for water in the city, XCMB (2006) establishes that there is a growing importance of managing the rainwater in a more sustainable way.

This means doing what many cities have started to do during the last decades; challenging the traditional concepts where water was to be lead as quick as possible to the recipients, and instead starting to implement a more holistic way of handling the water. To do this, XCMB (2006) suggests that new strategies must be developed. Laws and regulations must be renewed and improved, expertise in technical aspects must be gathered from experiences in the field, both domestic and international. The solutions must have support from the laws and policies of the city, and to realize the solutions, an increased economic support is needed.

Since local conditions such as climate, soil and topography play an important role in the implementation, it is important to choose solutions suitable for Xiamen. XCMB (2006) suggests that techniques of how to handle stormwater may be tested in different areas in the city, and evaluate the performance. When standards regarding stormwater management are written, XCMB (2006) continues by suggesting that these may be mandatory to implement when developing new areas in the city. The same source also acknowledges problems in implementing solutions in already urbanized areas. The possibility for retrofitting may in some areas be limited, but the situation is suggested to be solved in the best possible manner, since a large transformation of the infrastructure only to meet the drainage demand is not a realistic solution.

5.10 Yuan Dang Lake

The Yuan Dang Lake is situated in the western parts of Xiamen Island. The name Yuan Dang refers to tall lush bamboo reeds once growing along its shores (Campbell, 1997).

5.10.1 Historical review

For a long time, the area that today is Yuan Dang Lake was an open harbor, covering an area about 10 km^2. The vivid harbor hosted a variation of animals, and in the evenings, fishing boats returning to seek shelter. During the night, the area was a pleasant sight, with the glowing lights from the many boats (Zhou et al., 2003). In the 1970's, a number of land reclamation projects were carried out, reducing the area of the harbor, impacting the conditions of the biota to the extent that the harbor was slowly turning into a dead lagoon, unable to exchange enough water with the adjacent sea (ibid.). Foul water soon became a palpable problem. Every year there was an increasing amount of wastewater being released in the Yuan Dang Lake, constantly exacerbating the condition. With the increase in pollution, and an insufficient water exchange with the sea, the lake finally was not able host any fauna like fishes or birds (Chen et al., 2010). In 1980 there were around 40 000m^3 of sewage water released daily to in the lake, and the number was quickly increasing (Zhou et al., 2003). Around the same time, about 90% of the untreated industrial waste of Xiamen Island was released in the lake (Campbell, 1997). The conditions in and around the lake made the area very unattractive for local residents, and for companies to settle. The occupancy rate of ambient apartments was less than 25% (Zhou et al., 2003). The poor conditions were recognized by the local government, but little progress was made, mostly due to the lack of funds.

In 1984 Xiamen was selected as a special economic zone. The economical and infrastructural sectors experienced a rapid development (Zhou et al., 2003). In the same year, work was initiated to create a water pollution treatment center for Yuan Dang Lake. By this time the condition of the lake was severe. Xiamen television made a not very flattering report, stating that the lake was as ”a mountain of rubbish, overgrown weeds, polluted water, with flies and mosquitoes flying around” (ibid.). In 1988, the area of the lake had been reduced to about 2.2 km^2. By the same year the cleaning of the lake was set as a priority by the local government. The condition of the lake held back the development of the city, and reduced the incentives for domestic and foreign companies to invest in Xiamen (Zhou et al., 2003). The same year the Yuan Dang Lake Integrated Treatment Project was initiated. The main objectives were to improve the water quality and ecosystem health, improve the drainage and flood prevention systems and increase the amenity of the surrounding area (Thia-Eng, 2006). The first phase of the project lasted between May 1989 and June 1992. To improve the circulation of the sea, where the tidal water was replacing the water of the lake, a canal was dredged to lead the water to the inner parts of the lake at high tide, so the entire lake benefited from a circulating flow. The dredged material was used for land reclamation projects, such as parks. A total of 3.2 million m^3 of sludge was dredged during the first phase of the project (Thia-Eng, 2006). In 1992, a series of measures in the first phase of the Yuan Dang Lake Integrated Treatment had been carried out. Apart from the measures mentioned above, they also included putting pressure on industries, constructing municipal treatment facilities, constructing a 10 km retaining wall around the lake and carrying out scientific studies, to a total cost of 110 million Yuan (Zhou et al., 2003; Campbell, 1997; Thia-Eng, 2006). The, conditions of the lake had mended palpably, but further improvements were still required. The expansion of the city had increased the wastewater discharge to the lake significantly. In 1993, the lake received around 200 000m^3 of wastewater every day, of which 100 000 m^3 was not treated (Zhou et al., 2003).

The second phase of the Yuan Dang Lake Integrated Treatment Project lasted between June 1992 and December 1999. Measures of improving the lake in this phase included enhancing the sewage treatment capacity and constructing new wastewater treatment plants, the adding of 14 km embankment and 27 km of walking paths around the lake, installing pumping stations from the lake to the sea in order to improve the potential flood-preventing measures, and installing pumps with the capacity of transporting 2.5 m^3 seawater every second to the inner corner of the lake to prevent any potential dead pockets where the water is not circulating (Thia-Eng, 2006). Between 1992 and 1999 another 240 million Yuan RMB was invested in the improvement of the situation of the lake. As a result of the extensive work, the fauna was now slowly returning. Efforts to improve the water quality in the lake gave significant results (Zhou et al., 2003). The content of different contaminants in the lake throughout the years can be seen in Table 13.

Table 13: Level of contaminants in Yuan Dang Lake between 1982 and 2002. (Zhou et al., 2003)

Substances		1982	1987	1992	1997	2002
COD	(mg/l)	87.60	86.10	5.10	3.27	1.19
BOD_5	(mg/l)	68.40	145.50	6.93	9.29	2.63
DO	(mg/l)	0	0.10	-	4.56	4.24
NH3-N	(mg/l)	10.55	39.40	2.01	1.63	-
CN-	(µg/l)	5.00	3.00	3.00	7.00	7.00
Cd	(µg/l)	-	55.00	0.50	0.20	-
Cu	(µg/l)	152.00	273.00	12.00	24.00	14.00
Petroleum	(mg/l)	4.20	1.11	0.21	0.65	0.26
S^{2-}	(mg/l)	-	9.80	-	-	0.02

As seen in the table, most of the contaminants have been reduced to less than a tenth of the levels in 1982.

Even though a lot of money has been invested in improving the conditions of the lake, economists calculate that the long term benefits outweigh the costs with around 9:1. The long term benefits include an increase in investments in the area around the lake, and a significant increase in adjacent property-values (Thia-Eng, 2006).

In 2001 the volume of sewage water arriving to the lake every day had changed to 330 000m^3, of which 280 000m^3 was treated (Zhou et al., 2003).

Today, Yuan Dang Lake is one of the pilot projects Regional Program on Prevention and Management of Marine Pollution in East Asian Seas, which is sponsored by the United Nations Environment Program (UNEP). The lake today hosts a varied collection of fishes and birds (ibid.).

In 2011, the largest scale water quality improvement project is set to begin, to an estimated cost of 500 million Yuan. The project will include improved sewage interception, dredging and paving cobblestone under the inner, more polluted parts of the lake and the construction of new wastewater treatment plants (What's on Xiamen, 2011).

5.10.2 Characteristics

As of today the total water area of the lake is about 1.5 km^2. The drainage area reaching the lake is around 37 km^2, which is about 30% of Xiamen Island (Zhou et al., 2003).

There is a slow circulation of the water in the lake. The water is replaced through dam openings connected to the adjacent sea. With the help of the tide, water is transported in and out of the lake, creating a slow circulation. At the inlet, water runs through an innovative canal, reaching the inner parts of the lake when the tide is high. When the tide gets low, the water runs out from the parts coherent to the lake. By utilizing this system, there is a significantly better circulation of the water in the lake than if the inlet and the outlet would be at the same location. This innovative system for water circulation of the lake contributes to improving the quality of the water in the lake. The turnover time of the water is around 3 days, which is sufficient for the settling of particles and suspended solids, and for biological treatment processes, before the water enters the sea (Zhou et al., 2003).

The water in the lake is under constant observation, and as written in the historical review, a lot of effort has been put into improving the water quality throughout the years. The quality standard used for the water in the lake is the “Water Quality Standard for Recreation Areas” (GB 12941-91). The quality of the water in the adjacent sea is regulated by the “Marine Water Quality Standard” (GB 3097-1997). Parts of the limitations from the standard mentioned above are displayed in Table 14.

Table 14: Contaminant-standards for Yuan dang lake and the adjacent waters, according to Water Quality Standard for Recreation Areas (GB 12941-91) and the Marine water quality standard (GB 3097-1997). (Zhou et al., 2003)

Substances			GB 3097-1997	GB 12941-91
pH			6.8-8.8	6.5-8.5
DO	(mg/l)	>	3	4
COD	(mg/l)	≤	5	6
BOD_5	(mg/l)	≤	5	4
NH3-N	(mg/l)	≤	0.02	0.02
Active Phosphate	(mg/l)	≤	0.45	GB 3097-1997 is set as standard
Inorganic Nitrogene	(mg/l)	≤	0.50	GB 3097-1997 is set as standard
S^{2-}	(mg/l)	≤	0.25	GB 3097-1997 is set as standard
Fecal coliform	(n/l)	≤	2000	2000
SS	(mg/l)		Increase due to human activities ≤150	GB 3097-1997 is set as standard
Transparency	(m)		-	1.20

When compared to the actual values in Yuan Dang Lake reviewed further up in the text it is seen that the current levels of contaminants in the lake are within the limits when it comes to COD, BOD5and DO, while the NH3-N level in the lake still needs to be improved to reach the standards.

Though the quality of the water has improved significantly during the last decades, the lake is still haunted by a lot of problems. Sediments from untreated sewage water, mudslides and runoff from construction areas are considered serious issues for the lake. In 2001, 6240 kilos of sediments were added to the lake every day due to these factors. The high amount of sediments means that the lake is slowly getting shallower, resulting in that less water can be kept in the lake. In 1997, the lake could hold around 3 850 000 m^3 water. In 2001, this number had been reduced to 3 030 000 m^3 of water (Zhou et al., 2003).

The catchment area surrounding the lake includes large hills with steep slopes, and heavily urbanized areas, conducting the water quickly towards the recipient during a storm. Combined with water conducted in conventional pipes, the stormwater quickly reach the lake after the beginning of a storm. This means the water volume of the lake rises quickly at the event of a storm. The dam openings of the lake may be adjusted to meet the increased inflow to the lake, and there are today pumping stations which may help removing water from the lake. The short time for the water to reach the recipient makes it however hard to adjust the systems in time, often resulting in temporary flooding of areas in central Xiamen (Zhou et al., 2003). An automatic regulation system is now under construction for a quicker adjustment of the levels of water in the lake. Information is being collected and data bases from measuring points around the lake are created to better understand what measures need to be done to avoid flooding and keep a controlled level of the lake (ibid.).

The majority of water conducted to the lake is transported by combined sewage systems, which means that the stormwater is lead to the lake in the same pipes as the wastewater. This means that there is a heavy burden on the treatment plants during storms, and a lot of the wastewater must be lead around the plants directly to the lake, without any treatment. Frequent work is being done to renew the system and install separate pipe systems (Zhou et al., 2003).

The vegetation in Yuan Dang Lake, improving the recreational values and helping the treatment of the water, has increased steadily during the last decades. From covering 78 000 m^2 in 1993, these areas had increased to 315 000 m^2 in 2002. During the same time, the number of plants has increased from 35 to around 90 species (ibid.). The increase in vegetation in and around the lake will help improving the biological treatment processes of the lake.

There are today a lot of green areas surrounding the lake. Parks and recreational areas are common features in the environment. The local government has made big efforts to enhance the aesthetics, and today there are around 315 000 m^2 of green areas adjacent to the lake (Zhou et al., 2003). A recognized problem deriving from these green areas is the usage of fertilizers, which lead to an increased pollution of the lake (ibid.).

The area adjacent to the lake is today attractive for the development of properties, and a growing number of people are buying real estates in this area. In 2001 there were about 300 000 residents around the lake, with a steadily increasing number (Zhou et al., 2003).

Since the lake is an open recreational area where everyone can benefit from its features, it is sometimes hard to implement necessary measures for improving the conditions of the lake. A balance must be kept between necessary measures and the preservation of the aesthetics of the lake. Many implemented solutions are also intended to contribute to the amenity of the area, which are considered preferable solutions (Zhou et al., 2003).

6 Evaluation of sustainable urban stormwater solutions

The objective with this part is to analyze which solutions are feasible to implement in the central districts of Xiamen Island. The area of investigation where focus is put is the densely urbanized southern part of the drainage area of Yuan Dang Lake. This means the lake will be the point that all stormwater from the area of investigation be conveyed to before continuing to the ocean, which in this case is the final recipient. The total catchment of the lake is a vast area covering 37 square kilometers, which is about 30% of the entire Xiamen Island (Zhou et al., 2003). A map of the investigated area can be found in the introduction, namely Figure 1.

What follows are examples of different sustainable urban drainage solutions, which in a perspicuous way will evaluate the feasibility of implementing the solutions in the investigated area in central Xiamen. All calculations and abbreviations from the equations are displayed in Appendix B.

6.1 Stormwater ponds

In the central, urbanized district of Xiamen Island there is no possibility of retrofitting wet ponds. In areas adjacent to the mountains, which is a part of the drainage system leading water to Yuan Dang Lake, and in parks coherent to the lake, there are however possibilities to implement these solutions. As for today there are also a few ponds located in the central areas. These ponds are not used for stormwater management though, but are mainly implemented for its recreational purposes. There is however a possibility to use these installations for stormwater quantity and quality control.

Following are some calculations to analyze the potential of implementing ponds in central Xiamen.

The capacity of the pond must first be calculated. To simplify the equations, infiltration to the soil from the pond is considered to be neglectable.

The storage capacity of the pond is approximated by the formula:

$$\boldsymbol{\Delta V = \int_0^t (Q_{in} - EV_{pond} - Q_{out})dt} \quad \textbf{(1)}$$

Where ΔV is the storage volume of the pond (m^3), Q_{in} is the inflow (m^3/s), E_{pond} is the evaporation from the pond (m^3) and Q_{out} is the outflow (m^3/s). All equations with appurtenant abbreviations can be found in Appendix B. Rainfall directly on the pond is included in the calculated rain from the drainage area. Water in the pool is assumed to be separated in two parts, one temporary storage volume, and one permanent pool of water. The storage depth of the water in the pool is assumed to be one meter, and the depth for the permanent pool of water is 0.5 meters.

The inflow (Q_{in}) can be calculated using the Rational Method. In this case, rainfall directly on the pond is included in the calculated rain from the drainage area.

$$\boldsymbol{Q_{in} = \varphi \times A_{catch} \times I} \quad \textbf{(2)}$$

Where φ is the runoff coefficient (-), A_{catch} is the catchment area (m^2) and I is the dimensioning precipitation (m). The environmental factors regulating inflow to the pond varies depending on the location. The runoff area of Yuan Dang Lake on Xiamen Island can be considered to be either mountainous areas, or flat, highly urbanized areas. Calculations made in this paper will include two cases, which can be considered to be the most possible for the area of implementation of ponds in central Xiamen.

- Case1: The pond is situated close to vegetated mountainous area.
- Case2: The pond is situated in the central districts close to Yuan Dang Lake, adjacent to urban area.

In the area for the investigation, the first case will not be applicable, but since quite a substantial part of Xiamen island consists of mountains, the calculations of Case 1 is included for possible further future investigations.

Depending on where the pond is situated, the amount of water reaching the pond will vary. The characteristics of the runoff-area differ significantly. In the first case the entire runoff area is assumed to consist of hilly woodland, while in the latter case, the urbanized area is presumed to consist of enclosed buildings, with some coherent gardens and green areas. To facilitate the calculations, the different factors in the catchment affecting the runoff are collected in the runoff coefficient (φ). According to Svenskt Vatten (2004), the runoff coefficients are 0.1 for the vegetated mountainous area, and 0.6 in the urbanized area.

The dimensioning rain varies from different sources. Planned usage is an important factor in deciding which specific dimensioning rainfall to use. Other elements, like the limits of the outflow of the pond can be used to choose the dimensioning duration of the rain, different recurrence periods may be used (Nilsson, 2008). In this calculation, a 24-hour rain with a 10-year recurrence time will be used. Data about rainfall in Xiamen can be found in Appendix A.

The dimensioned area of the pond (A_{pond}) can be calculated by using the formula:

$$\boldsymbol{A_{pond}} = \frac{\boldsymbol{\varphi \times A_{catch} \times I(24h) - Qout{,}\mathbf{max} \times 3600 \times 24}}{\boldsymbol{h_{storage}}} \qquad \textbf{(3)}$$

Where φ is the runoff coefficient (-), A_{catch} is the catchment area (m^2), $Q_{out,max}$ is the maximum allowed outflow (m^3/s) and $h_{storage}$ is the storage height of the water in the pond. The storage volume of stormwater is assumed to be empty at the start of the rainfall. To facilitate the calculations, the depth of the pond is presumed to be equal in all parts of the pond and the volumetric loss due to side slopes in the pond is neglected.

The minimum catchment area of wet ponds is normally 10 hectares, to ensure a sufficient amount of water is reaching the pond for a suitable turnover time for the water in the pond.

The retention time (T_{ret}) in the pond may be calculated by the equation:

$$\boldsymbol{T_{ret}} = \frac{\boldsymbol{(V_{pond} - EV_{pond})}}{\boldsymbol{Q_{out}}} \qquad \textbf{(4)}$$

The maximum outflow of the ponds ($Q_{out,\ max}$) is dependent on the downstream conditions, and may vary significantly from different areas. In these cases, the ponds coherent to the mountains are situated upstream, and a limited outflow to minimize effects downstream is selected. For ponds in the urbanized areas the situation is different. Situated close to the Yuan Dang Lake, which can support a significantly higher outflow from the coherent pond, a higher maximum outflow can be chosen. The outflow values chosen for these calculations are 20 l/s and 200 l/s respectively. As long as the inflow is smaller than the maximum outflow value, the water level will not rise, and there will be no change in the storage volume.

Using equation (2) and (3), the area of the stormwater pond can be calculated. The calculations are made for the two different cases stated above, with results displayed in Table 15.

Table 15: Results of calculated area needed for stormwater ponds in Yuan Dang catchment, Xiamen

Case	Dimensioning rain (mm)*	Dimensioning catchment area, A_c (ha)	Required area for stormwater pond, A_p (m^2)	Pond proportion (A_p/ A_c)
1: Vegetated mountainous region	**316**	10	1469	1.5%
2: Heavily urbanized region	**316**	10	1902	1.9%

*Maximum 24-hour precipitation in Xiamen, with a recurrence time of 10 years.

During the conditions above, the ponds will occupy a small area related to the total catchment, with less than 2% in both cases. The pond situated in the urban area has a significantly higher inflow of water, when the catchment area is the same as in the case with the mountainous area. The increase in inflow of stormwater is however compensated by the comparably high outflow allowed from the first mentioned solution. In these two studied cases, the additional inflow, and outflow limits compensate each other, making the size of the ponds relatively similar in size.

When calculating the feasibility of ponds, it is important to calculate the monthly average outflow and turnover time of the water in the ponds. Using equation (4), and assuming a permanent pool of water 0.5 meters deep, the average monthly outflow and the turnover time of the water can be calculated. The monthly outflow is calculated using equation (1) and (2), and the average monthly precipitation and average evaporation during 2001 – 2010, found in Appendix A as the dimensioning rain. The outflow is calculated as a possible average value during the month, in order to keep the water balance, and have the surface of the water at an even level. Results are shown in Table 16.

Table 16: Average monthly outflow and turnover time of the water in a stormwater pond with the characteristics from table 14, a permanent storage depth of 0,5 m and a temporary storage depth of 1m.

			Case 1: Vegetated mountainous runoff area		Case 2: Heavily urbanized runoff area	
Month:	**Total rainfall (mm)**	**Average evaporation (mm)**	**Outflow (l/s)**	**Retention time: (days)**	**Outflow (l/s)**	**Retention time: (days)**
January	34.7	80.7	0.09	79.5	0.75	9.5
February	61.1	76.3	0.20	36.9	1.37	5.2
March	87.2	88.6	0.29	24.1	1.98	3.5
April	127.1	100.7	0.44	15.5	2.90	2.3
May	181.7	118.0	0.64	10.1	4.17	1.6
June	230.4	116.3	0.83	7.8	5.31	1.2
July	164.2	161.7	0.55	10.5	3.73	1.5
August	214.2	142.1	0.76	8.1	4.91	1.2
September	137.8	143.0	0.46	13.3	3.12	1.9
October	57.7	153.9	0.14	42.6	1.24	4.8
November	28.8	118.1	0.05	143.3	0.59	11.1
December	34.8	93.7	0.08	83.3	0.75	9.2
Average	113.31	116.09	0.38	39.6	2.57	4.4

As seen in Table 16, there will be a very limited average outflow in Case 1, with some months having values close to zero. The limited amount of water arriving to the pond is much due to the characteristics of the runoff area, consisting of woodland. Most of the water will be retained by the vegetation and the soil, hence not reaching the pond. A healthy pool with a descent turnover time for the water would require an additional source of water, which is contradictory to the purpose of the pond. A better solution would be to implement dry ponds, or temporary detention basins as solutions to heavy storms. These could provide the same flood protection and retardation of the water, but the extended ponding time of the water would be avoided. Using the same values and equations as above, the dry storage areas would be of the same size as the stormwater ponds. If just calculating the temporary storage time of the water in a detention basin after the dimensioning 24-hour storm, with a 10 years recurrence time, the ponding time for the stormwater would be 44.5 hours for the first case, and 26.4 hours for the second case, provided maximum runoff values were used. These ponding times are both below two days (48h), and at less intensive rainfalls, the ponding time would be even shorter, minimizing the risks of additional nuisances. At time periods between rainfalls, these retention areas could be used for other purposes, e.g. recreational areas.

For the second case, the calculated numbers are more reasonable, with an average retention time of 4.4 days. The figures vary quite significantly though, ranging from 1.2 to 11.1 days. May to September all have a retention time of less than 2 days, which often is the time period seen as a preferable ponding time. According to Strutler Jr, (1986), an average retention time about 2 days will assure a high level of treatment and sediment-removal, which are favorable features. To extend the ponding time of the water in the pond, the outlet of the water could be designed as either a munk or a Siphon. By doing this, the water level would keep a higher level between the rainfalls, promoting a longer ponding time of the water. Explanations about outlet solutions can be read in Chapter 3.1.2.

The retention time in the second pond will be significantly longer in the dry months (November – January). Though the treatment features like sedimentation will have a lot of time to work, the extended ponding time of the water may impact the quality, and nuisances with the water quality may increase.

Drainage area or regulatory storage volume may be altered to increase the inflow to the ponds, and thence the turnover time of the water. This will however reduce the retention time during the wet months, which is not desirable from a qualitative perspective.

If situated closely to Yan Dang Lake, a possible solution may be to install pumps, which may provide water from the lake to the ponds when necessary, in order to attain a more balanced retention time of the water. Good maintenance and close observation of the water quality in the pond may also prevent nuisances during the dry months.

A temporary storage height of one meter may be considered relatively high, and security measures may have to be installed to prevent accidents connected to the pond. In ultra-urban areas such as central Xiamen however, land is very valuable, and deep ponds will have to be installed in order to use the land as economically as possible.

Though occupying less than 2% of the drainage area, enough space will be hard to find in central Xiamen for retrofitting purposes of stormwater ponds. Possible areas of implementation are areas where old houses have been demolished. Most certainly this has been done to make way for new constructions though. Many different stakeholders in the city are all eager to get access to the valuable land, and it may be hard to convince the local government to construct a pond in these areas, where an extended infrastructure is considered to generate more economical benefits. There are however some existing ponds and open recreational areas in the central areas of Xiamen. These have the potential of being reconstructed to stormwater ponds or temporary detention areas, in order to better handle stormwater issues.

6.2 Swales

Swales may to some extent be used for retrofitting purposes, but mainly through redesigning conventional dikes and gutters.

Stormwater Center (2011c) and Brown et al., (2001b) states that the maximum drainage area for swales normally is 2 hectares. TRCA et al., (2010) echoes this design criterion, but adds that the drainage area shouldn´t exceed 1.4 hectares if 75% or more of the runoff area consists of hard surfaces. Since the urban areas of Xiamen already are fully developed, the potential of retrofitting these solutions are greatest next to roads, where there already exist strips of vegetation. These may be reconstructed to swales or enhanced swales. A drainage area of 1.4 hectares is therefore chosen. The swale is constructed to run along with the road and the drainage area. The width/length ratio for the drainage area is assumed to be 1:5, and the swale is constructed to run alongside the entire length of the catchment area. Water is presumably entering the swale all along its length. Curb cuts for infiltration to the swale should according to Cahill Associates Inc. (2006) be at least 0.3 meters wide, in order to prevent clogging.

To calculate the maximum flow in the swale, the first thing to find is the runoff coefficient (φ). The area surrounding the swale is considered to be either roads or vegetated areas. To aggravate a coefficient for the entire catchment, the following equation is used.

$$\boldsymbol{\varphi} = \frac{(\boldsymbol{\varphi_{road}} \times \boldsymbol{A_{road}}) + (\boldsymbol{\varphi_{vegetated\ area}} \times \boldsymbol{A_{vegetated\ area}})}{\boldsymbol{A_{catchment}}} \quad \textbf{(5)}$$

Where φ is the runoff coefficient (-) and $A_{.....}$ represents a percentage of the different represented catchment areas (%).All formulas and coherent abbreviations can be found in Appendix B. Swales in Xiamen will most likely will be situated close to roads, since this is basically the only potential area where this solution may be retrofitted. From on-site observations and estimations, the catchment areas surrounding the roads are assumed to contain 75% hard surfaces like roads and pavements, and 25% vegetated surfaces, like parks and green areas. According to Svenskt Vatten (2004) the runoff coefficient for roads (φ_{road}) is 0.8, while the coefficient for vegetated areas ($\varphi_{vegetated\ area}$)is 0.1.

The designing rainfall for swales varies from different sources. Anderson et al., (2001c) states that typically, the swale accommodates water from a 2-year storm. TRCA et al., (2010) dimensions the swales after a 4hour and 25 min Chicago storm. Many sources, including Stormwater Center (2011c) dimensions the swale after the largest flow from a 15- minute rain with a recurrence time of 10 years. There are additional flow limitations for the largest 15-minute 2-year-rain, and the so called Water Quality Flow. The latter is normally a 24-hour storm with a recurrence time of two years. The 15-minute rain with a recurrence time of 2 years is assumed to have 70% of the intensity of the 10-year-rain.

VADCR (1999) states that the maximum flow velocity of the water in the swale for the 10-year flow should be 2.1m/s, and the maximum two-year flow velocity of the water should be 1.5m/s. For the Water Quality flow, the design flow shouldn´t have a depth greater than 0.1 meters, according to KCDEPW (2008) Infiltration from the swale to the soil is considered neglectable in the flow calculations.

The runoff peak flow (Q) in the swale is calculated with the equation:

$$\mathbf{Q} = \mathbf{i} \times \boldsymbol{\varphi} \times \mathbf{A_{catch}} \quad \textbf{(6)}$$

Where φ is the runoff coefficient (-), A_{catch} is the catchment area (m^2) and i is the rainfall intensity (m/s). Vegetated channels shall have a trapezoidal or parabolic cross-section, and shall have side slopes of 3:1 (h: v) or flatter (KCDEPW, 2008). The same source further recommends a longitudinal slope between 1 and 2% The bottom width of a trapezoidal swale should be between 0.75 and 3 meters (TRCA et al., 2010). Since space is a limiting factor in this case, the swale in this calculation is estimated to have a bottom width of 1 meter, side slopes of 3:1, and have a longitudinal slope of 2%. An illustration of the swale can be seen in Figure 14.

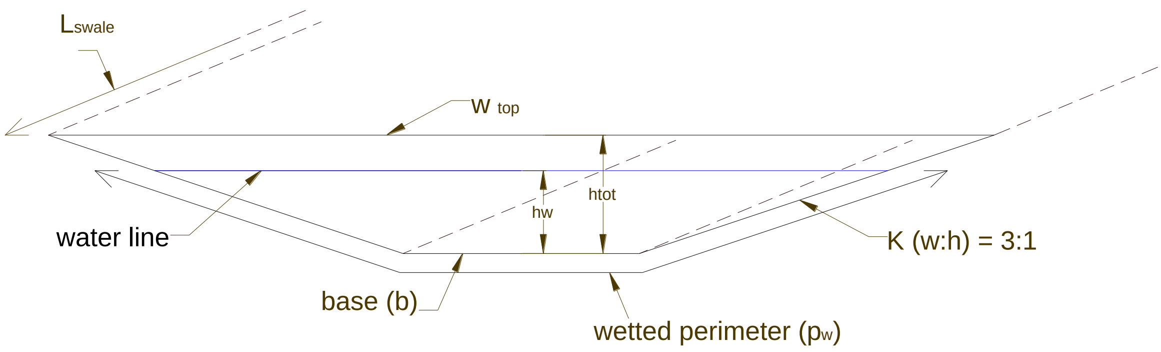


Figure 14: Simplified illustration of swale used in evaluation.

The velocity of the water (v) in the swale and the flow (Q) in the swale can be calculated using Manning's Equation:

$$\boldsymbol{v = M \times r_h{}^{(2/3)} \times s^{(1/2)}} \qquad \textit{and} \qquad \boldsymbol{Q = M \times A_w \times r_h{}^{(2/3)} \times s^{(1/2)}} \qquad \textbf{(7)}$$

Where M is the manning coefficient (-), r_h is the hydraulic radius (m), s is the longitudinal slope of the swale (%) and A_w is the cross-sectional area of the water in the swale (m^2). The hydraulic radius is calculated through the formula:

$$\boldsymbol{r_h = \frac{A_w}{p_w}} \qquad \textbf{(8)}$$

Where p_w is the wetted perimeter of the swale (m). For channels with heavy vegetation, which the swales in Xiamen are planned to be, the Manning coefficient (M) is 15. This number may be altered through changing the vegetation in the swale.

The cross sectional area of the water in the swale (A_w) is calculated by the equation:

$$\boldsymbol{A_w = b \times h_w + K \times h_w^2} \qquad \textbf{(9)}$$

Where the parameters can be seen in figure 14. The wetted perimeter is calculated through:

$$\boldsymbol{p_w = b + 2 \times h_w \times (1 + K^2)^{1/2}} \qquad \textbf{(10)}$$

According to Anderson et al., (2001c), the minimum freeboard over the maximum flow during the 10-year storm should be 15 centimeters, which also will be selected in this example. The total height of the swale is set to 0.5 meters. The maximum water height in the swale is now simply decided by removing 0.15 m from the top height.

Since the width/length ratio of the catchment is set to 1:5, and the swale runs alongside the runoff area, the length of the swale (and catchment) is calculated by equation 11:

$$\boldsymbol{L_{swale} = \sqrt{5 \times A_{catch}}} \qquad \textbf{(11)}$$

The top width is calculated by the equation:

$$w_{top} = b + 2 \times T \times h_{tot} \qquad \textbf{(12)}$$

With equation (12), the top width of the swale is calculated to 4 meters. When the top width of the swale is determined, the total area of the swale may be decided by the formula:

$$A_{swale} = L_{swale} \times w_{top} \qquad \textbf{(13)}$$

With this information, it is possible to estimate the maximum flow allowed in the swale for the different conditions. By using calculations (7) - (11), the maximum allowed flow in the swale at different occasions can be decided. When the maximum flow is decided, equation (6) is used to decide the maximum potential rain intensity that the swale can handle.

The results using above mentioned preconditions are displayed in Table 17:

Table 17: Parameters related to maximum allowed flow for swales in central Xiamen.

Flow	Dimensioning catchment area, A_c (ha)	Height of water in swale (m)	Q_{max} allowed (m^3/s)	Corresponding water velocity (m/s)	Corresponding rain intensity (mm/h)	Total area swale, A_s (m^2)	Proportion (A_s/ A_c)
10-year maximum flow	1.4	0.350	0.56	0.78	227.6*	1058	7.6%
2-year maximum flow	1.4	0.30	0.40	0.71	160.7**	1058	7.6%
2-year 24-hour-flow	1.4	0.10	0.05	0.39	20.7***	1058	7.6%

* Maximum calculated rain intensity for a 15-minute storm, with a recurrence time of 10 years.
** Maximum calculated rain intensity for a 15-minute storm, with a recurrence time of 2 years.
*** Maximum rain intensity for a 24-hour rain, with a recurrence time of 2 years.

With a maximum water height of 0.35 m, the swale can support a 15-minute-rain with the intensity of 227.6mm/h or a total rainfall of 56,9mm in 15 minutes.

As seen in the table, the flow velocities are well below the given limits of 2.1m/s for the 10-year flow and 1.5 m/s for the 2-year flow. For the water quality treatment flow, the swale can support a flow of $0.05 m^3/s$, or a rainfall intensity of 20.7 mm/h. By using numbers from appendix A, the 2-year 24-hour rain intensity can be calculated to 5.2 mm/h, well below the determined limits. The total percentage of the drainage area occupied by the swale is 7.6%, which is in the lower region of the range between 5 – 15%, suggested by TRCA et al., (2010)

These calculations show that swales may be a feasible solution to implement in Xiamen. All the limits for a successful implementation are met. Limitations to consider are the relatively large width of 4 meters needed. Even though some of the most space-conservative measures were used, the total width still ended up relatively large. Since the solution will be retrofitted, problems may arise creating a uniform longitudinal slope and a uniform flow, which may lead to ponding water in the swale. These considerations must be taken into the calculations when finding solutions for retrofitting purposes in central Xiamen. When planning and developing new areas of the city however, swales should be seen as a feasible solution for the transport of stormwater.

6.3 Canals

Canals can be seen as feasible solutions for transporting stormwater downstream in an urban environment. What differ canals from other solutions is that these solutions don´t contribute with the benefits normally associated to sustainable urban drainage systems, like detention or contaminant removal of the water. At the same time it isn´t restricted by the same limitations as other open stormwater solutions either. There is no need for erosion control in canals, so if regarding the canal as a separate system, there is no limit on the velocity of the water. Limits of the runoff area are only decided by the sizing of the canal. Maintenance-wise the canals are inexpensive as well.

Different materials may be used for the construction of canals, but usually some kind of concrete is utilized, which also is to be the case for this example. Manning's coefficient (M) for concrete canals is set to 70. Since the solution itself doesn´t limit the drainage area, an area of 3 hectares is assumed. The width/length ratio of the catchment is assumed to be 1:10. The canal is located along the total length of the drainage area. The canals as well are most likely to be implemented adherent to roads, hence the runoff coefficient (φ) is estimated to be 0.625, the same as in the case for swales. Equation (5), found in Appendix B, shows how this number was calculated. The longitudinal slope (s) is estimated to be 2**%.**

The canal is assumed to be of rectangular shape, with a bottom width of the canal estimated to be one meter. A freeboard of 15 centimeters over the maximum flow is assumed, see Figure 15.

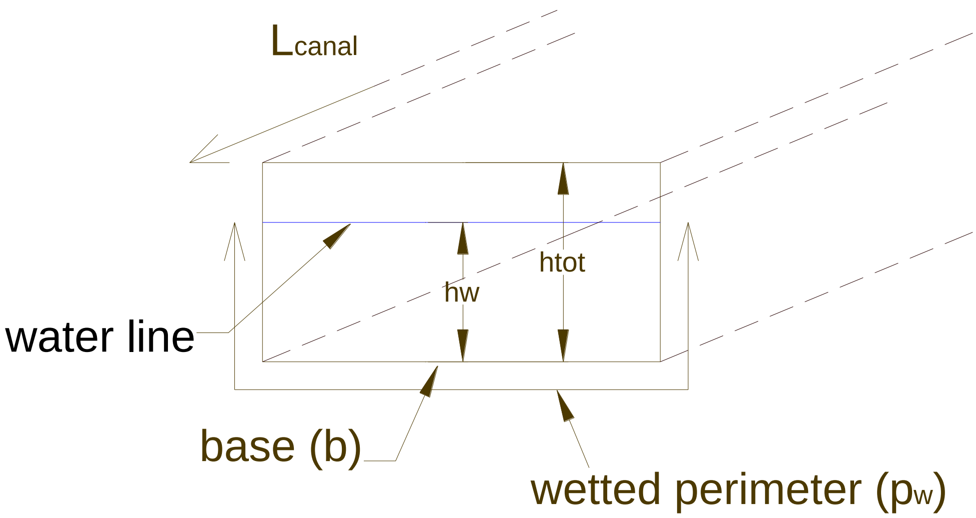


Figure 15: Simplified illustration of canal used in evaluation.

The maximum flow in the canal is decided using the Rational Method:

$$\mathbf{Q = i \times \varphi \times A_{catch}} \qquad \textbf{(6)}$$

Where φ is the runoff coefficient (-), A_{catch} is the catchment area (m^2) and i is the rainfall intensity (m/s). All equations with appurtenant abbreviations can be found in Appendix B. The cross section of the canal is presumed to be of a square shape, meaning that the width is the same in the bottom and the top of the canal.

The velocity (v) and the flow of the water (Q) can be decided by Manning's equation.

$$\boldsymbol{v = M \times r_h^{(2/3)} \times s^{(1/2)}} \text{ and } \boldsymbol{Q = A \times M \times r_h^{(2/3)} \times s^{(1/2)}} \qquad \textbf{(7)}$$

Where M is the manning coefficient (-), r_h is the hydraulic radius (m), s is the longitudinal slope of the canal (%) and A_w is the cross-sectional area of the water in the canal (m^2). For concrete canals, the Manning´s number (M) is normally around 70. The hydraulic radius (r_h) is calculated by the equation:

$$\boldsymbol{r_h = \frac{A_w}{p_w}} \qquad \textbf{(8)}$$

Where p_w is the wetted perimeter of the canal (m). The cross sectional area of the water in the canal is decided by:

$$\boldsymbol{A_w = b \times h_w} \qquad \textbf{(14)}$$

Where the parameters can be seen in Figure 15. And the wetted perimeter is decided by:

$$\boldsymbol{p_w = b + 2 \times h_w} \qquad \textbf{(15)}$$

As for swales, the height of the canal is set to 0.5 meters. With a 0.15 m freeboard, the maximum height of the water is decided to 0.35 meters.

Since the width/length ratio of the catchment is set to 1:10, and the canal runs alongside the entire runoff area, the length of the canal (and catchment) is calculated by equation 11:

$$\boldsymbol{L_{canal} = \sqrt{10 \times A_{catch}}} \qquad \textbf{(11)}$$

Finally, the area of the canal is decided form the equation:

$$\boldsymbol{A_{canal} = b \times L_{canal}} \qquad \textbf{(16)}$$

Using the equations listed above together with assumptions made, the maximum flow in the canal, during a storm lasting for 15 minutes may now be calculated.

The results using the assumptions and equations listed above are displayed in Table 18:

Table 18: Parameters related to maximum allowed flow for canals in central Xiamen.

Flow	Dimensioning catchment area, A_c (ha)	Height of water in canal (m)	Q_{max} allowed (m^3/s)	Corresponding water velocity (m/s)	Corresponding rain intensity (mm/h)	Total area canal, A_{can} (m^2)	Proportion (A_c/ A_{can})
10-year maximum flow	3	0.35	1.21	3.45	231.8*	548	1.8%

* Maximum calculated rain intensity for a 15-minute storm, with a recurrence time of 10 years.

The results above show that the canal gives a flood protection for a 15-minute-rain with an intensity of up to 231.8mm/h, if the assumptions made above are used. The 0.15 m freeboard above the maximal allowed water level may be seen as an insurance for flood protection even at higher flows.

As seen in the figures above, canals occupy a very small percentage of the drainage area. Heights and width of the canal may be altered to fit the local conditions. The velocity of the water in the canals is high, with a maximum dimensioning speed of around 3.45 m/s. This lack of retardation and treatment of the water must be considered when implementing these solutions. Small obstacles may in some cases be constructed in the canal, to adjust the flow velocity. Rolfsdotter-Jansson (2009) gives examples of these kinds of solutions, successfully implemented in open canals in the residential area of Augustenborg, Sweden.

A concern with canals is the high risk of clogging, if debris and dirt accumulates in the canal. In China, there are arguments speaking both for and against this to happen. An argument for the accumulation of litter is the fact that Chinese people in general throw a lot of garbage on the street, which easily can end up in the canals. On the other hand there are a vast number of city cleaners, removing the waste that ends up on the streets on a daily basis. This means that the canals, as well as other SUDS can have the debris removed regularly, a maintenance capacity that is rare in most of the developed countries. Taking these different aspects into consideration when deciding the suitability of canals is of great importance.

6.4 Infiltration devices

Infiltration devices work through a similar manner. There are differences however, with bioretention areas differencing the most from the other infiltration solutions. In this text, infiltration devices will be exemplified by bioretention areas and infiltration trenches.

6.4.1 Bioretention areas

Bioretention areas are solutions which have few limits, and are well suited for retrofitting purposes in ultra-urban areas (Stormwater Center, 2011e).

According to Brown, Stein, Warner (2001) the maximum ponding depth for water is 0.2 meters above the level of the soil. An additional freeboard of at least 5 centimeters over the maximum depth of the water should be added to the construction, according to the same source. Since space is very limited in the central areas of Xiamen, vertical sides are supposed to keep the ponding water in the bioretention area. Brown, Stein, Warner (2001) continues by stating that the bioretention area normally occupies approximately 10% of the drainage area and that stormwater from a catchment larger than 2 hectares shouldn´t be conducted to the device. TRCA et al., (2010) has an even more restricting approach, states that the runoff areas normally are small, with a maximum no larger than 0.8 hectares. If local soil-conditions are limiting, underdrains can be used to lead the water away from the bioretention area. The soil-conditions in the majority of central Xiamen, with compressed soil, the proximity to structures and installations and the risk of contaminating the groundwater make the usage of subdrains the most feasible solution, to lead the water downstream. A perforated pipe with a protective geotextile filter fabric is normally used as an underdrain (TRCA et al., 2010).

TRCA et al., (2010) states that the maximum ponding time of the water in the bioretention area should be 24 hours, since this is less than the breeding-cycle of mosquitoes. The minimum depth of the engineered soil in the bioretention area is 0.75 meters (Brown, Stein, Warner, 200). In this example, the soil is estimated to be one meter deep. The infiltration rate $(g_i)$of the engineered soil should have a minimum of 25mm/h according to TRCA et al., (2010), which also is the number that will be used here. An effective water storage capacity(W_{SC}) of 0.20 is assumed.

In the environment intended for this solution, there is not likely to be enough space for large installations. A more viable solution will be a number of small-scale bioretention areas, each handling a limited amount of water. Two bioretention areas with different sizes will be used in the calculations to decide the feasibility of the solution in central Xiamen. The first structure has the length of 3 meters, and the width of 2 meters and the second structure has a length of 7 meters and a width of 5 meters. The dimensioning precipitation is a 10-year rain, lasting for 24 hours.

When the dimensioning storm occurs, the soil is presumed to be dry. The initial total storage capacity of the bioretention area is decided by the maximum ponding depth and the storage capacity of the soil.

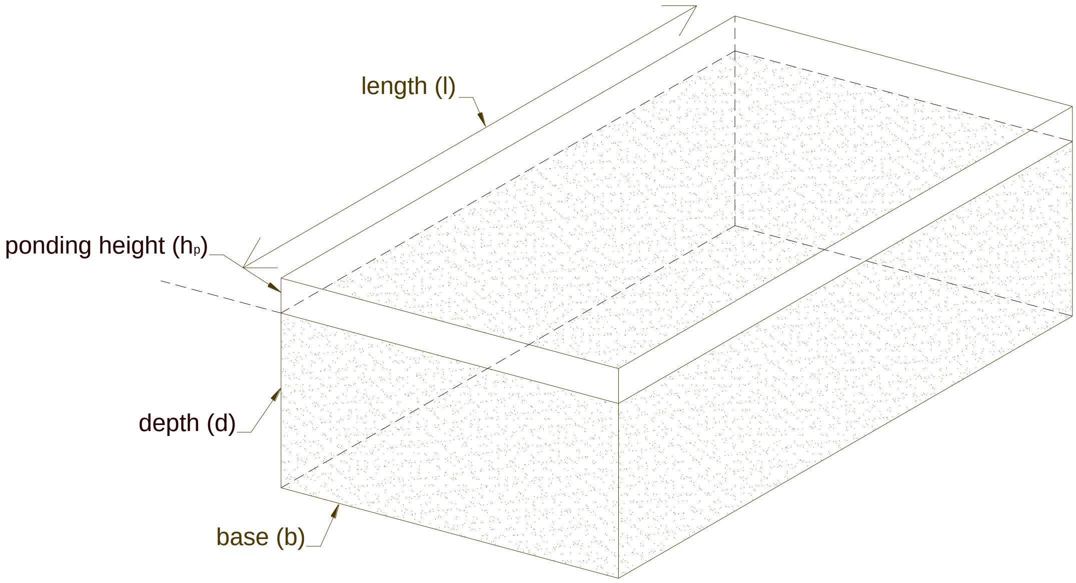


Figure 16: Simplified illustration of bioretention area used in evaluation.

The total volume of water possible for initial storage (V_{tot}) can be decided by the equation:

$$\boldsymbol{V_{tot} = A_{bioretention} * h_p + V_{bioretention} * W_{SC}} \qquad \textbf{(17)}$$

Where $A_{bioretention}$ is the area of the solution (m^2), h_p is the ponding height of the water (m), $V_{bioretention}$ is the volume of the bioretention area and W_{SC} is the water holding capacity of the soil (%). The dimensioning volume of stormwater conducted to the bioretention area (Q_{dim}) can be decided by equation (2):

$$\boldsymbol{Q_{dim} = \varphi \times A_{catch} \times I} \qquad \textbf{(2)}$$

Where φ is the runoff coefficient (-), A_{catch} is the catchment area (m^2) and I is the dimensioning precipitation (m). For asphalt and concrete, the runoff coefficient is 0.8. Since these solutions only handle stormwater from a very limited area, it is assumed that the entire catchment consists of hardened surfaces with the runoff coefficient 0.8.

The size of the catchment area can be decided by the equation:

$$\boldsymbol{A_{catch} = \frac{V_{tot}}{Q_{dim}\ per\ area\ unit}} \qquad \textbf{(18)}$$

When the maximum storage volume is decided, the catchment area is the only unknown element in equations. By rearranging these calculations, this area may be decided.

The ponding time of the water (t_p) can easily be decided by the equation:

$$\boldsymbol{t_p = \frac{h_p}{g_i}} \qquad \textbf{(19)}$$

Where (g_i) is the infiltration rate of the soil media (m/h). Using equations (2) and (17) – (19), the results displayed in Table 19 were calculated:

Table 19: Results of calculated space needed for bioretention areas in central Xiamen.

Dimensioning storm (mm)*	Area, bioretention device, A_b (m^2)	Potential catchment area, A_c (m^2)	Proportion (A_b /A_c)	Water ponding time (h)
316	6	43.7	13.7%	3.3
316	50	363.9	13.7%	3.3

* Maximum 24-hour precipitation in Xiamen, with a recurrence time of 10 years.

A percentage of 13.7% of the drainage area is a little above 10%, the suggested proportion by Brown, Stein, Warner (2001). Calculations show that the proportions between the potential catchment and the bioretention area do not change with the altering of the size of the latter. This fact makes it easy to decide the appropriate drainage area when designing bioretention areas as a stormwater solution. A ponding time of 3.3 hours is well below the set limit of 24 hours, which ensures the prevention of breeding possibilities for mosquitoes.

An issue with infiltration devices is the reduction of capacity and high rates of failure. Clogging and litter preventing infiltration must be avoided to reach satisfactory results. Bioretention areas have a high rate of removal if functioning according to the design, something that may help reducing stress on downstream recipients such as the Yuan Dang Lake. Plans for how to avoid issues like clogging must be developed and considered to assure good results. If possible, pretreatment devices like swales or filter strips should be constructed upstream, to remove some of the sediments which may reduce the infiltration rate. Native, tolerant plants should be planted in the bioretention area. The vegetation will enhance the treatment process of the water and increase the amenity in the area. It is important to incorporate flooding possibilities for the stormwater in the bioretention areas. Brown, Stein, Warner (2001) writes that all rain gardens must include an emergency overflow structure which safely will lead the water to appropriate areas.

6.4.2 Infiltration trenches

Infiltration trenches have great similarities to soakaways and infiltration chambers. Storage and infiltration mechanisms work in the same way. What differ are the design, and the limits of the drainage areas. In this example, an infiltration trench is chosen, but the same equations may be used for the other mentioned infiltration devices as well.

The suitable infiltration rate for soils where infiltration devices are implemented can vary significantly. Rates between 7.5 and 200 mm/h are acceptable, according to Brown, Stein, Warner (2001). The mean value for the infiltration rate in the central parts of Xiamen used in this example was decided from field studies by Hu (2004), where the infiltration rate after 30 minutes was calculated using Horton's equation. The mean infiltration rate was decided to 109.2 mm/h.

The depth of infiltration trenches are normally between 0.9 and 3.7 m, with 2.4 m as the most commonly used depth (USEPA, 1999a). TRCA et al., (2010) states however that if the infiltration rate in the surrounding soil is higher than 45 mm/h, the maximum depth of the trench should be 2 meters, in order to prevent soil-compaction and loss of permeability. Hence 2 meters is the depth chosen for this example. The width normally varies between 0.6 and 2.4m (TRCA et al., 2010). a width of 1 meter is chosen in this example. The length of the device will be set to 10 meters. A granular material of 50 mm clear stone, with a void-ratio (e) of 0.4 will fill the trench.

When designing stormwater drainage systems such as infiltration trenches, the dimensioning rainfall varies from different sources. RVSS (2008) uses a 24 hour-rain with a recurrence time of 10 years, which is the dimensioning rain that will be used in this example.

During a 24-hour storm the total volume of water the infiltration trench can handle (V_{tot}) is decided by adding the storage volume of the trench (Vs) with the volume infiltrated in the soil (Vi) during the time period of the rain.

$$\boldsymbol{V_{tot} = Vs + Vi} \tag{20}$$

All equations with appurtenant abbreviations can be found in Appendix B. An infiltration trench is illustrated in Figure 17.

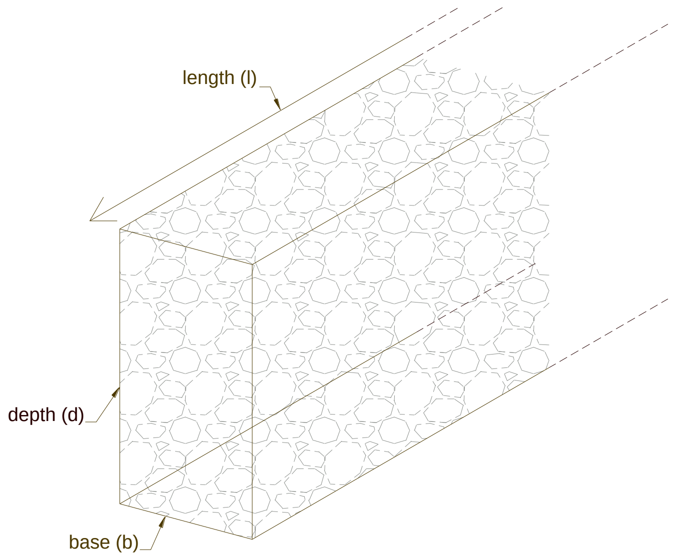


Figure 17: Simplified illustration of infiltration trench used in evaluation.

The storage volume of the trench (Vs) is calculated using equation 21:

$$\boldsymbol{Vs = l_{trench} \times b_{trench} \times d_{trench} \times e} \tag{21}$$

Where e is the void ratio for the material in the trench (%) and the rest of the parameters are seen in figure 17. The volume of water that percolates into the soil during the 24h period (V_i) can be calculated using the ground area where the water can infiltrate, and multiply this by the infiltration rate during the predetermined time.

$$\boldsymbol{V_i = l_{trench} \times b_{trench} \times g_i \times 24} \qquad \textbf{(22)}$$

Where g_i is trhe infiltration rate ot the underlying soil. The dimensioning volume of stormwater conducted to the bioretention area (Q_{dim}) is decided by equation (2):

$$\boldsymbol{Q_{dim} = \varphi \times A_{catch} \times I} \qquad \textbf{(2)}$$

Where φ is the runoff coefficient (-), A_{catch} is the catchment area (m^2) and I is the dimensioning precipitation (m). Just like with bioretention areas, these solutions only handle stormwater from a very limited area, so in this case as well, it is assumed that the entire catchment consists of hardened surfaces with the runoff coefficient 0.8.

To calculate the catchment area this device can support, the following equation is used:

$$\boldsymbol{A_{catch} = \frac{V_{tot}}{Q_{dim}\, per\ area\ unit}} \qquad \textbf{(18)}$$

Like the last example, the catchment area is the only unknown, and by combining equation (2) and (18), this may now be determined.

These calculations may now be used to calculate the values related to the usage of infiltration devices in Xiamen. The results are displayed in Table 20:

Table 20: Results of calculated area needed for infiltration trenches in central Xiamen.

Dimensioning rain (mm)*	Area, Infiltration Trench, A_i (m^2)	Potential catchment area, A_c (m^2)	Proportion (A_b /A_c)
316	10	139.6	7.2%

* Maximum 24-hour precipitation in Xiamen, with a recurrence time of 10 years.

The high infiltration rate of the soil makes this solution a feasible option in Xiamen. The proportion of 7.2% of the catchment area occupied by the infiltration trench does not change, if the same ratio between the size of the trench and the runoff area are kept. This makes it easy to determine the drainage area, when implementing these solutions. Because of the conditions in the highly urbanized areas of central Xiamen, with packed soil, a lot of buildings and a high concentration of pollutants, these solutions may not be feasible in the central parts. A better solution would be to implement infiltration trenches coherent to parking lots or residential In less densely urbanized parts the city. As written earlier, same equations as used above may be used to calculate the feasibility for soakaways and infiltration trenches.

For infiltration devices such as this one, pre-treatment is of great importance in order to avoid clogging and failures in performance, which unfortunately is a common issue. Pre-treatment may be realized through filters, which can be designed to remove both small and large particles. Other open stormwater solutions such as filter strips or swales may also be used as pre-treatment devices. The sides of the infiltration trenches should be lined with a geotextile fabric, to prevent adjacent soils from clogging, and reducing the infiltration capacity.

6.5 Green roofs

The implementation of green roofs is particularly suitable in ultra-urban areas, where there often is a lack of space for realizing many sustainable urban drainage solutions. Since vegetated roofs don't claim any new area and provide a lot of additional benefits, these are considered highly feasible solutions. As written in Chapter 3.6.1, green roofs can be constructed with a thin soil layer (extensive roofs), or a thick soil layer (intensive roofs).

This example will include calculations of the two different designs during the same climatic conditions. GVSDD (2005) writes that a common thickness of the soil media in extensive roofs is 7.5cm. For intensive roofs, soil-layer up to 30 cm thick is common (Czemiel Berndtsson, 2004). For this example, the thickness of 7.5 cm and 25 cm respectively are chosen. The slope of the roof is assumed to be a few percent, enough to promote natural, gravitational drainage of excess water.

Observations carried out on green roofs by Bengtsson (2005, cited in Czemiel Berndtsson, 2010) found the field capacity to be 45%, and the wilting point to be 15%. The same source describes the water storage capacity as the difference between the field capacity and the wilting point. In these calculations, the values mentioned above will be used.

To calculate the retention of stormwater in green roofs, it is important to know the evapotranspiration rate of the water retained in the soil of the green roofs. Climate data like monthly rainfall and potential evapotranspiration (E_p) during the last decade is found in Xiamen Statistics Bureau (2001-2010), where the average values are calculated.

When knowing the potential evapotranspiration the actual evapotranspiration (E_t) is decided by the following criteria's: E_t

1. $\theta \geq \theta_{fc}$ → $E_t = E_p$
2. $\theta_{wp} < \theta < \theta_{Fc}$ → $E_t = E_p \times \left(\frac{\theta - \theta_{wp}}{\theta_{fc} - \theta_{wp}}\right)$
3. $\theta < \theta_{wp}$ → $E_t = 0$

$\theta = Water\ content\ in\ the\ soil$

$\theta_{Fc} = Field\ Capacity, soil$

$\theta_{wp} = wilting\ point, soil$

In the case with green roof, the water that is not kept as a part of the field capacity is removed from the roof as runoff. The maximum level of water in the green roofs is hence the field capacity of the soil. This means that the equation that will be used to calculate the actual evaporation is:

$$\mathbf{E}_t = E_p \times \left(\frac{\theta - \theta_{wp}}{\theta_{fc} - \theta_{wp}}\right) \quad \textbf{(23)}$$

All equations with appurtenant abbreviations can be found in Appendix B. When knowing the actual evapotranspiration, the amount of water leaving the roof can be calculated. The differential between the actual water content and the field capacity of the soil is what is stored in the soil. When storms generating runoff from the roofs (Q_r) occurs, the equation can be written as:

$$\boldsymbol{Q_r = I - (\theta_{Fc} - \theta_{current})} \quad (Q_r > 0) \tag{24}$$

$$\boldsymbol{\theta_{current} = \theta_{last\ rainfall}} - (\mathrm{E}_t \times \boldsymbol{days\ without\ rainfall}) \tag{25}$$

Where I is the dimensioning precipitation (mm). With these equations, the runoff reduction achieved by green roofs can be calculated. Values for a single storm-event or for a coherent time period can be used. Many design guides, including TRCA et al., (2010) use extensive time-periods for calculating the stormwater reduction. For this example, the runoff-reduction is estimated for two months, the rainiest and one of the most arid months of the year in Xiamen, namely June and December.

To calculate the monthly reduction of rainfall provided by the green roof, a day to day approach is used. Using Excel, the formulas above were implemented to calculate the actual evapotranspiration and runoff for each day in the months. As seen in Appendix A, the average rainfall for the chosen months is 348.3 mm for June, and 28.0 mm for December. Data about the average amount of rainy days in these months is also displayed in the statistics, showing an average of 16.2 rainy days in June, and 6.1 rainy days in December. The potential evapotranspiration was found in the same source, 164.3 mm for June, and 120.7 mm for December. The water content of the soil in the beginning of the month is assumed to be half of the soil's field capacity($\theta_{Fc}/2$). To facilitate the calculations, the total rainfall was simply divided by the number of rainy days in the months, creating a number of identical rainfalls, evenly distributed in the month. Though differentiating from the actual rainfall-events, these calculations may give a hint of the quantity-reduction of stormwater in green roofs.

Results from the calculations may be seen in Table 21:

Table 21: Calculated runoff reduction from green roofs in central Xiamen.

			Intensive roofs		Extensive roofs	
Month	Total rainfall (mm)*	Rainy days	Runoff reduction (mm)	Reduction percentage	Runoff reduction (mm)	Reduction percentage
June	230.4	16.2	152.3	66%	117.0	51%
December	34.8	6.1	34.8	100%	34.8	100%

* Average monthly rainfall for the period 2001 – 2010. (Xiamen Statistics Bureau, 2001-2010)

These values are to be seen as values for a unit, e.g. a square meter. Having the percentage of reduction during the selected months makes it easy to calculate the reduction in a certain area, where green roofs are to be implemented.

As seen in the displayed results, the reduction of stormwater from both extensive and intensive is relatively high. A reduction of 66% and 51% in the rainiest month is a considerable reduction. The climate of Xiamen, with a high potential evapotranspiration is an important factor for the high reduction of stormwater. The similar values from the two different kinds of roofs are partly a consequence of the way of calculating the runoff, with evenly distributed rainfalls during the month. In reality, the magnitude and frequency of the rain varies significantly, and in these cases, the intensive roof is better equipped to absorb heavy rainfalls. The water storage capacity for the extensive roofs used in this example is 24mm, while the intensive roof has the capacity to store 75 mm, which is a considerable difference. If heavy rainfalls occur with long dry periods in between, the difference in runoff reduction between the two alternatives will be more significant.

In the dry month, December, all rainwater will be absorbed in both cases, if using evenly distributed rainfalls during the month in the calculations. Water absorbed by the soil will be reduced through evapotranspiration. The water content in the soil will be slightly reduced, but stay well above the wilting point. This shows that the vegetation on green roofs have good chances of surviving the dry months, without the need of extensive maintenance.

If implementing green roofs in Xiamen, the average magnitude and frequency of the rainfall must be researched, to see which kind of green roofs that is most suitable for implementation. The need for maintenance must also be considered. While the need for maintenance in extensive green roofs is minimal if constructed correctly, the intensive roofs need a certain amount of care for the vegetation to survive.

For many of the skyscrapers, there is a possibility to create a recreational area on the roof, where residents can benefit from the recreational values of the green roofs. Here intensive roofs, with a better possible variation of plants and vegetation are the most suitable solution. The extra weight of the green roof must be considered, and calculations must be made to assure right conditions the vegetation on the roof, to survive throughout the year. Apart from the stormwater reduction and aesthetical values, the implementation of green roofs will also help removing pollutants from the air during dry periods, reduce the heat-island effects and isolate the buildings against heat-fluxes, all valuable contributions to the environment of the city.

6.6 Rainwater harvesting

Another potential solution of stormwater management is rainwater harvesting, where the stormwater is collected, to be used for a later occasions. The most suitable areas in a city for rainwater harvesting are considered to be roofs, which also will be the areas of investigation for this example.

Since the implementation in Xiamen will mainly be as retrofitting, the most liable field of usage of the water would be for non-domestic purposes. To re-install all toilets or other domestic non-potable water devices for entire building complexes would be very expensive and demand a lot of efforts, where the downsides would eclipse the potential benefits of the installations. For non-domestic usages like irrigation or street cleaning, rainwater harvesting can be seen as a more feasible solution. In this example, the water will be used for irrigational purposes of green areas.

In ultra-urban cities, the percentage of rooftop area varies. Gong, Yang, Yu (2008) and CPPD (2008) refer to studies concluding that between 20 and 30% of the area in a densely populated city normally consists of rooftops. Since there is no specific data available for Xiamen, an estimated value of 30% in the area of investigation will be chosen. Of these roofs, 70% will be considered as feasible for the implementation of rainwater harvesting systems.

The reduction of first flush diversion must also be accounted for in the equation. According to LaBranche et al., (2007), about 5% of the rainfall is appropriate to remove with the first flush.

Estimations about the irrigational needs of water can be made with information from Zhou et al., (2003), writing that 315000 m^2 of green areas need 300 000 m^3 a year of irrigational water. This means that one square meter of green area will need 0.95 m^3 irrigational water (300 000/315 000 m^3) yearly.

The percentage of green areas in Xiamen can be found from China Statistics Press (2010), which displays data saying that 39.5% of the city of Xiamen consists of green areas. Though the actual percentage of green areas is assumed to be smaller in the investigated area, there will be adjacent parks and green areas, within the potential reach of the collected stormwater.

The potential of collecting rainwater ($V_{collected}$) can be calculated using the following equation:

$$\boldsymbol{V_{collected} = P_{roof} * U * \left(1 - F_f\right) * A_{control\ area} * I} \qquad \textbf{(26)}$$

Where P_{roof} is the percentage of rooftops in the area of investigation (%), U is the percentage of roofs feasible for rainwater harvesting (%),F_f is the first flush reduction (%),$A_{control\ area}$ is the total area investigated and I is the Dimensioning precipitation (m). All equations with appurtenant abbreviations can be found in Appendix B. The water needed for irrigational purposes ($V_{irrigation}$) can be decided by:

$$\boldsymbol{V_{irrigation} = N_{irrigation} * P_{green\ areas} * A_{control\ area}} \qquad \textbf{(27)}$$

Where $N_{irrigation}$ is the need for irrigation per unit of green area (m^3/m^2), $P_{green\ areas}$ is the percentage of green areas in the investigated area (%) and $A_{control\ area}$ is the total area investigated (m^2) The need for irrigation is assumed to be equal throughout the year. The fact that the green areas need for water increases during warm summer months is assumed to be compensated by the increased amount of rainfall during these months. Climate data used in the calculations is collected from Appendix A. In this example, a control area of 1 ha is chosen. Using the equations and assumptions above, the results in Table 22 were calculated.

Table 22: Results for rainwater harvesting.

Month	Volume rainfall collected (m^3)	Volume needed for irrigation (m^3)	Percentage of irrigation-usage covered
January	85.1	312.7	27%
February	194.5	312.7	62%
March	144.3	312.7	46%
April	322.5	312.7	103%
May	331.8	312.7	106%
June	694.9	312.7	222%
July	347.8	312.7	111%
August	444.2	312.7	142%
September	385.7	312.7	123%
October	142.3	312.7	46%
November	37.2	312.7	12%
December	55.9	312.7	18%
Total:	**3137.47**	**3752.5**	**84%**

There is a significant variation in the potential volume of rainwater collectable for different months during the year. During the rainy months, which is about half of the year, the complete need for irrigational water can be met. In the dry months on the other hand the demand is far from met, with the potential water collected decreasing to well below 20% of the monthly need. According to TRCA et al., (2010), the stormwater shouldn´t be stored in the tanks for a longer time period than 10-12 days, since this may jeopardize the quality and increase nuisances. This means the option of saving water from the rainy months for later use is not feasible. The excess water during the rainy months may instead be used for other purposes, such as street cleaning or firefighting.

Potential problems may include finding sufficient space for the tanks in adjacency to the areas where the water is collected. Pipes, power lines and other underground facilities may aggravate the positioning of the tanks. Positioning of the tanks beneath the ground will however be the best solution, since the temperature may reach well over 30 degrees in the warm months. Constructing the tanks underground partly isolates the water from the high temperatures, hence reducing some temperature affected problems like bacterial and algae growth. Regular controls and maintenance of the system must be carried out, to ensure the quality of the water. One big pro with this solution is that the in-situ storage of stormwater for irrigation will decrease the need for transporting the water, reducing energy costs and the need to expand the distribution-system. The water collected will contribute to a reduced stress on downstream solutions and recipients.

6.7 Stormwater solutions not evaluated

The sustainable urban drainage solutions of wetlands and filter strips will not be considered as feasible solutions for retrofitting purposes on Xiamen Island, and will not be evaluated in this report. A brief explanation why is given below for each solution.

6.7.1 Wetlands

The reason why wetlands will not be considered as a solution is mainly because of the vast amount of land required. In an ultra-urban environment like central Xiamen there is simply not enough space for implementing a wetland. This solution is a downstream solution, constructed far down the flow path. In the area in central Xiamen investigated in this report, Yuan Dang Lake serves as the downstream solution.

For areas of Xiamen located on the mainland, wetlands may be a feasible solution. When dimensioning wetlands, the same approach as for dimensioning ponds may be used. In a warm, subtropical climate like the one in Xiamen, nuisances like odor and mosquito-breeding may be frequent issues if the wetland is not correctly constructed, or poorly maintained, facts that need to be considered before constructing a stormwater wetland.

6.7.2 Filter strips

Filter strips will not be considered in this report because of its limited retention and treatment abilities, and the large proportion of the drainage area it occupies. When retrofitting stormwater solutions in a highly urbanized area, the device should preferably occupy a small part of the drainage area. Though filter strips are good for pretreating water and removing sediments for infiltration devices, these solutions are considered not to be feasible in central Xiamen. The fact that the strips need a sheet flow to function properly restricts the potential areas if implementation even further. As for wetlands, this solution may be feasible in other parts of Xiamen, mainly on the mainland, where there are larger areas available. In the central parts of Xiamen Island, the solutions are not considered feasible however.

7 Effects of implementation in Xiamen

7.1 Current situation

There is today no plan or strategy of how to handle or use the rainwater in Xiamen (XCMB, 2006). Traditional concepts are still dominant. Water is conveyed directly to the recipients, often in a combined pipe system. At the moment, there are 19 major pipes on the Southern side of Yuan Dang Lake, leading sewage and stormwater to the treatment plants, before reaching the recipients (Zhou et al., 2003). As described in chapter 5.10.2 about Yuan Dang Lake; when storms occur, the capacity of the plants is not sufficient. This means that some of the water needs to be conveyed to the lake without any treatment, increasing the stress and stormwater related nuisances of the lake. Separate systems are successively replacing the combined systems, but there is still a lot of work to be done (Zhou et al., 2003).

To evaluate the possibility to implement different solutions, as well as the potential impact on the stormwater, it is important to consider the prevailing conditions in central Xiamen.

To evaluate the proportions of different kinds of sustainable urban stormwater devices in the central district, a test area was chosen. This area is to represent a typical heavily urbanized section of the city, and the proportions of different features are assumed to be valid for other similar urban areas of the city. The total size of the area investigated is 148 hectares.

To estimate the proportions of different areas, initial evaluations were made with the help of Google Maps and AutoCAD. By combining the functions of these programs, relevant lengths, areas and proportions could be estimated. When preliminary calculations had been made, field-studies were executed in the selected area to get a more accurate assessment of the area. Particular focus was put on large and small roads, pavements, green areas, coherent ponds and potential temporary stormwater detention areas, such as football fields, running tracks or tennis courts. The estimation of rooftop-areas is explained in chapter 6.6 about the evaluation of rainwater harvesting.

7.2 Ponds

In the area of investigation, like in most of central of Xiamen, there are scattered installations of ponds and potential temporary stormwater storage areas, like sports grounds.

7.2.1 Results

To estimate the potential catchment area the wet and dry ponds can accept water from, the same conditions and equations used in the evaluation chapter about stormwater ponds (6.1) were applied. The conditions from case 1 in the example are assumed to be valid in the entire area investigated. The dimensioning rain of 24 hours, with a recurrence time of 10 years was also the same as in the evaluated example. Of the total potential temporary storage areas, 60% of the available land was estimated to be feasible to transform. As written earlier, the total control area is 148 hectares. Results from the investigated area are shown in Table 23.

Table 23: Calculated results if retrofitting ponds as a sustainable urban drainage solution in central Xiamen.

Installation	Investigated area, A_i (ha)	Potential area for retrofitting the solution, A_s (ha)	Proportion of investigated area, (A_s/A_i)	Corresponding catchment area, A_c (ha)	Proportion of investigated area, (A_c/A_i)
Wet Ponds	148	2.4	1.7%	32.6	22.0%
Temporary stormwater detention ponds	148	3.1	2.1%	37.9	25.6%

As seen above, there is a high potential for stormwater retention by wet and dry ponds in the control area. If constructed correctly, the runoff may be slowed down considerably, mitigating the conditions for downstream stormwater solutions. There may be problems conducting the water from the catchment area to the ponds, which may reduce the potential of the solutions. The temporary retention areas, the dry ponds, only provide retention of the water, and do not notably decrease the level of contaminants of the water. If the stormwater retention is seen as an early step in a sustainable urban management train, the retardation of the water will make the other solutions work better, which may be seen as a contribution to the improvement of the water quality. In dry periods, these areas will be used for other recreational purposes.

7.3 Rooftops

A majority of the rooftops in Xiamen does not serve a purpose today. At best, they are used for drying laundry. Since there seems to be no existing conflict of interests of how to use the rooftops, the implementation of stormwater management solutions seems highly feasible.

Green roofs and rainwater harvesting are both feasible solutions to implement in Xiamen. There are however some facts arguing against the installation of rainwater harvesting. The significant yearly variations of rainfall will make this solution unreliable, and the argument that the implementation of rainwater harvesting may reduce the expansion of the pipeline system may not be valid in this case, since the dry months provide less than 20% of the water needed for irrigation. The rest of the water would have to be transported to the areas of irrigation in the conventional way. This means that the economical and infrastructural benefits would decrease considerably compared to if the rainfall was more evenly distributed throughout the year. Another fact speaking against the implementation of rainwater harvesting is the ongoing investment in reusing treated wastewater for non-potable uses. As written in chapter 5.3, the city has recently invested 32 million Yuan in expanding the capacity of using treated wastewater for similar purposes as the potential use for the stormwater. If both systems are developed, this may lead to a competition between the two, and a potential abundance of non-potable water, without a field of usage. In newly constructed buildings, rainwater harvesting solutions may be considered to be installed, as an alternative for some domestic, non-potable fields of usage. In this evaluation of central Xiamen, cases with buildings under construction are a small minority however, and the effect of implementing the above mentioned solutions here will not be investigated further in this text.

7.3.1 Results

The most feasible solutions with the local conditions of Xiamen would thence be green roofs. This solution will help reducing the stormwater runoff, partially treat the water, and bring a number of additional benefits, described in chapter 3.6.4 to the central districts. As revised in chapter 3.6.2, the majority of the green roofs are of the extensive kind. 80% of the green roofs in Germany are extensive roofs, according to Becks et al., (2010). The same proportions are estimated to be applicable in central Xiamen as well. The implementation of extensive green roofs will create less additional weight for the roofs compared to intensive roofs, and also demand less maintenance. Intensive roofs are most likely to be implemented on top of larger buildings, where people can benefit from the recreational values of the installation. As written in chapter 6.6 about the evaluation of rainwater harvesting, 30% of the central area is estimated to consist of rooftops. The percentage of rooftops feasible for retrofitting is reviewed in chapter 3.6.2, where Becks et al., (2010), gives a variation of 16-61% feasibility of rooftops for retrofitting green roofs. Concerning the rooftops in central Xiamen, 60% are considered to be feasible, or only need minimal adjustments to be able to support the installation of green roofs. The dimensioning rain will be the same as in the calculated example, average monthly precipitation for June and December. Using the same calculations as in the evaluations about green roofs and rainwater harvesting, the monthly stormwater reduction provided by these solutions can be seen in Table 24.

Table 24: Calculated results of stormwater reduction, if retrofitting green roofs as a sustainable urban drainage solution in central Xiamen.

	June	December
Total rainfall (mm)*	230.4	34.8
Stormwater retained (mm)**	124.4	34.8
Stormwater reduction	54%	100%
Reduction of stormwater, recalculated for investigated area	9.7%	18%
Total volume of water retained (m^3)	33167	9277

* Average monthly rainfall for the period 2001 – 2010. (Xiamen Statistics Bureau, 2001-2010)
** Calculated for an estimation of 80% extensive roofs and 20% intensive roofs.

The green roofs retain 54% and 100% of the stormwater during June and December respectively. If these numbers are used to calculate the reduction in the investigated area, the stormwater detention is 9.7% and 18% in the different months. This is a considerable reduction of the stormwater runoff in the area, and it is created without claiming any extra land, which is a valuable feature in heavily urbanized areas, such as central Xiamen. During heavy storms, the impact of green roofs is limited however. Since only a relatively small amount of the water can be stored in the soil, most of the water will continue downstream during these occasions. As displayed above, these solutions have the greatest impact when several smaller rainfalls occur during a spread out time period. This fact makes it hard to make a combined evaluation with other evaluated solutions like stormwater ponds or bioretention areas, where a 24 hour rain with a recurrence time of 10 years in this paper is used for dimensioning.

7.4 Bioretention areas

7.4.1 Potential areas of implementation

Pavements

On the pavements in central Xiamen, it is very common with planted trees. The frequency between the installations varies from a few meters to up to 20-30meters. Field evaluations show that the most common distance between the trees is around 6 meters, and that the area of the tree pits is 1.1*1.1 meters. Further observations from the investigated area show that the average width of the pavement is between 4-5 meters. A normal pavement may be similar to the one displayed in Figure 18.

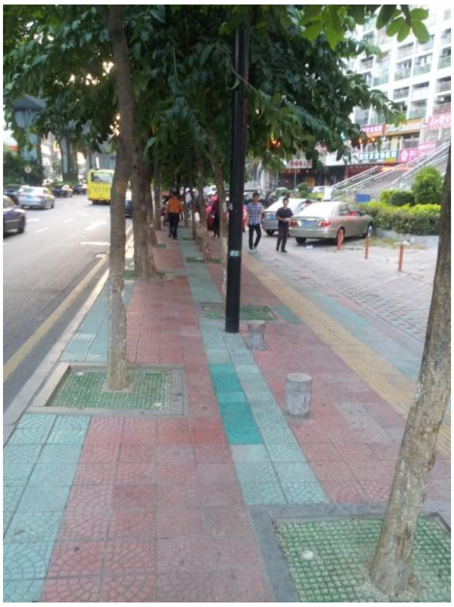


Figure 18: A typical pavement in Xiamen.

The trees give a comfortable shelter from the sun in the warm months, and may provide many of the additional benefits associated with bioretention areas. For the moment, stormwater management is not one of the enjoyed benefits however. As seen in the figure, the edges of the installation are at the same height as the rest of the pavement, leaving no volume for ponding of stormwater in the event of a rainfall. Since the installations aren´t intended to be bioretention areas, the soil-media of the installations is not adapted for handling stormwater. The soil limited volume will also prevent the tree from growing successfully.

Roads

Alongside larger roads there are installations of vegetated strips. Areas like road crossings also have larger installations of vegetation. The vegetated strips often separate a single lane from the main part of the roads. In some cases these green strips also separate the sidewalk from the street. Field observations show that these strips normally have a width of between 2-3 meters. Often vegetated with a lush variety of plants, these solutions increase the aesthetical values of the city, which is an important aspect for Xiamen, a popular tourist destination in China. Examples of green areas in central Xiamen are shown in Figure 19:

Figure 19: Green areas in central Xiamen.

Vegetated areas may also be found next to buildings, open areas or other suitable locations where there is enough space for implementation. Benefits, deriving from urban vegetation will be enjoyed by the city. Unfortunately stormwater related issues have not been considered during the implementation. The edges of the installations are not constructed for detaining water. Many flowers of today, planted in these green areas are put there to increase the amenity values, but it is very doubtful that these flowers would survive the impact of heavy storms with ponding water. Choosing plants which will withstand the different conditions in the bioretention area is of great importance.

Because of the relative high amount of pollutants in the city, the bioretention areas are preferably constructed with an underdrain, in order to reduce the risk of groundwater contaminations. This will also prevent nearby structures from potential harm from increased water content in the ground.

Since the solutions will be implemented in a retrofitting manner, the size of the solutions will vary significantly. Instead of planning how big the solution needs to be for a certain drainage area, the approach in Xiamen should be to evaluate the potential catchment from the existing green area. Many bioretention areas of small sizes may interact, and the combined effect may be enough to handle water from a larger drainage area. It is important to provide a sufficient maintenance of the devices, to assure a good efficiency.

7.4.2 Results

In Xiamen, the green areas cover almost 40% of the surface area of the city. Though unevenly distributed, there still exists a multitude of green patches in the heavily urbanized central districts of Xiamen. In the heavily urbanized control area of Xiamen, the percentage of green areas is estimated to be around 20%.

Since the green areas mentioned above areas already exist, there is no reason why these should not be reconstructed to better handle stormwater, and become a part of the stormwater management train. The structures will basically remain the same in appearance. Amenity values, which are important to the aesthetics of the city, will remain, but the feature of managing stormwater will be added as an extra benefit. If converting already existing green areas, yet again no extra space is needed, which is an important aspect to consider. Far from all green patches will be feasible to convert to bioretention areas. The position and accessibility of the green area will be an important factor if it is beneficial to convert the structure to a bioretention area. The largest quantities of green areas, with the highest accessibility are located close to roads and pavements, and it is most probable that these may be transformed to bioretention areas. Of the green areas, 30% are estimated to have high potential of efficiently being reconstructed to functioning bioretention areas.

To increase the potential bioretention area, the small tree pits of today spread along the pavements may possibly be reconstructed. The solutions would benefit on combining two or three tree pits, making one larger area. This larger combined area of soil would, except from increasing the feasibility of converting it into a bioretention area, also improve the conditions for the vegetation in the devices. Suggestions of how implemented urban bioretention may look like are displayed in Figure 20.

Figure 20: Urban bioretention areas (TRCA et al., 2010).

To calculate the total potential effects of implementing bioretention areas in the investigated district, the same equations and assumptions as in chapter 6.4.1, where bioretention areas are evaluated were used. The dimensioning storm is, like for the example regarding bioretention, set to a 24-hour storm with a recurrence time of 10 years. The potential catchment area acceptable by the bioretention solutions is displayed in Table 25.

Table 25: Calculated results if retrofitting bioretention areas as a sustainable urban drainage solution in central Xiamen.

Installation	Investigated area, A_i (ha)	Potential area for retrofitting the solution, A_S (ha)	Proportion of investigated area, (A_S/ A_i)	corresponding catchment area, A_C (ha)	Proportion of investigated area, (A_c/ A_i)
Bioretention area	148	8.9	6.0%	64.9	43.8%

Even though only a small part of the green patches of the investigated district were estimated as suitable converting into bioretention areas, the total impact is still significant. 43.8% of the total catchment can be handled by these solutions. This shows that many combined small scale solutions may have an important impact on the final results.

Bioretention areas are considered to be a relatively expensive stormwater solution (Stormwater Center, 2011e). These considerations are based on the fact that the solutions are constructed in new areas of development, where they have to be built from the ground. Since the potential areas in Xiamen already are landscaped, a lot of the costs are already covered, which means that the cost specifically for the bioretention area will be less significant.

7.5 Soakaways, infiltration trenches and infiltration chambers

Infiltration devices such as soakaways, infiltration trenches and infiltration chambers may be potential solutions to implement in central Xiamen. The same conditions as for bioretention areas apply, which means that the solutions implemented in the control area preferably should be constructed with an underdrain, to reduce the risk of groundwater contamination and minimize the risk of creating harm to underlying structures. In areas outside the investigated area, there may be a limited possibility of implementing these solutions without underdrains. Feasible areas may be adjacent to hill slopes, or coherent to a park, where there is a lower level of urbanization, and hence not suffering from the same level of nuisances as the most heavily urbanized parts of the city.

For soakaways and infiltration chambers, there is a possibility of implementation in the investigated area in central Xiamen. With a restricted groundwater infiltration, these solutions would work more as underground storage facilities of water, detaining the water and releasing it in a controlled flow rate through underdrains, mitigating downstream conditions. Due to lack of information about the conditions of underground facilities and pipes in central Xiamen, it is hard to speculate about potential volumes of water to handle in these underground solutions. Further, more extensive investigations in this field would be necessary to find the correct values.

7.6 Permeable paving

The implementation of permeable pavement, especially at smaller parking areas is widespread in Xiamen. Permeable paving similar to the one shown in Figure 21 is commonly seen throughout Xiamen.

Figure 21: A parking area with permeable paving in central Xiamen.

There are however some serious problems with the permeable paving in Xiamen of today. First of all, the pavements are often in a poor condition. Maintenance-wise not much is done. As written before, infiltration devices are very sensitive to clogging, and there is a high rate of failure among these devices. The rate of failure and poor performance may thus be expected to be high in the infiltration-capacity of the devices. The second issue, which eclipses the slightest possibility for the permeable paving to work, is the fact that it is constructed on top of solid, impermeable concrete, just like the rest of the pavements in Xiamen (Wang, personal communication). This means that in the current state, the permeable pavements in Xiamen don´t serve the purpose as sustainable stormwater devices.

This solution is well suitable for retrofitting however, since no extra space is needed for implementation. The already existing parking areas with non-functional permeable paving covers may be converted to correctly constructed permeable pavements. Since the rate of failure is high for these solutions, it is important to have a sufficient maintenance of the devices, in order to assure an adequate performance. The high number of street cleaners can play an important role in the maintenance of the infiltration devices. Since the water shouldn´t infiltrate the ground due to earlier explained reasons, the infiltrated water from the permeable paving could potentially enter into storage basins with underdrains, similar to what is described for infiltration devices above. This would assure a certain amount of treatment for the stormwater from the infiltration along with the detention in the underground basin, before continuing downstream. As written above, it is hard to speculate about the underground conditions, in order to make evaluations about the potential of this solution. This field may be the subject to further, more extensive in-depth analysis of the potential of implementing these solutions.

Infiltration devices, with the exception of bioretention areas don´t entail any additional aesthetical values, which may be seen as a negative aspect.

7.7 Canals

There are currently some concrete canals leading a limited amount of the stormwater towards Yuan Dang Lake. These are covered with thin concrete blocks, which ´t make them a not entirely open stormwater solution (Hu, personal communication). The canals are however an important means of conveying the water downstream along the flow path. Though these solutions do not entail any quantitative or qualitative benefits by themselves, they are necessary for the water to reach the lake. Instead of working as a separate unit, canals may be regarded as a part of the stormwater management train. Underdrains from abovementioned infiltration devices may be lead to an adjacent canal, which means that the flow entering the canal may be better controlled due to the upstream stormwater solutions.

In the investigated area, it is assumed that one canal may be implemented alongside every large road leading towards Yuan Dang Lake. In the area there are 6 of these roads, which mean that an equal amount of canals may transport the water from the area towards the lake. To facilitate the evaluation, characteristics of the canal are assumed to be the same as in the calculated example, chapter 6.3, which means a one meter wide canal with a maximum flow depth of 0.35m. These limited dimensions make the solution easy to implement alongside the roads where no canals exist today. Equations, characteristics and assumptions needed to be able to evaluate these solutions are assumed to be the same as in chapter6.3. The intensity of the dimensioning rainfall is set to a limit of 250mm/h, which is notable storm intensity, very unlikely to occur. To simulate the worst scenario, water from the entire runoff area is assumed to contribute to the flow.

Since the canals are a part of the stormwater management train, calculations made assume that the solutions reviewed above, ponds, bioretention areas and green roofs are implemented, and affect the investigated area according to calculated evaluations. Knowing these characteristics, the flow in the canals may be estimated. Results from the estimations are displayed in Table 26.

Table 26: Calculated flow characteristics if retrofitting canals as a sustainable urban drainage solution in central Xiamen.

Assumed maximum rainfall intensity (mm/h)	Calculated corresponding flow (m^3/s)	Maximum flow per canal (m^3/s)	number of canals	Maximum total flow in canals for investigated area (m^3/s)	Spare capacity of canals
250	6.44	1.21	6	7.26	11.2%

As seen in table 26, the canals are able to handle rain-intensities even in this scale. There is even a spare capacity of 11% in the canals. The fact that ponds and bioretention areas are assumed to detain stormwater according to previous evaluations, from a majority of the investigated area, significantly mitigates the flow conditions in the canals. If infiltration devices like permeable paving, soakaways and infiltration chambers are implemented as an additional stormwater solution, the flow conditions in the canals would improve even further. When smaller rainfalls occur, Green roofs will play an important role in detaining the water. In an example like the one above, where the maximum flow is evaluated, the impact from the green roofs will be limited however. The roofs are in this case only assumed to decrease the runoff-coefficient slightly, and are not assumed to detain any specific volumes of stormwater. When the stormwater conducted form the canals reach Yuan Dang Lake, special outflow-areas should be designed, to assure that the high velocity of the transported water do not damage the surrounding environment at the recipient. Dimensions of the canals may be altered to in the best possible manner suit the area of implementation.

7.8 Yuan Dang Lake

All the stormwater in the investigated drainage area will end up in Yuan Dang Lake, before being release in the sea. As written earlier in chapter 5.10.2 about Yuan Dang Lake, there are treatment processes such as sedimentation and biological uptake, reducing the contaminants in the water before it enters the sea. Since the water level in the lake is affected by regulatory measures at the inlet and fluctuates with the tide, the surface level of the lake is easily regulated. The downstream installation of Yuan Dang Lake will be the last step in the stormwater management train, before the water reaches the final recipient. Because of the comprehensive work put into improving the conditions in the lake, there is no urgent need for reconstructing the lake for better handling stormwater. Focus should instead be put on reducing the untreated sewage water reaching the lake. For a more extensive review about Yuan Dang Lake, readers are advised to read chapter 5.10.

7.9 Other solutions

In the area of investigation, swales will not be considered as a feasible solution. The fact that it needs a width of 4 meters makes it hard to retrofit in the central districts of Xiamen. Existing vegetated strips, with a potential of being converted to swales are located coherent to the larger roads. These are however only 2-3 meters wide, which is not sufficient for the implementation of swales. The extra area demanded for this solution is not considered possible to spare in this area of investigation. It would be close to impossible to convince the local government to sacrifice valuable land for the implementation of swales. Another issue would be to construct the swales with a correct longitudinal slope, conducting the water towards Yuan Dang Lake without the risk of ponding water.

In the outskirts of the city, close to large roads or adjacent to parks, swales may be a feasible solution. In the investigated area in this report however, swales will not be seen as a feasible solution.

Wetlands and filter strips are also not considered feasible solutions in central Xiamen. Reasons why are discussed in chapter 6.7.

7.10 Potential flow reduction

After evaluating the solutions above, it is possible to estimate the impact these devices would have in the event of a storm. As explained before, the impact of the different solutions varies depending on the rainfall, and it is hard to make evaluations including all different situations. To display one potential result from the implementation of the solutions reviewed above, effect of the runoff rate from a 24-hour storm with a recurrence time of 10 years in the investigated area in central Xiamen is evaluated. To simplify the process, the rainfall of 316 mm is assumed to have a constant intensity during the 24 hours. Though this is not how a rainfall occur in reality, the evaluated results will still serve its purpose and give the reader an indication of the potential reduction in flow rate due to the implementation of sustainable urban drainage systems in the investigated area.

The combined flow rate from the entire area if no SUDS are implemented is calculated using equation (6), which can be found in Appendix B. Estimated flow after the potential solutions are implemented is retrieved from evaluations in preceding chapters. Results are compared, in order to see the potential impact in the investigated area in central Xiamen. To facilitate, only the maximum potential flow is displayed, without fluctuations. A simplified chart displaying the maximum flow rates in the investigated area is seen in Figure 22.

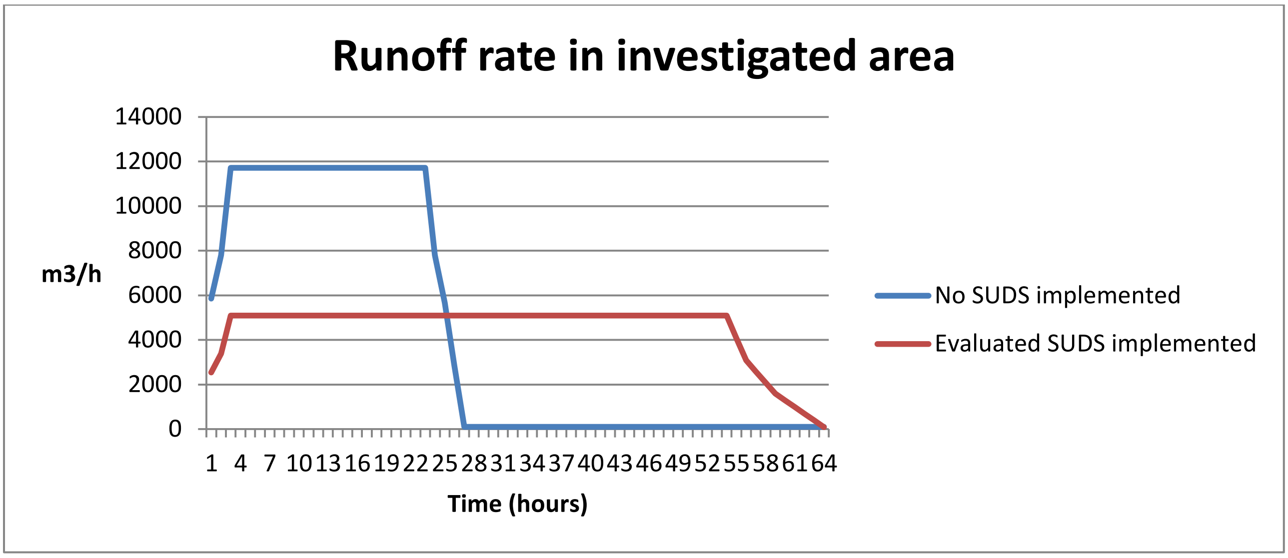


Figure 22: Stormwater runoff rate in central Xiamen, during a 24-hour storm with a recurrence time of 10 years.

This chart can be compared with Figure 2 in chapter 2.2, which in general terms explains the effects on urban runoff quantity, with and without sustainable urban stormwater solutions. Figure 22 shows a similar pattern, and shows that the maximum runoff is reduced to less than half of the original value, if the devices are implemented according to the evaluations in preceding chapters. The flow is spread out on a longer time period, which will reduce the stress on pipes as well as the recipients. The chart shows that there is a significant potential of improvement regarding stormwater management in central Xiamen, if SUDS are retrofitted in a correct manner. At the occasion of rainfalls of a smaller magnitude, a larger proportion of the rain will most likely be detained by the implemented stormwater solutions, hence not causing stress on the downstream recipients. The time period since the last rain and the saturation of the soil are important factors implementing the amount of water detained in the devices.

7.11 Conclusions

The sustainable urban stormwater drainage solutions evaluated in this text to be the most feasible in the heavily urbanized control area in central Xiamen are: green roofs, dry or wet ponds, bioretention areas, soakaways, infiltration chambers, permeable paving, canals, and finally Yuan Dang Lake. Though concrete canals may not be considered the best sustainable stormwater solution, evaluations show that other potential solutions for downstream transportation are not feasible for implementation in the area of investigation.

Retrofitting differs significantly from planning the implementation of sustainable urban drainage systems in new areas, where the land may be adjusted to better interact with the planned solutions. To include the stormwater management in an early stage of the planning is frequently underlined by experts in the field. In already urbanized areas, this is not possible however. Retrofitting in an already constructed often implies that existing devices may simply be reconstructed to better handle stormwater. It is hard to achieve the same unity in performance as when the stormwater solutions are a part of the planning of the area.

As shown in this paper, there is however room for significant improvements in stormwater management within an existing highly urbanized area, without the need for claiming new areas for the treatment of stormwater.

If the suggested solutions are implemented, a stormwater management train will be created. A possible flow path of the stormwater is that the water starts on the green rooftop. The runoff continues to an infiltration device, where the water is infiltrated through the soil media, to reach the underdrain. From here the water is conducted to a canal, transporting the water to Yuan Dang Lake, before finally reaching the final recipient.

This is just one potential of many ways the stormwater in the investigated control area may take towards the final recipient. In this example, the stormwater management train consists of 4 different solutions, all contributing to increase the quantitative and qualitative standards of the water. It is important for the stormwater to encounter several different stormwater solutions on its' path downstream, to achieve maximum potential qualitative and quantitative improvements.

8 Discussion

8.1 Local conditions

Issues regarding stormwater management are matters which Xiamen, as well as many other Chinese cities, will have to deal with within a near future. Traditional concepts of stormwater handling combined with a rapid urbanization have created serious qualitative and quantitative problems related to the stormwater management. Receiving water bodies are still in great need of improvements, and stormwater related flooding is a problem of Xiamen.

With a subtropical climate, and an average yearly rainfall of over 1300 mm per year, there is an abundance of rain which needs to be taken care of. By implementing sustainable urban drainage systems, rainwater may be converted into a benefit for the city. The open stormwater solutions will increase the amenity, improve the quality standards, reduce the risk of flooding, and last but not least increase people's awareness of stormwater management. The mentality of many residents in Xiamen today towards the environment is very decadent. People know that litter will be removed within a day or two by street cleaners, which reduces the incentive to go the extra meters and throw the garbage in the trash-cans. The implementation of SUDS combined with the distribution of information may increase the awareness of stormwater management, which may be one step in the right direction towards enlightening the citizens about the prevailing environmental situation, and change regular people's attitude towards littering.

Similar to many other cities in China, acceptance of the sustainable urban drainage concept has still not fully reached Xiamen. An example where the lack of plans for stormwater management is obvious is in the local governments webpage about the city's gardening (XMG, 2011b). Several pages are written about the afforestation and green belts of the city, but not a single word is mentioned about the stormwater situation, and how these solutions may help mitigating the downstream stormwater situation. Since green areas already exist in most areas of the city, reconstructing these to better handle stormwater may many times not be that big a process. The management cost of the sustainable urban drainage solutions will not increase significantly either, since much of the expenses already exist today, with the maintenance of the green areas. A new way of approaching stormwater related issues may be close though. In the book "Xiamen water saving proposal (2005-2020)", XCMB (2006) has a chapter dedicated to the need of improved stormwater management, which indicates a first step in the changes in attitude towards these solutions.

The geographical conditions of Xiamen are somewhat special. With the central parts of the city located on an island, the sea, which is the final recipient, is never distant. Though the vast sea is not as sensitive to pollutants as rivers or small lakes, the qualitative improvements provided by sustainable urban stormwater solutions are still of great importance, and may be seen as one piece in the environmental puzzle. To attain the best results, changes in stormwater management must be accompanied by improved management of wastewater. Efforts to reduce the amount of untreated wastewater released in Yuan Dang Lake and the ocean have significantly improved the conditions, but there is still a long way to go. The fact that most of the pipes in Xiamen are of a combined system makes it hard to protect the recipients against stormwater related emissions of untreated wastewater. With the implementation of sustainable urban drainage systems, these types of flooding will be less frequent, which is of great importance for the condition of the recipients. National standards are set as guidelines for the allowed levels of contaminants in Xiamen. Many limits in the standards are today met, but a lot of the pollutants are still at a level far above the allowed limits. The fact that some limits in the standards have been reached shouldn't mean that the goal should be considered reached though. There should be an ambition of constantly improving the prevailing situation. The standards set an acceptable maximum limit for emissions. This doesn´t mean the values are good.

Calculations in this thesis have been focused on the quantitative improvements derived from the potential implementation of sustainable urban drainage systems in central Xiamen. The solutions will however also contribute to a noteworthy contaminant-removal from the stormwater, as described in Chapter 3, about the different stormwater solutions. To determine the contributing removal of pollutants from the implementation of sustainable urban drainage systems in Xiamen, further specific studies in the field will have to be conducted.

Since the concept of sustainable urban drainage systems still is new in China and Xiamen, it is important to look at countries with more experience in the field, in order to better evaluate feasible solutions. By obtaining techniques and data in the field from experienced actors, many errors may be avoided, and a better rate of efficiency may be reached. Sweden is a country with several decades of experience in the field, with expertise that may be valuable for China.

Because of the fact that the area investigated in this report is heavily urbanized, the solutions will have to be implemented through retrofitting. The privilege of planning the solutions from an early stage of the development of an area will not be possible. Solutions will rather be implemented where there right potential exists. The area selected for this these is meant to be seen as a typical urban district in central Xiamen, and the conclusions from this study should be applicable for other similar areas in the city.

In the preceding chapter, the different alternatives for retrofitting are evaluated for the central parts of Xiamen showed that if the implemented correctly, the impact in the area of investigation would be significant, with a considerable improvement in the urban stormwater management.

8.2 Potential improvements

There is today no plan of how to handle stormwater water in a sustainable manner. It is important to give this question exposure, to change the attitude of policy makers and the administrational bodies of Xiamen. A comparison can be made to Malmö in the 1990´s, when the concept of SUDS went from meeting heavy skepticism in the beginning of the decade, to being commonly accepted and encouraged by the end of the same decade. Through hard work and proof of efficiency in implemented solutions, the attitudes were slowly changed among the decision makers in the Swedish municipality. A similar process is possible in Xiamen. Instead of regarding the water as a burden, which should be removed as quickly as possible, it should instead be regarded as a potential asset. Introducing discharge-standards, which is popular in Sweden, may encourage private actors to invest in sustainable urban stormwater devices, which may contribute to a quicker transformation towards this holistic approach of treating stormwater.

The city's many street cleaners should be a part of the maintenance of the open stormwater solutions. Many devices obtain the best level of performance if regularly maintained. Xiamen has an advantage against most western cities in the fact that there are workers out cleaning the streets on a daily basis. Gardeners also keep the green areas of Xiamen in a lush condition. If instructed how to correctly maintain the stormwater solutions within their area of responsibility, this would assure a good condition, and high efficiency of the implemented devices.

The administrational sector on water-related issues in Xiamen is today very extensive. When it comes to stormwater related questions, it is often unclear who has the final responsibility. Questions are often transferred between different departments, and sometimes even falls between the chairs, which may make it hard to take the right decisions. To be able to handle questions related to stormwater correctly, it is important with an efficient organization, where every sector knows their field of responsibilities. The conditions regarding legislations and administration in Xiamen varies quite significantly from the Swedish counterparts. The chapter about the Swedish conditions may be compared with the Chinese system, for the reader to put the two different systems in perspective. The two examples from Sweden, Växjö and Malmö, show Swedish examples regarding the potential of implementing stormwater solutions, and the continuous work and dedication that is needed to succeed in the field of sustainable urban stormwater management.

To be able to make the right decisions, it is also important that there are clear legislations and distinct regulations, which should provide a solid foundation for decision making. Laws regarding stormwater management should be valid on a both regional and national level, to facilitate the decision making. Xiamen, as well as many other parts of China is today starting to accept the fact that changes in the current stormwater management system is necessary and slowly realizing the potential benefits of sustainable stormwater management. With approaching changes, it is important that laws and policies are developed to guide these changes.

8.3 Yuan Dang Lake

In the case of Yuan Dang Lake, the city has come far during the last decades in reducing the level of contaminants, and improving the conditions of the surrounding area. From being seriously polluted in the 1980's, the lake is today a popular area for recreation. Contaminants levels have dropped to under a tenth of the values a few decades ago. The lake is under constant observations, and potential improvements are constantly investigated and realized. This fact makes it a feasible downstream recipient, where improvements in the quality of the water quickly are registered.

Yuan Dang Lake is of great importance when it comes to stormwater management on Xiamen Island. Since the catchment covers around 30% of the island, stormwater management is an important factor implementing the state of the lake. With the implementation of sustainable urban drainage systems in Xiamen, another valuable contribution to the improvement of the lake's condition will be added.

8.4 Uncertainties

There are some uncertainties which should be highlighted in reviewing this report. One important issue regarding the data obtained for the evaluations of different stormwater solutions was the difficulties to obtain sufficient rainfall-data. The Climate bureau of Xiamen, which holds the information, could not sell the specific data, which had the consequences that obtainable data like 24-hour storms and average monthly data was used instead for the calculations. The length of the time series for the 24-hour storm was limited, which makes it hard to evaluate if the chosen value indeed is the right number, if evaluated during a longer period of time.

Estimations made in the evaluations have been done with the help of similar sources of information and field observations, in order to resemble the natural conditions in the best manner possible. There is always an element of uncertainty with estimations however, which may somehow have influenced the final results.

Information collected from Chinese sources has been realized through the help of native Chinese speaking people. The amount of information available has however made it necessary to choose certain chapters of interest to translate. This means that important information may have been overlooked. Another uncertainty is the age of some of the information. Available data about local conditions in Xiamen were often a few years old, and changes may have been implemented since the information was printed. A tendency in current, ongoing development in Xiamen is however displayed, providing the reader with insight in the ongoing changes in Xiamen. Another uncertainty about the obtained information lies in the difficulty to judge the objectivity of the Chinese written sources.

8.5 Future work

As concluded in the discussion, this report evaluates the feasibility of implementing sustainable urban drainage systems in Xiamen, in a perspicuous perspective. For the implementation in certain areas, further more specific information will have to be gathered and evaluated. The same applies for the implementation of certain solutions. Depending on the purpose of the solution, and the downstream regulations, different rainfalls may be used for dimensioning. To facilitate the transformation to a sustainable urban stormwater management system, information and experiences should be collected from countries with a longer history in the field of SUDS. As reviewed in this report, Sweden has a long history of implementing these solutions, and may share valuable insights with Xiamen. By obtaining useful information, Xiamen will be able to avoid common mistakes when constructing the stormwater solutions, hence reach satisfactory results faster, in a more economical way.

To be able to conclude the definite effects of the solutions, further in-depth analysis, where all the local conditions of Xiamen are evaluated, must be carried out. Before the solutions are implemented, small-scale tests should have been conducted, to assure the feasibility in the local conditions, and avoid drastic future changes. This thesis may be seen as the foundation for further investigations in the field of sustainable urban drainage systems in Xiamen.

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Appendix A: Climate data for Xiamen

Average monthly rainfall 1961 - 1990		
Month	Rainfall	**Evaporation**
January	**37,7**	**88,6**
February	66.9	74.3
March	76.5	87.2
April	124	109.2
May	154.7	122.4
June	207.1	145.8
July	150.4	200.2
August	144	191.9
September	96.3	178.2
October	32.1	192.8
November	27.8	145.9
December	26.1	115.8
Total:	**1143,6**	**1651,3**

Source: http://wenku.baidu.com/view/8895a90303d8ce2f00662318.html

Average monthly rainfall 2001-2010:					
Month:	**Rainy days**	**Total rainfall (mm)**	**Maximum rainfall (mm/24h)**	**Average evaporation (mm)**	**Relative humidity (%)**
January	7.8	34.7	16.2	80.7	72.1
February	9.3	61.1	23.4	76.3	75.6
March	13.3	87.2	29.9	88.6	76.3
April	13.4	127.1	42.3	100.7	78.1
May	14.9	181.7	58.7	118.0	79.0
June	16.2	230.4	83.7	116.3	83.2
July	10.9	164.2	62.4	161.7	78.7
August	12.7	214.2	77.6	142.1	80.0
September	10.0	137.8	58.5	143.0	74.3
October	3.7	57.7	48.7	153.9	67.1
November	5.2	28.8	14.1	118.1	68.7
December	6.1	34.8	15.0	93.7	68.9
Total:	**123,3**	**1347,5**	**150,6**	**1391,2**	**75,2**

Source: (Xiamen Statistics Bureau, 2001-2010)

Detailed information 2001 -2010.

source: (Xiamen Statistics Bureau, 2001-2010)

2010					
Month	**Rainy days**	**Total rainfall (mm)**	**Maximum rainfall (mm/24h)**	**Average evaporation (mm)**	**Relative humidity (%)**
January	1	3.2	3.2	82.4	63
February	5	13.6	10.8	72.4	76
March	12	136	33.9	83.3	74
April	11	140.1	51.4	112.4	64
May	6	60.7	47.5	129.3	66
June	14	203.3	70	92.5	81
July	10	139.2	117.4	135.4	78
August	7	104.3	59	139.4	76
September	7	9.4	4.1	156.1	68
October	1	4.9	4.9	164.9	58
November	5	74	37.2	93.3	73
December	10	31.8	10	85.2	75
Total:	**89**	**920,5**	**117,4**	**1326,7**	**71**

2009					
Month	**Rainy days**	**Total rainfall (mm)**	**Maximum rainfall (mm/24h)**	**Average evaporation (mm)**	**Relative humidity (%)**
January	14	59.1	26.7	69.3	71
February	17	46.6	13.4	69.1	66
March	14	21.9	7	89.1	66
April	16	96.2	46.5	80.2	83
May	18	126.8	23.9	117.6	72
June	23	361.7	95.9	87	83
July	15	195.9	55	131	79
August	10	83.8	24.3	137.3	78
September	12	29.8	17.3	138.8	71
October	6	106.9	104.3	115.4	71
November	3	9.6	7.2	118.5	62
December	8	7.9	4	76.6	63
Total:	**156**	**1146,2**	**104,3**	**1229,9**	**72**

2008					
Month	**Rainy days**	**Total rainfall (mm)**	**Maximum rainfall (mm/24h)**	**Average evaporation (mm)**	**Relative humidity (%)**
January	8	-	17.2	79.4	67
February	6	-	14	69.3	70
March	14	-	35.5	64.3	78
April	13	-	44.6	87.9	73
May	14	-	36	106.8	75
June	20	-	102.9	86.3	84
July	4	-	1.1	173.5	73
August	17	-	79.9	122.1	78
September	10	-	34.6	123.2	68
October	3	-	7.8	151.3	60
November	5	-	7.4	126	58
December	2	-	14.6	68.7	70
Total:	**116**	-	**102,9**	**1258,8**	**71**

2007					
Month	**Rainy days**	**Total rainfall (mm)**	**Maximum rainfall (mm/24h)**	**Average evaporation (mm)**	**Relative humidity (%)**
January	10	40.2	16	71.9	74
February	7	116.4	50.7	77.8	74
March	17	137.7	25.8	70.7	75
April	12	187	43.3	77.2	79
May	20	512.2	212.2	80.1	81
June	19	169.5	36.1	78.3	84
July	11	486.9	156.8	128.5	77
August	10	108.1	52	133.1	75
September	7	30.5	13.1	136.6	69
October	-	-	-	154.6	58
November	7	84	50.2	94.8	68
December	4	98	46.9	90	65
Total:	**124**	**1970,5**	**212,2**	**1193,6**	**73**

2006					
Month	**Rainy days**	**Total rainfall (mm)**	**Maximum rainfall (mm/24h)**	**Average evaporation (mm)**	**Relative humidity (%)**
January	8	2.1	0.7	74.7	68.5
February	20	90.4	19.7	46.8	85.9
March	15	216.1	68.3	64.1	75.8
April	15	66.5	19.8	78.5	80.2
May	24	129.8	27.6	87.7	87.3
June	21	186.3	66.8	93.3	83.1
July	12	15.6	7.5	149.5	76
August	17	339.1	125.4	112.5	79
September	8	203.8	65.8	129.1	71.9
October	5	86.9	66.5	136.4	66.2
November	5	0.7	0.7	102	68.1
December	6	12.7	6.4	102.5	58.4
Total:	**156**	**1350,9**	**125,4**	**1177,1**	**74,9**

2005					
Month	**Rainy days**	**Total rainfall (mm)**	**Maximum rainfall (mm/24h)**	**Average evaporation (mm)**	**Relative humidity (%)**
January	12	14.7	7.1	65.9	80
February	8	66.9	25.1	74.2	80
March	14	45.9	9.3	74.8	84
April	13	87.2	21.2	100.5	79
May	15	152.5	69.8	106.8	84
June	12	67.5	25.3	138.4	77
July	15	76.7	31.2	147.2	79
August	16	195.4	60.6	129.9	80
September	15	259.7	68.9	103.2	84
October	1	0.7	0.7	159.7	65
November	7	2.3	1	110.2	73
December	6	17.5	13.8	88.6	76
Total:	**134**	**987**	**69,8**	**1299,4**	**78**

2004					
Month	**Rainy days**	**Total rainfall (mm)**	**Maximum rainfall (mm/24h)**	**Average evaporation (mm)**	**Relative humidity (%)**
January	8	66.5	27.9	73.3	75
February	16	8.6	7.4	60.2	83
March	17	76.2	26.7	76.3	82
April	13	159.6	84.2	83.7	86
May	15	185.2	66.4	100.5	84
June	16	190.9	68.8	91.1	84
July	5	2.3	1.2	179.3	77
August	10	173	97	145.3	80
September	9	129	106.9	131.6	77
October	3	95.7	85.6	148.4	70
November	5	4.4	4	101.4	76
December	0	0	0	90.4	73
Total:	**118**	**1091,4**	**106,9**	**1281,5**	**79**

2003					
Month	**Rainy days**	**Total rainfall (mm)**	**Maximum rainfall (mm/24h)**	**Average evaporation (mm)**	**Relative humidity (%)**
January	9	33	11.2	69.3	73
February	5	12.2	3.9	73.6	73
March	9	21.6	12.5	89.2	76
April	7	49.5	31.9	101.5	79
May	9	150.7	54.3	113.7	78
June	10	79.6	24.7	119.8	83
July	14	202.6	60.3	123.7	83
August	14	470.4	140.6	105.5	84
September	12	135.6	47.5	113.9	78
October	8	10.3	4.8	102.4	75
November	8	56.5	22.5	95.5	73
December	11	68.5	17.4	66.4	80
Total:	**116**	**1290,5**	**140,6**	**1174,5**	**78**

2002					
Month	**Rainy days**	**Total rainfall (mm)**	**Maximum rainfall (mm/24h)**	**Average evaporation (mm)**	**Relative humidity (%)**
January	8	68	36	99	76
February	5	12	7	95	78
March	12	108	54	138	74
April	16	160	52	120	81
May	16	202	67	156	82
June	17	324	68	172	85
July	10	105	65	193	82
August	6	201	93	217	78
September	18	320	153	162	76
October	4	3	2	188	70
November	3	1	0	168	61
December	7	9	3	101	63
Total:	**122**	**1513**	**153**	**1809**	**76**

2001					
Month	**Rainy days**	**Total rainfall (mm)**	**Maximum rainfall (mm/24h)**	**Average evaporation (mm)**	**Relative humidity (%)**
January	3	18	10	102	73
February	13	183	82	79	79
March	8	36	14	138	72
April	19	251	44	101	83
May	8	11	5	185	76
June	14	524	316	160	85
July	14	273	100	242	78
August	18	262	86	156	86
September	4	73	63	195	73
October	3	2	2	189	73
November	9	55	25	136	73
December	6	82	43	117	75
Total:	**119**	**1768**	**316**	**1800**	**77**

Appendix B: Equations and equation abbreviations

Equations

(1) $\Delta V = \int_0^t (Q_{in} - EV_{pond} - Q_{out}) dt$

(2) $Q_{in} = \varphi \times A_{catch} \times I$

(3) $A_{sel} = \frac{\varphi \times A_{catch} \times i - Qout,max(24h)}{h_{storage}}$

(4) $T_{ret} = \frac{(V_{pond} - EV_{pond})}{Q_{out}}$

(5) $\varphi = \frac{(\varphi_{road} \times A_{road}) + (\varphi_{vegetated\ area} \times A_{vegetated\ area})}{A_{catchment}}$

(6) $Q = \varphi \times A_{catch} \times i$

(7) $v = M \times r_h^{(2/3)} \times s^{(1/2)}$ and $Q = A \times M \times r_h^{(2/3)} \times s^{(1/2)}$

(8) $r_h = \frac{A_w}{p_w}$

(9) $A_w = b \times h_w + K \times h_w^2$

(10) $p_w = b + 2 \times h_w \times (1 + K^2)^{1/2}$

(11) $L_{swale} = \sqrt{5 \times A_{catch}}$

(12) $w_{top} = b + 2 \times T \times h_{tot}$

(13) $A_{swale} = l_{swale} \times w_{top}$

(14) $A_w = b \times h_w$

(15) $p_w = b + 2 \times h_w$

(16) $A_{canal} = b \times l_{canal}$

(17) $V_{tot} = A_{bioretention} * h_p + V_{bioretention} * W_{SC}$

(18) $A_{catch} = \frac{V_{tot}}{Q_{dim}\,per\,area\,unit}$

(19) $t_p = \frac{h_p}{g_i}$

(20) $V_{tot} = Vs + Vi$

(21) $Vs = l_{trench} \times b_{trench} \times h_{trench} \times e$

(22) $V_i = l_{trench} \times b_{trench} \times g_i \times 24$

(23) $\mathrm{E}_t = E_p \times \left(\frac{\theta - \theta_{wp}}{\theta_{fc} - \theta_{wp}}\right)$

(24) $Q_{roof} = I - (\theta_{Fc} - \theta_{current})$

(25) $\theta_{current} = \theta_{last\,rainfall} - (\mathrm{E}_t \times days\ without\ rainfall)$

(26) $V_{collected} = P_{roof} * U * (1 - F_f) * A_{control\,area} * I$

(27) $V_{irrigation} = N_{irrigation} * P_{green\,areas} * A_{control\,area}$

Equations used for different stormwater-devices.

Stormwater Ponds:	**1, 2, 3, 4**
Swales:	**5, 6, 7, 8, 9, 10, 11, 12, 13**
Canals:	**6, 7, 8, 11, 14, 15, 16**
Bioretention areas:	**2, 17, 18, 19,**

Infiltration trenches: **2, 18, 20, 21, 22**

Green roofs: **23, 24, 25**

Rainwater Harvesting: **26, 27**

Abbreviations

Abbreviation	Meaning	Unit	Used in equation
V	Volume	(m^3)	4, 17, 26, 27
Q	Flow	(m^3/s)	7
ΔV	Volume of storage	(m^3)	1
V_{tot}	Total volume acceptable	(m^3)	17, 18, 20
Q_{dim}	Dimensioning stormwater volume	(m^3)	18
V_s	Storage volume	(m^3)	20, 21
V_i	Infiltrated volume	(m^3)	20
$Q_{roof+A29}$	Runoff roof	(m^3)	24
A	Area	(m^2)	5, 13, 16, 17, 26, 27
A_{catch}	Catchment area	(m^2)	2, 6, 18
A_w	Cross sectional area of flow	(m^2)	8, 9, 14
$h_{storage}$	Storage height of water	(m)	3
I	Dimensioning precipitation	(m)	2, 24, 26
r_h	Hydraulic radius	(m)	7, 8
p_w	Wetted perimeter	(m)	8, 10, 15
h_w	Height of water	(m)	9, 10, 14, 15
h_{tot}	Total height of installation	(m)	12
B	Base	(m)	9, 14, 15, 16, 21, 22
H	Height	(m)	11, 21
L	Length	(m)	13, 16, 21, 22
w_{top}	Top width	(m)	12, 13
h_p	Ponding height of water	(m)	19
EV_{pond}	Volume evaporated from the pond.	(m^3)	1, 4
E_p	Potential evapotranspiration	(mm)	23
E_t	Actual evapotranspiration	(mm)	23, 25
i	rainfall intensity	(m/s)	3, 6
v	cross sectional average velocity	(m/s)	7
$Q_{out,max}$	Maximum volume that is allowed to exit	(l/s)	3
Q_{in}	Inflow	(m^3/s)	1, 2, 6

Q_{out}	Outflow	(m^3/s)	1, 4
g_i	Infiltration rate	(m/h)	19, 22
T	Duration of rain	(h)	1, 5
T_{ret}	Retention time of water	(h)	4
t_p	Ponding time	(h)	19
φ	Runoff coefficient	(-)	2, 3, 6
M	Manning´s coefficient	(-)	7
s	Longitudinal slope	(%)	7
W_{sc}	Water capacity for soil	(%)	17
E	Void ratio	(%)	21
Θ	Water content in soil	(%)	23, 24, 25
θ_{FC}	Field capacity of soil	(%)	23, 24
θ_{wp}	Wilting point	(%)	23
U	Roofs feasible for stormwater device implementation	(%)	26
P	Share of installment in investigated area	(%)	26, 27
F_f	First flush reduction	(%)	26
K	Tilt of sides	(v:h)	9, 10
$N_{irrigtion}$	Need for irrigation	(m^3/m^2)	27

Appendix C. Article

Sustainable Drainage and Surface Water Management in Xiamen, China - *A case study in Urban Stormwater Management*

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Abstract

In Xiamen, similar to many other Chinese cities, there is today no sustainable plan for the management of stormwater. Stormwater is conducted through underground pipes towards the final recipients, without any treatment or detention. Flooding and poor conditions in the recipients are consequences derived from this kind of management. The main focus with this thesis is to evaluate the possibility of retrofitting sustainable urban drainage solutions in the central parts of Xiamen, in order to achieve a better qualitative and quantitative control of the stormwater. Through literature studies, reviewing local data and by investigating the current conditions in the city, different sustainable urban drainage methods are evaluated, in order to determine suitable solutions for Xiamen.

Evaluations show that green roofs will be the most feasible solution on rooftops. Open recreational areas and recreational ponds located in central Xiamen may be converted to better detain stormwater. Green areas in central Xiamen are relatively abundant, and have the potential be redesigned to bioretention areas. Other Infiltration devices such as permeable paving, soakaways and infiltration basins may be installed where space is available. Because of the risk of groundwater contamination, infiltration devices should be installed with underdrains. Area-demanding solutions like wetlands, green filter strips and swales are difficult to realize in central Xiamen because of the lack of space.

Stormwater is conducted downstream in concrete canals to Yuan Dang Lake, which is regarded as the final downstream recipient, before the stormwater released to the sea. This thesis shows that if the suggested solutions are implemented, the stormwater will be intercepted by several devices on its way downstream, which will contribute to notable improvements in Xiamen’s stormwater management. Runoff rates after the implementation of the solutions are evaluated to be less than half of the current values, for a 24-hour storm, with a recurrence time of 10 years.

Keywords: sustainable urban drainage systems, SUDS, Xiamen, China, stormwater

Introduction

Xiamen, a city of 2.5 million people located on the eastern shores in Southern China, has seen an remarkable development in economy and infrastructure during the last decades (Lai, 2010). This rapid development has however often come to the price of the environment. With a rapid expansion of infrastructure, hard surfaces are replacing permeable soil, not allowing the water to infiltrate and quickly leading it towards the recipients. The removal of stormwater is an issue which for a long time has had a low priority, resulting in the increase of urban flooding and stormwater related nuisances.

The main recipients of Xiamen Island are either the sea, or Yuan Dang Lake. Formerly an open harbor, Yuan Dang Lake has been created through a series of land-reclamation projects, and today has a size of 1.5 km^2 (Zhou et al., 2003). The lake is under constant observation, and the condition of the water has improved significantly during the last decades (ibid.).

This thesis will treat the possibilities of implementing sustainable urban drainage systems (SUDS) in central Xiamen, as a means of better controlling stormwater runoff, from a quantitative, qualitative and aesthetical perspective. The district investigated is a densely urbanized part of the Yuan Dang Lake catchment in central Xiamen, with a total area of 148 hectares. Xiamen's location in China, and the area of investigation is displayed in Figure 1.

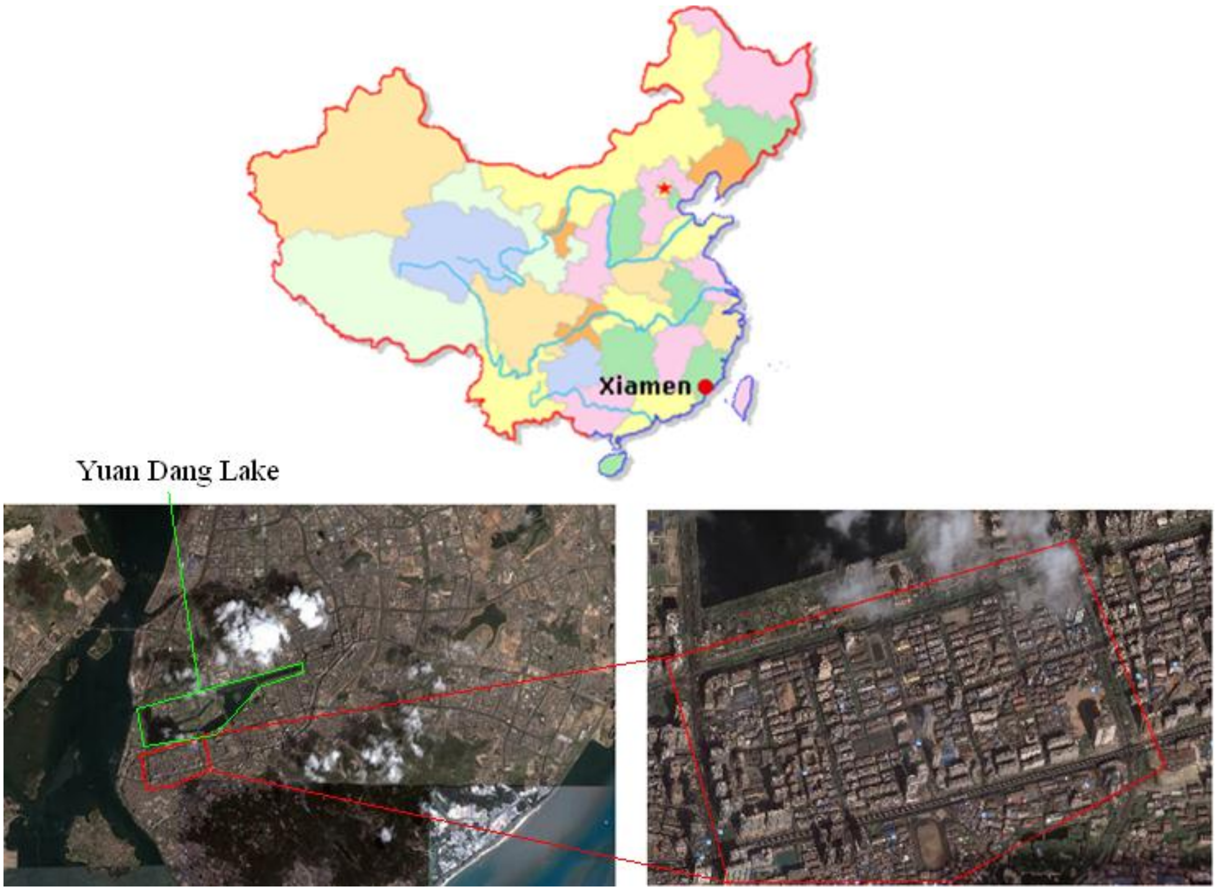

Figure 23: The location of Xiamen in China, followed by the investigated area in central Xiamen (Top China Travel, 2011; Google maps, 2011).

Though existing in western countries for several decades, the sustainable urban drainage approach is still considered relatively new in China. Finding which sustainable urban stormwater solutions are feasible for retrofitting in central Xiamen, the main aim with this thesis, may lay the foundation for further more detailed future investigations in the field.

Method

Collected information from authors and institutions of various nations has been reviewed to find pertinent information for this study. Additional information has in some cases been retrieved through mail conversations with people having expertise in the field of investigation. Local information about Xiamen has been obtained through direct observations in the field, local sources and through conversations with my tutor and other professors at Xiamen University. Based on the local conditions and evaluations of compiled information, examples and calculations have been realized. In cases when data was not available, or when the limited time of the study constrained the possibility to obtain information, relevant approximations derived from existing data have been made.

Local Conditions in Xiamen

Xiamen is situated in a sub-tropical zone, enjoying a yearly average temperature of around 20.8 ℃ (XMG, 2011c). During the last decade, the average rainfall was about 1347 mm in a year, with an average potential evapotranspiration of 1391mm (Xiamen Statistics Bureau, 2001-2010).

The national laws that regulate the emission standards to water bodies and sets standards for the water management in Xiamen are The Environmental Protection Law, The Water Resource Law and The Water Pollution Prevention and Control Law (WPL) (World Bank, 2006).

Many departments are involved in the administration of water related questions in Xiamen. This comprehensive structure of administration makes it hard to say who has the final responsibility. Problems may be transferred between offices, or sometimes even fall between the chairs, impeding progress in many important questions(XCMB, 2006).

Yuan Dang Lake

The Yuan Dang Lake is located in the western parts of Xiamen Island. For a long time, the area that today is Yuan Dang Lake was an open harbor, covering about 10 km^2. A number of land reclamation projects were carried out in the 1970's, reducing the area of the harbor, and creating a lake which today has an area of about 1.5 km^2 (Zhou et al., 2003). The condition of the water in the lake was for a long time extremely poor, but through a series of measures, the condition was successively improved. There is however still wastewater reaching the lake without any treatment, and the combined pipe-system which is dominant on Xiamen Island contributes to occasional flooding of treatment plants at the event of heavy storms, leading to an exacerbated condition in the lake (Xiamen Water, 2008). Though still a lot to do, many of the contaminants in the lake are today reduced to less than a tenth of the most critical values in the 1980's (Zhou et al., 2003). The total drainage area of the lake is around 37 km^2, which is about 30% of Xiamen Island. Water in the lake is replaced through dam openings connected to the adjacent sea. With the help of the tide, water is transported in and out of the lake, creating a slow circulation. The turnover time of the water is around 3 days, which is sufficient for the settling of particles and suspended solids, and for biological treatment processes (Zhou et al., 2003). Yuan Dang Lake is seen as the final downstream stormwater solution, before the water enters is released in the sea.

Evaluation of SUDS in central Xiamen

This chapter will evaluate if some of the most common stormwater solutions are feasible to implement in central Xiamen through retrofitting. Calculations of the solutions most likely to have the potential to implement were done using simplified equations. Rainfall data from Xiamen, found in Appendix A, was used in combination with measures from studies in the field or relevant estimations, when the necessary measurements were not possible to obtain.

Green roofs

In the decision between rainwater harvesting and green roofs, the latter was evaluated as the most feasible solution for retrofitting in central Xiamen. To evaluate the potential effects, average monthly rainfall during one of the wettest months and one of the driest months, June and December respectively were used for the calculations. Rainfall data was obtained from Xiamen Statistics Bureau (2001-2010). In accordance with values from Germany described by Becks et al., (2010), 80% of the potential green roofs in Xiamen were estimated to be extensive (thin soil layer) and the remaining share was assumed to be intensive (thick soil layer). The runoff reduction in June was calculated to be 51% and 66% for the different kinds of roofs respectively. In December, both roofs detained the entire volume of rainfall. These values were used to evaluate the rainfall reduction, spread out on the entire area of investigation. Results showed that almost 10% of the rainfall in the investigated area in June, and 18% in December will be detained by the implementation of green roofs, with the precondition that the rain fall is distributed evenly throughout the month. Another important aspect when implementing green roofs is the multiple additional benefits this solution entails.

Stormwater ponds

The feasibility of stormwater ponds was estimated for a 24-hour storm with a recurrence time of 10 years. Thought occupying quite a vast area of land, the ponds were only calculated to claim around 1.9% of the catchment area. The area in Xiamen investigated does not have any extra space available for constructing these solution however, it would have to be implemented through retrofitting. Wet ponds or dry detention ponds were both feasible solutions. Maps and field investigations showed that there existed some adjacent parks with ponds, as well as some recreational areas like football-fields, which had the potential of being reconstructed to stormwater ponds and dry ponds respectively. It was further determined that if implemented, the ponds altogether had the potential of taking care of the water from around 48% of the area of investigation in this study.

Bioretention areas

With a very flexible design, bioretention areas are highly suitable for retrofitting purposes. Though one solution will only make a limited difference, a number of devices working together will have a significant impact on the stormwater runoff (Stormwater Center, 2011e). The general proportion of green areas in Xiamen is around 40%. Though occupying a smaller share in the investigated area, there is still a big potential for this solution. To prevent potential contamination of the groundwater, and avoid potential damage on underground structures, the solutions should be constructed with an underdrain, conducting the water to a nearby canal. Like for ponds, a 24-hour storm with a recurrence time of 10 years obtained from Xiamen Statistics Bureau (2001-2010) was used in the evaluation. The size of the bioretention area was evaluated to be around 14% of the catchment area.

Using determined values, it was calculated that bioretention areas could handle stormwater from around 44% of the investigated area. Since the green area already exists and are maintained regularly, the increase in management costs for these stormwater device will be less significant than if constructed in a new area.

Remaining infiltration devices, namely permeable paving, soakaways, infiltration trenches and infiltration basins were considered as possible solutions for implementation. The lack of knowledge about the underground conditions in central Xiamen and the lack of time restricted however further investigations, which may be subject to another study in the field.

Canals

For concrete canals, the maximum potential rainfall intensity was decided, to see how big storms the canals could handle for a predetermined catchment area. For a 15-minute rain, the canals could handle a rainfall with the intensity of 232mm/h if the drainage area was 3 ha, and no SUDS were implemented. Calculated to only occupy around 1.8% of its' adjacent catchment area, the solutions are very space-conservative. The canals are a somewhat controversial solution, which do not provide the otherwise for SUDS characteristic quantitative and qualitative stormwater improvements. The solution does however not suffer from the same limits in dimensioning and water velocity as many other solutions, which made it feasible for implementation in central Xiamen. The canals are preferably constructed alongside larger roads, in the direction towards Yuan Dang Lake. There are 6 of these roads in the area investigated, hence an equal amount of canals was assumed to be possible to implement. A predetermined rain intensity was chosen to determine the impact of canals in the investigated area, with the precondition that the abovementioned solutions had been implemented according to earlier chapters. If conducting water from the entire area of investigation during a rainfall with the intensity of 250 mm/h, there was still an additional 11% capacity of the canals which was not used, validating the feasibility of the canals as a stormwater solution.

Solutions not considered feasible

A number of the common stormwater solutions were evaluated as not feasible for retrofitting in the investigated area in central Xiamen. Solutions considered were wetlands, filter strips and swales. The main reason why these solutions were not seen as feasible was the amount of space needed for the implementation. Land is a valuable asset in central Xiamen, and when retrofitting solutions, it is important to make sure the additional space required is kept to a minimum. In other, less densely populated areas of the city, or when constructing new areas, these solutions may however be feasible to implement.

Potential flow reduction

After evaluating the solutions above, the impact in the event of a storm could be determined. The results of the different solutions varies depending on the rainfall, and it is hard to make evaluations covering all potential cases. In this example, a 24-hour storm in Xiamen, with a recurrence time of 10 years was chosen. The total flow rate from the investigated area, if no SUDS were implemented, and after the implementation of previously described solutions were calculated. Simplified results displaying the maximum flow rates and the runoff are displayed in figure 2.

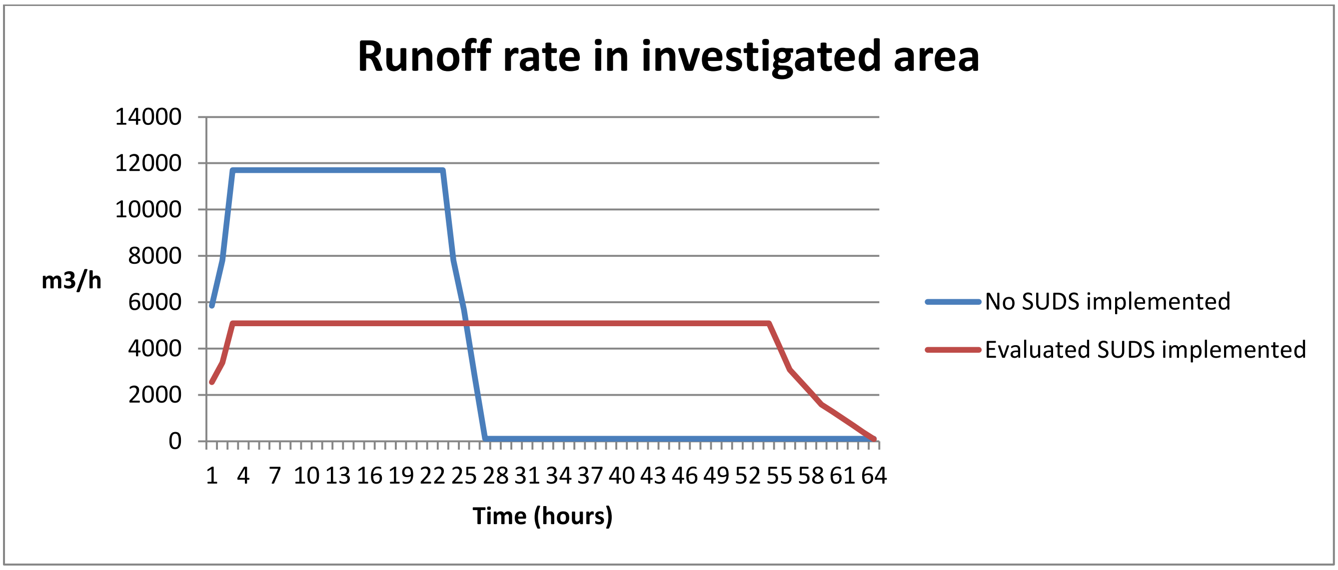

Figure 2: Stormwater runoff rate in central Xiamen, during a 24-hour storm with a recurrence time of 10 years.

Figure 2 shows that the maximum runoff is reduced to less than half of its original values, if the devices are implemented according to preceding evaluations. The flow is spread out over a longer period of time, which will reduce the stress downstream on the recipients. The chart shows that there is a significant potential of improvement regarding stormwater management in central Xiamen, if solutions are retrofitted in a correct manner.

Conclusions

As shown in this paper, there is a potential for significant improvements in stormwater management within an existing highly urbanized area, without the need for claiming new areas for the treatment of stormwater.

If the suggested solutions are implemented, a stormwater management train will be created. A possible flow path of the stormwater is that the water starts on the green rooftop. The runoff continues to an infiltration device, where the water is infiltrated through the soil media, to reach the underdrain. From here the water is conducted to a canal, transporting the water to Yuan Dang Lake, before finally reaching the final recipient. In this example, the stormwater management train consists of 4 different solutions, all contributing to increase the quantitative and qualitative standards of the water. This is just one potential of many ways the stormwater in the investigated control area may take towards the final recipient. It is important for the stormwater to encounter several different stormwater solutions on its' path downstream, to achieve maximum potential qualitative and quantitative improvements.

Discussion

Issues regarding stormwater management are matters which Xiamen, as well as many other Chinese cities will have to deal with within a near future. Traditional concepts of stormwater handling combined with a rapid urbanization have created serious qualitative and quantitative problems related to the stormwater management. Receiving water bodies are still in great need of improvements, and stormwater related flooding is a problem of Xiamen.

With a subtropical climate, and an average yearly rainfall of over 1300 mm per year, there is an abundance of rain which needs to be taken care of. By implementing sustainable urban drainage systems, rainwater may be converted into a benefit for the city. The open stormwater solutions will increase the amenity, improve the water quality standards and reduce the risk of flooding, all valuable contributions to central Xiamen.

Calculations in this report have been focused on the quantitative improvements derived from the potential implementation of sustainable urban drainage systems in central Xiamen. The solutions will however also contribute to a noteworthy contaminant-removal for the stormwater. To determine the removal of pollutants from the implementation of sustainable urban drainage systems in Xiamen, further specific studies in the field will have to be conducted.

Since the concept of sustainable urban drainage systems still is new in China and Xiamen, it is important to look at countries with more experience in the field, in order to better evaluate feasible solutions. By obtaining techniques and data in the field from experienced actors, many errors may be avoided, and a better rate of efficiency may be reached. Sweden is a country with several decades of experience in the field, with expertise that may be valuable for China.

Because of the fact that the area investigated in this report is heavily urbanized, the solutions will have to be implemented through retrofitting. The privilege of planning the solutions from an early stage of the development of an area will not be possible. Solutions will rather be implemented where there right potential exists. The area selected for this these is meant to be seen as a typical urban district in central Xiamen, and the conclusions from this study should be applicable for other similar areas in the city.

The city’s many street cleaners should be a part of the maintenance of the open stormwater solutions. Many devices obtain the best level of performance if regularly maintained. Xiamen has an advantage against most western cities in the fact that there are workers out cleaning the streets on a daily basis. Gardeners also keep the green areas of Xiamen in a lush condition. If instructed how to correctly maintain the stormwater solutions within their area of responsibility, this would assure a good condition, and high efficiency of the implemented devices.

In Yuan Dang Lake, many limits in the national pollution-standards are today met, but a lot of pollutants are still at a level far above the allowed limits. The fact that some limits in the standards have been reached shouldn’t mean that the goal should be considered reached though. There should be an ambition of constantly improving the prevailing situation. The standards set an acceptable maximum limit for emissions. This doesn´t mean the values are good. Implementing sustainable urban drainage systems should be considered as one important means of improving the current environmental situation in Xiamen.

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