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Faculty of Landscape Architecture, Horticulture and Crop Production Science

Water plazas as innovative approaches for managing urban stormwater

– A design proposal for Södervärnsplan, Malmö

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PREFACE

During my academic years, an interest for sustainable stormwater management in urban areas has aroused. After my exchange year in Netherlands it grown even more and I therefore took the opportunity with this master thesis to explore the topic further.

I want to thank my supervisor Frida Andreasson for reading the work and advicing me during the whole process. I also want to thank Anders Folkesson for your time and insights and Rudi van Etteger at Wageningen University for helpful advices in the beginning of the process.

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ABSTRACT

Urbanisation in combination with a changing climate put high pressure on future cities to deliver sustainable, liveable and attractive urban places. Traditionally, many green and blue spaces in cities have been removed and replaced with impervious pavements or buildings in order to manage the need for densification. This have resulted in an affected hydrological cycle that no longer operate in urban areas the same way as it does in natural conditions. When precipitation is increasing and extreme rainfalls occurs more frequently, the hardscaped cities cannot manage the amount of water and urban flooding is a fact. This leads to an urging need for climate adaptation and modernisation of the conventional way to manage stormwater. One way of managing stormwater in a more sustainable way is the concept of Water plazas. Basically, it is a plaza that will be dry and available for people to enjoy most time of the year but which after a heavy cloudburst temporarily can store rainwater. In this way flooding of surrounded buildings and infrastructure may be prevented.

The objective of this research has been to investigate the concept of water plazas and sustainable stormwater management in urban places. To do this a literature review was conducted and the existing water plazas of Benthemplein in Rotterdam and Tåsinge Plads in Copenhagen was visited and analyzed. The outcome was then implemented in a conceptual design proposal for a climate adaptive, resilient water plaza at Södervärnsplan in Malmö.

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1. INTRODUCTION

1.1 Urbanisation and densification

In 2017 the world population was numbered to over 7.6 billion people (United Nations, 2018). This number is growing with about 1.1% per year, which lead to an estimated world population of 9.8 billion people in 2050 (ibid.). Consequently, population increase leads to increased housing demand and a primarily growth in urban areas (United Nations Human Settlements Programme, 2016). 55% of today's population lives in urban settlements and until 2050 this is expected to reach 68% (United Nations, 2018). To manage this, cities have the two options of densification and/or sprawling. In the European context most cities show an increased densification and even new urban expansion areas tend to be relatively dense constructed (Broitman & Koomen, 2015; Kabisch & Haase, 2011; Mohajeri et al., 2015).

The rapid increase of population and urbanisation put high pressure on the future cities to deliver sustainable, liveable and attractive urban places, accessible for all inhabitants.

1.2 Climate change

On top of increasing population and urbanisation, occurring climate change creates even bigger challenges for the future cities. Climate change and global warming is now general facts that affect us all and require immediate action (IPCC, 2014).

Due to the increasing atmospheric greenhouse gas concentrations, the last three years have been the warmest ever recorded and the trend does not seem to turn (WMO, 2018). Rising temperature have resulted in melting ices in polar areas and new studies indicate an accelerating sea level rise that until year 2100 is estimated to have increased by 65 centimetres (NASA, 2018). Rising temperature will also affect the earth's water cycle in a way leading to increased storm events with extreme precipitation in some areas, and decreased precipitation and risk of drought in other areas (UN-Water, 2010). In general, wet regions will get wetter and dry regions dryer, but many countries will also suffer from longer periods of both extremes (Seager et al. 2010). This will generate an increase of urban flooding, and low-lying coastal cities will have to find solutions to deal with the rising sea level (IPCC, 2014; Nicholls and Cazenave, 2010).

As a response to this situation the Paris agreement, COP21, was declared in December 2015 with the aim to bring all nations together in the fight against, and adaptation to, occurring climate change. The stated goal is to keep the temperature rise below 2 degrees Celsius (UNFCCC, 2014).

1.3 Polluted waters

Urbanisation also brings issues with water management and water quality (Ellis & Hvitved-Jacobsen, 1996). Rainwater that runoff the surface instead of evaporating or infiltrating the ground is called stormwater runoff. In urban areas this is the water that falls on the buildings and pavements and needs to be drained away. This water is often much polluted, mainly from the pollutants it washes of the catchment areas but also from the rainwater itself and from the air. Apart from stormwater there is wastewater, which also contains many pollutants. This water is a result from human life and activities and comes from toilets, showers, washing machines, industries etcetera. (Butler & Davies, 2010)

To maintain public health as well as environmental health it is therefore of great importance that both stormwater as wastewater is properly drained and treated. If not so, pollution load goes directly to receiving water bodies and groundwater which may cause bad conditions for aquatic plants and animals, human health risk if exposed to the water and non-potable fresh water (Ellis & Hvitved-Jacobsen, 1996). To prevent this, all European member states should follow the European Water Framework Directive (WFD, 2000) which aim is to preserve, protect and improve the quality of European water bodies.

Another big contributor to polluted waters is fertilisers, herbicides and pesticides from agriculture (Novotny, 1999). However, this study will focus on urban areas and agriculture will therefore not be covered.

1.4 Urban stormwater management

The traditional way to manage urban stormwater is to divert it to gutters and into the under-ground sewer system for transportation out of the city as fast as possible. Under normal circumstances, this is a good and efficient way, but heavy rainfalls can overload the capacity of the pipes and cause flooding (Stahre, 2004). To manage the expected increase in rainfall many cities would need to expand their sewer systems in order to prevent flooding. Such reconstructions are however very costly and other solutions that can complement the pipe system are tried out (Hoyer et al. 2011; Malmö stad, 2018). This has resulted in a variety of new ways to manage stormwater and the concept of *sustainable stormwater management* has gotten a lot of attention. The idea is to recreate a water cycle in urban areas that more closely match the natural one (Hoyer et al. 2011). Instead of diverting the stormwater to the sewer system as fast as possible the aim is to manage it close to where it falls in systems that slow down the runoff rate and letting the water evaporate and infiltrate. Such systems can be swales, basins, green roofs etcetera. In that way, less stormwater volume finally reaches the pipes and heavy rainfalls will be more manageable and the flood risk decrease (Stahre, 2004; Woods-Ballard et al. 2015). If the stormwater is managed in visible systems on the surface it can also be used as a positive resource that contribute to amenity and biodiversity in the city (Jose et al. 2015) as well as it serves an educational purpose that increases peoples understanding for stormwater management (Echols & Pennypacker, 2008).

There are several models for sustainable stormwater management, all slightly different and suitable for different occasions, and the terminology of these practices also vary between disciplines and regions of the world (Fletcher et al. 2014).

Most common names/approaches that is applied in the field is:

- SUDS - Sustainable Urban Drainage System (United Kingdom)
- WSUD - Water Sensitive Urban Design (Australia)
- LID - Low Impact Development (North America and New Zealand)
- BMP - Best Management Practice (North America)
- BGI - Blue Green Infrastructure (North America)

(Fletcher et al. 2014)

Sweden, Denmark and Netherlands all have terminology in its own languages (Fletcher et al. 2014). As a research based in European context, the term sustainable urban drainage system (SUDS) will hereafter be used.

1.4.1 Water plazas

One way of managing stormwater in a sustainable way is the concept of *Water plazas*. Basically, it is a plaza + water storage. The idea is that the plaza will be dry and available for people to enjoy most time of the year but that it after a heavy cloudburst temporarily can store rainwater (fig. 1.1). In this way flooding of surrounded buildings and infrastructure may be prevented. It is also a way to make the money invested in water management visible for the public instead of hidden under ground. Hence it becomes a multifunctional concept where water management is only one part but aesthetics and recreational values just as important. In this way, the experience of the plaza differs with the weather conditions and creates diverse play opportunities for children. (Boer et al. 2010)

Water plazas can be designed in many different ways and often consists of a combination of several SUDS in order to optimally manage the stormwater (Explained further in chapter 2).

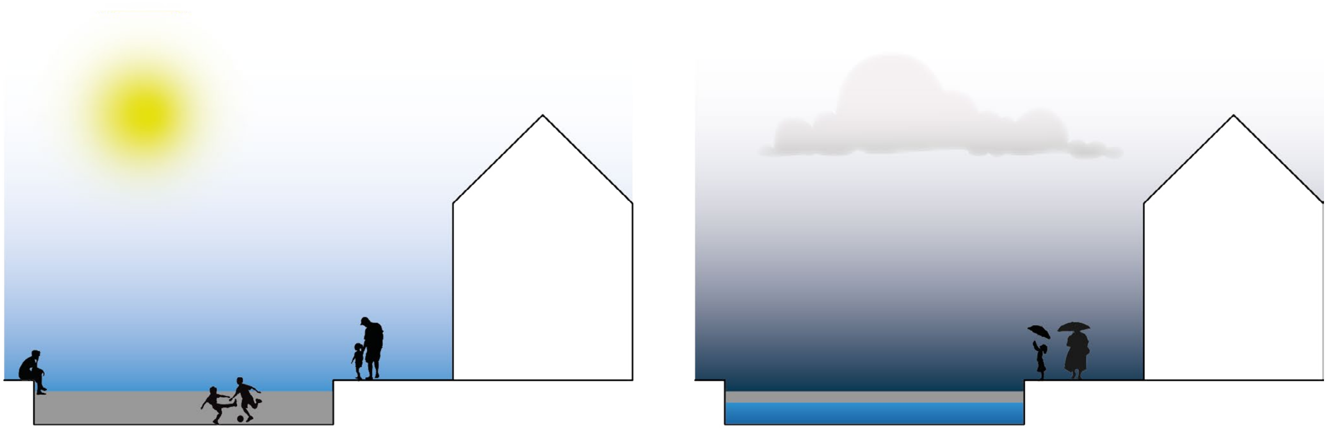


Figure 1.1. The concept of water plazas: Available for recreation during dry weather and storage for rainwater during wet weather (Remade by author after Boer et al. 2010).

1.5 Problem statement

Urbanisation and denser cities in combination with a changing climate leads to a big environmental change in comparison to the natural conditions. In urban areas a big part of the green spaces is removed and replaced by impervious pavements or buildings and natural water bodies are replaced by pipes. This results in an affected hydrological cycle, hence high peak flows and increased flood risk as well as reduced evapotranspiration and groundwater recharge. Industries and heavy traffic also contribute to polluted receiving waters which cause health hazard for humans as well as badly affected aquatic ecosystems. (Semadeni-Davies et al. 2008)

The problem statement is concretised in figure 1.2.

To deal with this problem it is also important to create awareness among the public. Water management is a demanding task and it costs a lot of money to maintain existing systems as well as construct new systems in order to keep the city dry and sanitary (Hoyer et al. 2011). However, since most of the systems are hidden under ground it may be hard for the tax-paying citizens to understand where the money goes. SUDS may be a way to show the solutions and create awareness and understanding about the topic (Echols & Pennypacker, 2008; Woods-Ballard et al. 2015).

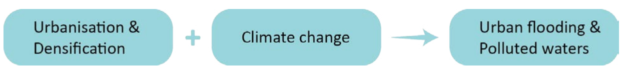


Figure 1.2. The problem statement.

1.6 Societal practical relevance

Lately, heavy rainfalls have hit European cities more often, causing flooding and resulted in widespread damage to public and private property. This leads to high economical costs for municipalities, insurance companies, as well as private citizens (Berghuijs et al. 2017; Nobre et al. 2017). The definition of extreme rainfalls vary between countries worldwide, but is usually based on statistic precipitation and defined as amounts exceeding a certain threshold during a set period of time. A bit simplified, the Swedish definition is those above 40 mm under 24 hours (SMHI, 2018), the Dutch one above 50 mm under 24 hours (KNMI, 2018) and the Danish one 15 mm under 30 minutes (DMI, 2018). The 2 July 2011, Copenhagen was hit by a cloudburst that measured 135 mm of rain under 24 hours (DMI, 2011) which caused big problematic flooding and damage that reached a total cost of 6 billion Danish crowns (Beredskabsstyrelsen, 2012). In Malmö, the last rainfall that caused big problematic flooding occurred the 31'st of August 2014 when 100 mm of rain fell under 24 hours (SMHI, 2014). According to Sydsvenskan (2014-09-04), at least 3,000 buildings were damaged, and the damage reached 600 million Swedish crowns (Kommunstyrelsen, 2017). Same rain also hit Copenhagen that measured 135 mm of rain under 24 hours (DMI, 2014). In Rotterdam, a heavy rainfall occurred the 28 of July 2014 that measured 132 mm (KNMI, 2018).

Current sewer systems in many European cities are old and not designed to manage this amount of water (De Feo et al. 2014). Apart from lack of capacity, a common problem in older pipes is clogging of roots from trees and shrubs that finds its way into the pipes through leaks and joints. In Malmö, Rolf and Stål (1994) show that pipes fitted before 1970 have a much larger root intrusion than pipes fitted after 1970. Smaller pipes normally need to be cut inside every year to remove the roots which is a time consuming and costly task regarding the large amount of pipes that exist (Randrup et al. 2001).

In combination with urbanisation this leads to an urging need to modernise and expand the existing systems. It is also an opportunity to find new sustainable solutions to replace, or at least relieve, the conventional drainage system. Furthermore, new innovative systems can contribute to climate adaptation strategies by the benefits of controlling the stormwater quantity and improving the water quality as well as improve the amenity and biodiversity in the city (Woods-Ballard et al. 2015). SUDS has also shown to be cost effective in comparison to traditional stormwater management (Kirby, 2005).

The city of Malmö is facing an extensive densification to reach the goal of growing with 100 000 more inhabitants (Malmö stadsbyggnadskontor, 2010). The city-planners argue that Scanias cities are misbegotten and wastefully planned and easily could densify a lot more with smarter and more effective city planning as shown in many other cities worldwide (Sydsvenskan, 2018-03-04). In addition, the surrounding areas of Malmö consists of precious arable land that should be conserved, and expansion of the city would also result in larger distances for people to travel and more CO^2 emissions (Malmö stadsbyggnadskontor, 2010). Consequently, the city planners work with an urban densification strategy and strives towards developing the city-centre into a “big-city character”. This will result in higher pressure on existing green spaces and water management, and also pose a threat to replace smaller green spaces with new constructions (Malmö stadsbyggnadskontor, 2010).

To get an insight in what this growth may entail, it is interesting to investigate bigger cities as Rotterdam and Copenhagen in this case. Research on this topic is nothing new and there are several examples that address urban stormwater solutions (Eckart et al. 2017; Jefferson et al. 2017). However, in the Swedish context, and the city of Malmö, most of the existing projects deal with solutions in private/semi-private residential areas and there is nothing done that specifies the research on water plazas at public spaces.

1.7 Objective and hypothesis

It is hypothesised that by supplementing the traditional stormwater management with a water plaza consisting of SUDS a more natural water cycle would develop even in dense cities. It could relieve areas that are particularly vulnerable and known to have problems with flooding or polluted water (Stahre, 2004). In this way, the runoff would decrease and so the risk of flooding. If the systems are designed open instead of hidden under ground, they are also hypothesised to be pedagogical by means of creating awareness among the public about the need of sustainable stormwater management. In that way, people may even get used to, and learn to accept, the idea that some areas will flood regularly in order to keep its surrounding areas dry.

The objective is concretised in figure 1.3.

To get an in-depth understanding of sustainable stormwater management and particularly the implementation of water plazas, the objective of this research is to investigate what has been done in the leading European cities of Rotterdam and Copenhagen and how this knowledge can be implemented at Södervärnsplan in the Swedish city of Malmö. To fulfil this, case studies was conducted at Benthemplein water plaza in Rotterdam and Tåsinge Plads water plaza in Copenhagen. The results of the case studies are aimed towards identifying different strategies to handle the problem of urban stormwater and flood risk. The existing place Södervärnsplan in Malmö worked as main case in order to implement the knowledge given by literature and reference cases which resulted in a conceptual design proposal of a climate adaptive, resilient water plaza.

Figure 1.3. The objective.

1.8 Context

Below, the three cities (fig. 1.4) this research focuses on are introduced. Benthemplein plaza in Rotterdam and Tåsinge Plads in Copenhagen work as reference cases and Södervärnsplan in Malmö as the main case. Benthemplein and Tåsinge Plads are further described in chapter 3 and Södervärnsplan in chapter 4.

Figure 1.4. Location of the mentioned cities in the research.

1.8.1 Rotterdam

Netherlands is a relatively small country but densely populated with high urbanisation to house all its 17 million inhabitants (CBS, 2018). In addition, almost half of the country´s surface lies below sea level (Dufour, 2000). With climate change and rising sea-levels Netherlands is in a vulnerable position that have forced the Ministry of Infrastructure and Environment (Rijkswaterstaat, 2011) to develop high technological solutions to deal with water (fig. 1.5). At the low-lying areas, the water is now constantly managed artificially with a so-called polder system (fig. 1.6) (De Graaf et al. 2009).

Rotterdam is the second biggest city in Netherlands, inhabited by around 635 000 people (Municipality of Rotterdam, 2017). With 80% of its surface lying below sea level, water is a critical element that is managed with very advanced techniques to keep the city dry (Municipality of Rotterdam, 2018). To prepare for a changing climate, the municipality adopted the *Waterplan 2 Rotterdam* with strategies of water management that includes solutions to improve water storage, water quality and flood protection in the city. The goal is to make Rotterdam 100% water proof until 2030 (Municipality of Rotterdam, 2007).

Benthemplein (fig.1.7) is one project that resulted from the Waterplan 2 Rotterdam (Municipality of Rotterdam, 2007). According to Rotterdam Climate Initiative (2018) this is the first large scale water plaza in the world and it was officially opened in December 2013.

Figure 1.5 show the weirs used to control the water level in the ditches in Wagen

Figure 1.6. The polder in Wageningen, Netherlands is temporarily filled with water after some days of heavy raining and accordingly protects the city from flooding.

Figure 1.7. Aerial photo showing Benthemplein water plaza in Rotterdam, Netherlands (Google, 2018).

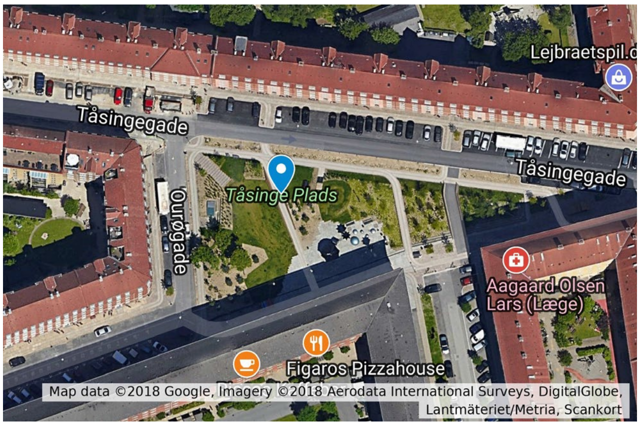


Figure 1.8. Aerial photo showing Tåsinge Plads water plaza in Copenhagen, Denmark (Google, 2018).

1.8.2 Copenhagen

Copenhagen is the capital of Denmark with around 603 000 inhabitants (Københavns Kommune, 2017). After the climate summit, COP15, in Copenhagen in December 2009, the municipality of Copenhagen developed a new Climate Adaptation Plan. The plan anticipates the most probable climate scenarios that may occur as a result of climate change, and list adaptation strategies and appropriate solutions on how to deal with them (City of Copenhagen, 2011). Their goal is to become a CO^2 neutral city until 2025 since higher CO^2 levels implies greater climate change and impacts (ibid.). As a part of this, the Cloudburst Management Plan was developed with methods and recommendations for managing increased precipitation (City of Copenhagen, 2012).

The first climate-resilient neighbourhood that emerged from these new policies was Saint Kjelds district in Copenhagen and within this the square Tåsinge Plads (fig. 1.8). This square is designed as a green oasis that collect the local stormwater and was officially opened in December 2014 (Klimakvarter, 2015).

1.8.3 Malmö

Malmö is Sweden's third biggest city with around 335 000 inhabitants (counted 2017). A number expected to grow with 15% until 2027 and which will imply a demand of at least 21 400 new housing (Stadskontoret, 2017). As a part of Malmö densification strategy, approaches to develop the green areas in the city are mentioned. Densification will result in higher pressure on the existing green areas which is why they need to be developed to withstand. This includes improved accessibility, usefulness and expansion of green areas on walls and roofs as well (Malmö stadsbyggnadskontor, 2010).

To manage future climate change and extreme rainfalls, the municipality of Malmö adopted the Cloudburst plan for Malmö in 2017. The aim with this is to increase the city's resistance to the consequences of cloudbursts. To do this they recommend green-blue strategies that creates synergies between water management and city planning. As a part of this they especially promote water plazas but describes them as multifunctional activity areas that temporarily floods during heavy rainfall. (Kommunstyrelsen, 2017)

Malmö is also internationally recognised for designing innovative stormwater solutions as the projects in Västra hamnen (fig. 1.9. & 1.10) and Augustenborg (fig. 1.11 & 1.12) which indicate a positive attitude from the city planners towards projects like this (Malmö stad, 2008). Now it is time to step up and join the trend of water plazas as shown in Rotterdam and Copenhagen.

Figure 1.9. showing a rain-garden as stormwater management in Västra hamnen, Malmö.

Figure 1.11 showing the open stormwater management in Augustenborg, Malmö.

Figure 1.10 showing the stormwater management in open gutters in Västra hamnen, Malmö.

Figure 1.12 showing the open stormwater management in Augustenborg, Malmö.

The area Södervärnsplan (fig. 1.13 & 1.14) will act as main case in this research for designing a water plaza in Malmö. The place is chosen for its central location, highly paved surroundings and the fact that close by areas got badly flooded after the rainfall in 2014 (Kommunstyrelsen, 2017). Södervärnsplan is further described and analysed in chapter 4.

Figure 1.13. Aerial photo showing Södervärnsplan, Malmö. Red counters showing the borders for the park (Remade by author after Kartor Malmö, 2018)

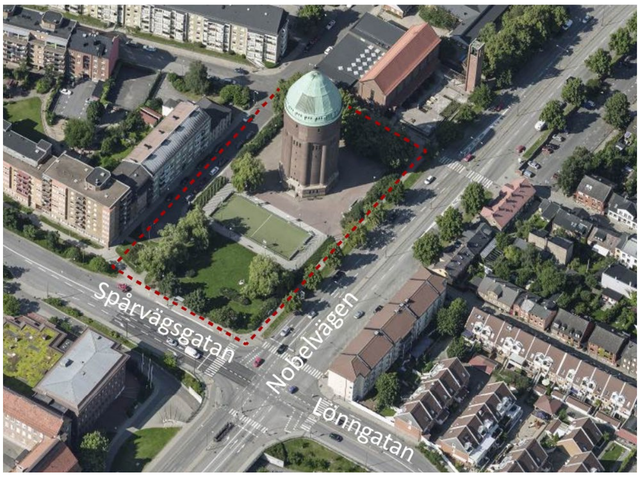


Figure 1.14 showing the location of Södervärnsplan.

1.9 Research question

To explore the hypothesis and achieve the research objective, following main research question was formulated:

MRQ:

- How can sustainable stormwater management in shape of water plazas prevent flooding, relieve the existing drainage system, create awareness of the problem and contribute to greenery and recreation for people at Södervärnsplan in Malmö as exemplified in the city of Rotterdam and Copenhagen?

To be able to answer this, the following sub research questions has to be answered:

SRQ:

- How does a water plaza work and what can be learned from Rotterdam's Benthemplein and Copenhagen's Tåsinge Plads?
- What are the potentials and limitations of water plazas?
- How is the existing drainage system in the area around Södervärnsplan working and how could a water plaza contribute to improve this situation?

1.10 Methodology

1.10.1 Philosophical world-view and research design

Creswell (2014) uses the term world-view as a general philosophical orientation that the researcher brings to the study based on educational background and objective of intended research. The world-view influences the research approach such as qualitative, quantitative or mixed methods and guide the actions of research. Accordingly, Creswell has developed following classification of world-views: constructivist, (post)positivist, transformative and pragmatic. Most relevant in this research is the constructivism which is commonly used in social science and typically takes a qualitative approach of research. This means involving the researcher to interpret individual meanings and certain contexts based on historical and social perspectives. The (post)positivistic research on the other hand originate from natural science and tend to test hypothesis and verify theories through quantitative methods. The transformative world-view is used in humanities science and typically take a participatory approach when addressing controversial social issues that may have a political agenda and seek for reform. Finally, the pragmatic world-view acknowledge that research may require a mix of all three approaches described above to understand the research problem. This means a more liberal view that research occurs from several contexts such as social, historical, political etcetera. In this way the researcher is free to mix methods to fit the need of the research. (Creswell, 2014)

Since this research aim to integrate sustainable stormwater management on urban public plazas there are several factors to consider when approaching the research objective. Hence, a (post)positivist approach is needed to research the nature and technical strategies of hydrology, climate change, biodiversity etcetera. Furthermore, a constructivist approach is needed to research the socio-cultural situation in the case-studies and include creativeness and aesthetic values for the design process, allowing personal values brought into the study. In this case, a pragmatic knowledge claim provides freedom to choose the procedures needed to research these factors.

Lenzholzer et al. (2013) build upon Creswell's world-views when developing a further division they call *Research through design*. They claim this to be a discipline-specific research method for landscape architects since research and designing are carried out in parallel to find solutions to problems within a specific context.

1.10.2 Data collection and analysis

Research on design

A literature review that covered relevant topics was conducted to get an in-depth understanding of existing research. Databases used for access was mainly Google scholar (Google, 2018), the library of Swedish University of Agricultural Sciences (SLU, 2018) and the library of Wageningen University (WUR, 2018). Search words have been: Bioretention systems, Climate change, Ecological design, Green-blue infrastructure, SUDS, Sustainable stormwater management, Urban drainage, Urban flooding, Water plazas etcetera. New literature was then collected from other relevant researcher's reference lists.

Case studies on the reference objects in Rotterdam and Copenhagen and the main case in Malmö was conducted. This included site visits and analysis for every case. Rotterdam and Copenhagen were observed in the spring and summer of 2018 at two different occasions each to get a broader understanding about the places function and use that just reading the literature cannot provide. Benthemplein plaza also had a web-cam that enabled a live view over the plaza 24 hours (Martens, 2018). Södervärnsplan in Malmö was, as the main case, visited at several occasions during the spring and summer of 2018 to get a broad understanding of the place.

During the observations, the places was approached with an open mind to let the first impressions come up. Walks in and around the places provided a feeling of the atmosphere. The stormwater management solutions was then observed in detail and tried to understand even though it did not rain at any of the site visits. It was also observed if there were people using the places and how they used them. Other strengths, weaknesses, opportunities and threats that came to mind was noted as explained beneath. At each visit, several pictures were taken as memories and in order to be viewed later in the process for possibly new insights.

Dialogues with stakeholders or designers responsible for the projects were done to the extent possible in order to obtain personal information about the design process, result, current practice etcetera.

SWOT-analysis

To compile and concretise the results from the visits and dialogues a SWOT-analysis was performed for each case. A SWOT-analysis is a method where strengths, weaknesses, oppor-

Table 1.1. SWOT-analysis matrix (Adapted from Hay & Castilla, 2006)

	Helpful (-to achieve the objective)	**Harmful** (-to achieve the objective)
Internal (attributes of the place)	**Strengths**	**Weaknesses**
External (attributes of the environment)	**Opportunities**	**Threats**

tunities and threats are identified and evaluated. This is typically presented in a matrix (table 1.1.) and the outcome should provide an overview that helps in decision-making to achieve the objective (Hay & Castilla, 2006). The method was initially developed for business venture in the financial sector but are today used in all kind of projects, including urban planning (Boverket, 2006).

In this research, the analysis was based upon how well the places function as water plazas according to the recommendations stated by Woods-Ballard et al. (2015) for successful SUDS-design (see chapter 2, page 23) and how well they work with the ideas of eco revelatory design. However, for the analysis of Benthemplein and Tåsinge Plads only strengths and weaknesses were stated since it was concluded not to be useful to analyse their opportunities and threats due to the fact that they were not to be re-designed. For Södervärnsplan a full SWOT-analysis was done.

Eco-revelatory design

The site analysis and the design process are based upon the ideas from the concept of eco-revelatory design. This field within landscape architecture aims towards revealing ecological phenomena and promote awareness about what is relevant and essential to the ecology of the site (Galatowitsch, 1998). Thayer (1998, p.129) describes it like making ecosystems visible and "bringing hidden realities to the surface". He means that by revealing ecological processes in the built environment by making them visible we get a chance to interpret and reflect about their importance as well as our place as humans within nature. To design a place like this Galatowitsch (1998) list three criteria: First, one should focus on highlighting one or a few ecological phenomena that is relevant to the place so that the message will be easy understood and make sense; Second, the ecological phenomena should be revealed as honest and proper as possible; Third, the new design should not result in negative impact on the existing ecosystem or human hazard.

To achieve this, the message must be understandable and make sense at the actual site. Eco-revelatory design is just as much about the people visiting and using the place. People will only learn about the ecological phenomena if the place itself is interesting and arouse curiosity to do so. Spirn (1998) claim that people are part of the landscape and hence provide its context and meaning. She means that every place is dynamic and its identity is shaped by both humans as natural processes. Thus, its present context is a result from past times together with thoughts of what will be the future.

1.10.3 Design process

Research through design

The learning outcome from the literature review, case studies and dialogues were then assessed and implemented in the design process for proposing a water plaza at Södervärnsplan in Malmö.

In the initial phase of the design process, hand-sketches worked as the main tool for generating a concept and primal shape for the proposal (fig. 1.15). Sketching has proven to be an important process in designing since it facilitates creativeness, cognitive activity, exploration of different alternatives, problem solving, perception and translation of ideas (Do et al. 2000). In comparison to digital media for sketching, such as CAD, traditional hand sketches offer more freedom for doodling and re-drawing which triggers the designer to reinterpret the design and try out more solutions (Bilda & Demirkan, 2003). This often result in a deeper recognition of conflicts and possibilities and accordingly higher frequency of re-drawings which could mean a more thoughtful result (ibid.).

Besides the sketching, a physical model of

Södervärnsplan in scale 1:200 was constructed. The material used was mainly carton and modelling clay plastilina (fig. 1.16). De Jong (2016, p.4) defines modelling within landscape architecture as “a way of sketching in three dimensions”. Her research concluded that a physical model is especially useful for understanding the topography and spatiality of a place. The three-dimensional model also facilitates testing different shapes, placements and scales and instantly grasp the effect every option generates.

The model was used as a tool in the design process for trying out different solutions and not as an object supposed to represent the final design. The procedures within the design process is further explained in chapter 5.2.

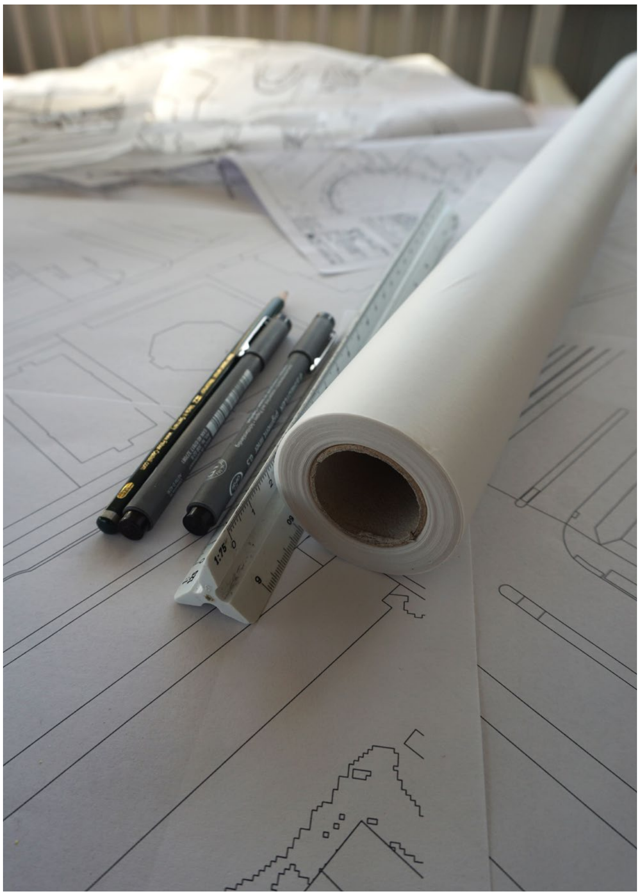


Figure 1.15. showing the material used for sketching

Figure 1.16 showing the material used for building the physical model.

2. LITERATURE REVIEW

2.1 Hydrology

2.1.1 Water cycle

The water cycle is the continual movement of water on Earth, from liquid to vapour to ice in an ongoing cycle driven by the sun. Under natural circumstances water goes through processes of evaporation, condensation, precipitation, infiltration, surface runoff and subsurface flow as shown in figure 2.1 (U.S. Geological Survey, 2016). Evapotranspiration represents the process of water evaporating from soil and vegetation surfaces in combination with plant transpiration during photosynthesis. This is an important process of the water cycle as it highly contributes to the atmospheres water vapour, hence is very important for the formation of precipitation (Narasimhan, 2009).

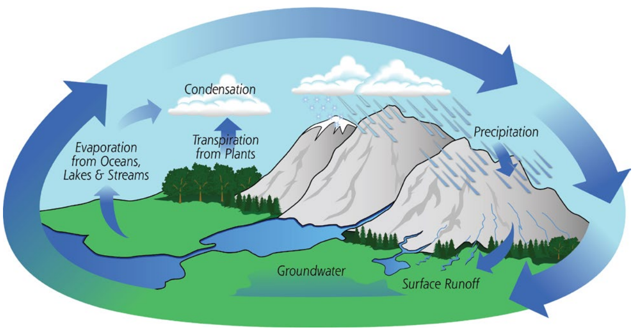


Figure 2.1. The water cycle (Source: https://www.flickr.com/photos/atmospheric-infrared-sounder/8265046380 CC BY 2.0, modified by author).

2.1.2 Water in urban areas

Urbanisation changes the natural conditions to the extent that the water no longer can run its natural course. Due to the large extent of paved surfaces in urban areas the water cannot infiltrate the ground and instead the major part rapidly runs off the surfaces (fig. 2.2). The water flows much faster over paved surfaces and through pipes than it does over natural surfaces and in natural currents. Figure 2.3 shows that both runoff rate (e.g. how fast the runoff is discharged from the site) and runoff volume is increasing considerably as the environment get urbanised. Consequently, the lack of infiltration leads to decreased groundwater recharge and base-flow to rivers and streams. Neither is there much time for the water to evaporate and the low level of vegetation cover highly reduces the evapotranspiration. (Butler & Davies, 2010)

This leads to a warmer and dryer climate within the city compared to surrounding areas, also called the Heat Island Effect (Hoyer et al. 2011).

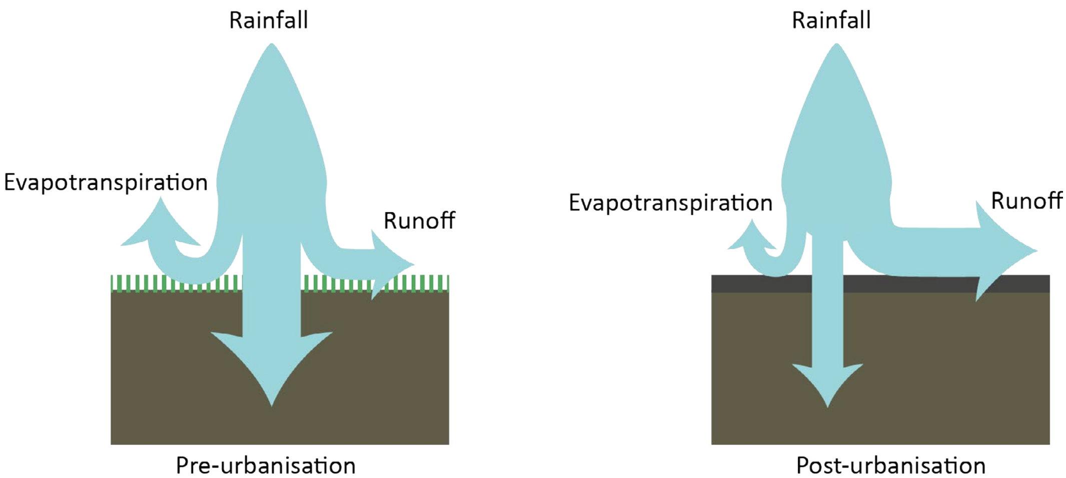


Figure 2.2. The difference between how rainwater operate in non-urban vs urban areas (Remade by author after Butler & Davies, 2010).

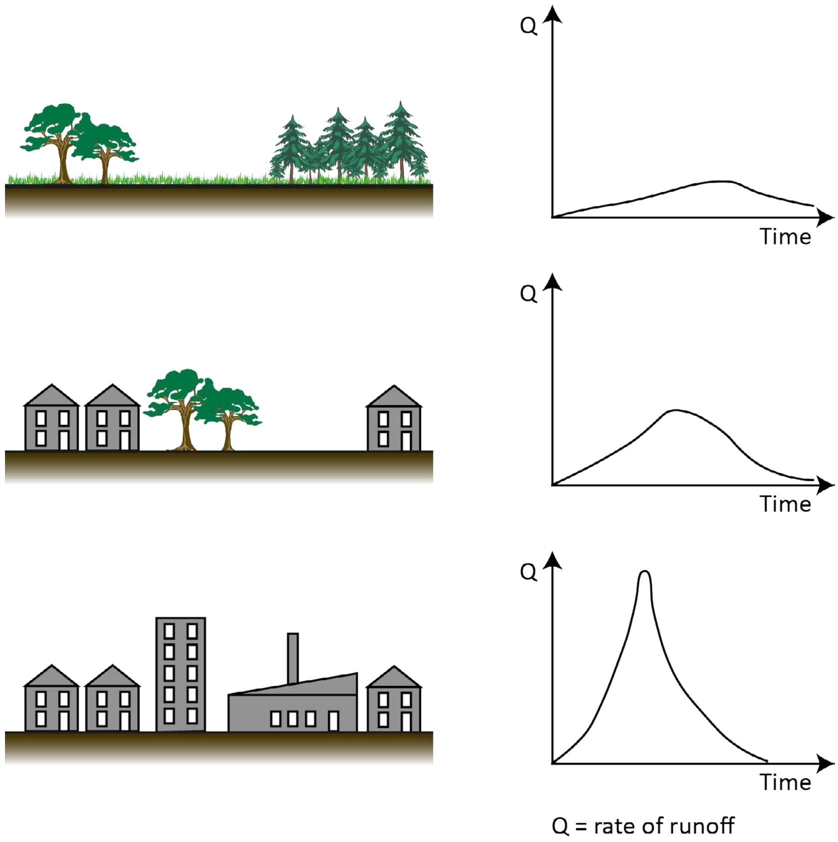


Figure 2.3. Peak flow and runoff in rural, semi-urban and urban environment (Remade by author after Butler & Davies, 2010).

2.2 Wastewater and stormwater quality

Apart from affecting the water cycle, urbanisation also causes issues with pollution and urban surfaces, air and waters is often contaminated with a range of pollutants (Woods-Ballard et al. 2015; Ellis & Hvitved-Jacobsen, 1996; WFD, 2000).

Wastewater contains both organic and inorganic materials and is contaminated by waste from households, companies and industries. The main pollutant sources from households are human excreta and other solids flushed into the toilet, food waste (mainly fats) and detergents from dishwasher and washing machines. From industries there are a considerably larger variety of pollutants and it often contains heavy metals and a lot of chemicals as acids, toxins and bacterials as well as resistant organic compounds. (Butler & Davies, 2010)

Concerning stormwater, the kind of pollutants mainly depend upon the catchment area the water has passed. Traffic, industries, waste incineration etcetera releases many pollutants in the urban atmosphere. From the atmosphere it can then be absorbed and dissolved by precipitation which results in polluted stormwater. It can also settle on urban surfaces and then enter the stormwater when the precipitation hit the surface. Emissions, corrosion and abrasion from traffic also release zinc, hydrocarbons, iron, chromium, lead and metal particles on the roads. Erosion and corrosion from roads and buildings also produces a considerable amount of particles that form sediment in the stormwater. The toxic level of these sediments depends on the condition of the buildings and which materials they consist of. Other sources that contributes to polluted stormwater is salting of roads during winter conditions, animal faeces, fallen leaves and organic litter as well as all kind of trash. (Butler & Davies, 2010)

Stormwater runoff has shown to be one of the leading causes to contamination of receiving waters (Lee & Bang, 2000; Ellis & Hvitved-Jacobsen, 1996). The rapid runoff explained above wash off surface pollutants and rapidly leads them directly to the receiving waters without significant treatment. The highest concentration of pollutants normally peak in the very beginning of the rainfall. This phenomenon is called the first flush and occur since the first runoff flush off all the accumulated pollutants from the catchment surfaces (Lee & Bang, 2000). All receiving waters can to some extent naturally purify its water; however, today's urban areas contribute with pollutant loads that highly exceed this capacity (Butler & Davies, 2010).

2.3 Soil structures and water movement through soil

How water operates in soil and to what extent infiltration is possible or not completely depends on the structure of the soil. The soil is structured as a network where the properties depend on the size and arrangement of particles versus pore spaces within the soil. Table 2.1 is showing the texture of the soil. Finer particles may also group together and create aggregates, hence behave as larger particles. This normally happens in clay soils, resulting in soil structures with high stability that maintain their shape even when saturated with water. This makes these types of soil better at resisting erosion than less stable soils that rather disperses and end up in the water. Less stable soils often have a high content of silt particles. (McIntyre & Jacobsen, 2000)

Table 2.1. Size of soil particle (After McIntyre & Jacobsen, 2000, p.2)

Soil particles	Diameter (mm)
Gravel	>2.0
Very coarse sand	1.0 -2.0
Coarse sand	0.5 - 1.0
Medium sand	0.25 - 0.5
Fine sand	0.1 - 0.25
Very fine sand	0.05 - 0.1

To provide space for air, water and root growth within the soil, it is desirable with big pore spaces between the particles. A well-structured soil with aggregates both has macro-pores between the aggregates and micro-pores inside the aggregates which creates a very good soil for water infiltration and vegetation growth. On the contrary, a soil with densely packed particles leaves very small pore spaces and is hence hard for roots to penetrate and water to infiltrate. (McIntyre & Jacobsen, 2000)

Water moves down through the soil with the force of gravity. However, water adheres to soil particles, and in combination with surface tension, it can be held in small pore spaces instead of moving downwards. The smaller the pores the closer the particles and the water are then held even tighter. Because of this, soils with larger pores are drained quicker than soils with smaller pores. This creates a problem if the topsoil is packed and has a structure with very small pores so that the water is held there instead of infiltrating the subsoil. In that case the water will not enter the subsoil until the topsoil is completely saturated and the force of adhesion and surface tension will let go for the gravity. (McIntyre & Jacobsen, 2000)

In urban areas soils may be heavy packed from cars and machines driving on the surface during construction or even from pedestrians and animals walking on the surface. The time for the soil to recover depends on the weather conditions and how deep the compacted layer stretches. However, even for quite shallow compactions the recovery may take several years. (Kozlowski, 1999)

A compact soil drains slowly and if the soil stays saturated for a long time anaerobe conditions may occur, hence a risk that the vegetation root system dies from lack of air (McIntyre & Jacobsen, 2000).

2.4 Urban stormwater management

2.4.1 Traditional drainage system

Stormwater drainage and sanitary sewer systems have been found as early as ca. 4000 BC in ruins in ancient cities of the Mesopotamian Empire, today's Iraq. Well organized systems were also used by civilizations in the Indus valley as well as the Minoan civilizations ca. 3000 BC. Later on, these systems were further developed by the Hellenes and the Romans. (De Feo et al. 2014)

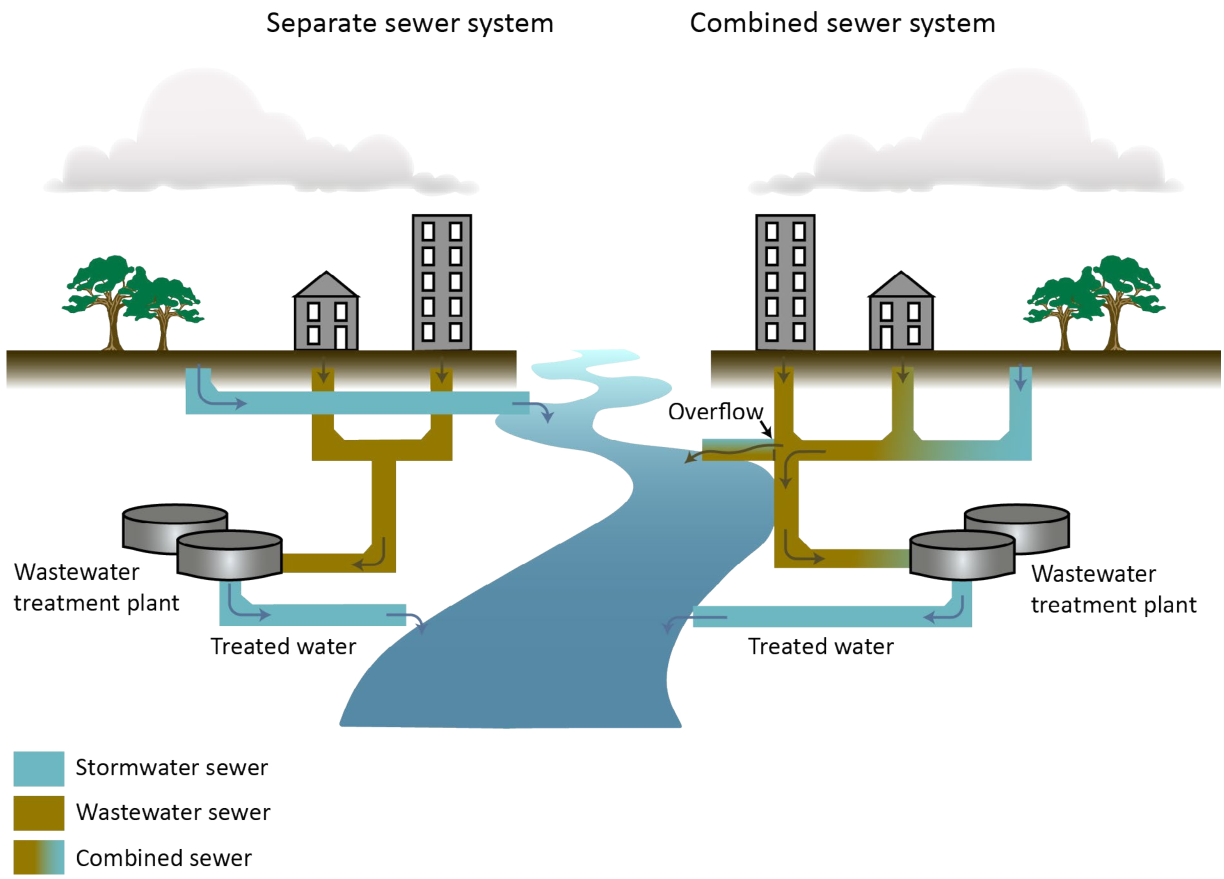


Figure 2.4. Separate versus combined sewer system (By author).

Today the most common systems to manage waste- and stormwater is *Combined sewer system* or *Separate sewer system* (fig. 2.4). The combined sewer system transports both sanitary wastewater and surface/stormwater in the same pipeline while the separate sewer system transports wastewater and stormwater in two separate pipes (Butler & Davies, 2010).

In the combined system the sewer network is dimensioned to meet the capacity of a normal water inflow. However, during rainfall the inflow increases according to the amount of stormwater, and to handle this water and avoid flooding the sewer is provided with an overflow. This is called a combined sewer overflow (CSO) and during heavier rain than normal these systems derives some of the flow from the sewer straight into the nearby watercourses (Butler & Davies, 2010).

Generally, most developed countries over the world recommend separate systems since combined systems have been considered to cause more pollution (Brombach et al. 2005). However, Brombach et al. (2005) states that this is not completely true and that both systems contribute to different kind of pollution. They mean that the separate systems release less biological oxygen and nutrients while the combined systems are way better concerning settleable solids and heavy metal treatment. Similar results are shown by De Toffol et al. (2007). This result is understandable since the main source of heavy metals is surface runoff from roads and in a separate system this water does not pass the treatment plant. In a combined system around 80% of the total water runoff passes through the treatment plant, while in a separate system this is less than 50% (Brombach et al. 2005).

2.4.2 Sustainable Urban Drainage System (SUDS)

As an alternative to these traditional drainage systems, the idea with SUDS is to work towards a drainage system that more closely resembles the natural water cycle (Hoyer et al. 2011). Instead of leading the stormwater to underground pipe systems as fast as possible, the idea is to delay and/or temporarily store the rainwater as close to the source as possible. In that way the water operates more like it does in rural areas (as shown in fig. 2.2 & 2.3 on page 19 & 20) (I.e. more evapotranspiration and infiltration and less runoff volume and lower peak flow) (Stahre, 2004).

Woods-Ballard et al. (2015, p.6) describes SUDS as a concept that “maximise the opportunities and benefits we can secure from surface water management”. In that way, benefits of water quantity, water quality, amenity and biodiversity can be achieved (Woods-Ballard et al. 2015). SUDS often imply to manage the stormwater in open and visible systems over ground, since it in that way also contributes with educational, recreational and ecological values apart from the main function to relieve the sewers (Stahre, 2004). By disconnecting the stormwater from combined sewer systems, and instead manage it with SUDS, combined sewer overflows can be significantly reduced and so also the pollution load that reaches the receiving waters (Semadeni-Davies et al. 2008).

If constructed and maintained correctly, SUDS has shown to be cost-effective solutions to manage urban stormwater in terms of both quantity, quality as amenity values (Kirby, 2005). Sometimes, they may however appear messy and unpleasant for public not used to designs like these, especially if inadequately maintained (Echols, 2007). Promoting awareness about the underlying problems and the benefits of the SUDS concept, can in that case encourage and inspire a change of view (Hoyer et al. 2011).

To achieve a successful SUDS-design, following functions should be promoted:

- Using surface water runoff as a resource.
- Managing rainwater close to where it falls.
- Managing runoff on the surface.
- Allowing rainwater to infiltrate the ground.
- Promoting evapotranspiration.
- Slowing and storing runoff to mimic natural runoff characteristics.
- Reducing contamination of runoff through pollution prevention and controlling the runoff at source.
- Treating runoff to reduce the risk of urban contaminants causing environmental pollution.

(Woods-Ballard et al. 2015, p.9)

However, every design has site specific conditions to consider and the mentioned aims must be seen as guidance to strive to achieve as far as possible rather than an obligation to provide them all.

2.4.2.1 SUDS Management Train

SUDS do not stand for one specific solution itself but works as an umbrella term for different ways to manage stormwater. To achieve optimal result the water normally needs to be treated with a mix of components, e.g. a management train (fig. 2.5). The main components of such systems is: Harvesting systems where rainwater is captured and used within the local area; Infiltration systems that facilitate the waters infiltration capacity into the ground; Pervious pavement systems that allow water to penetrate the material and in that way reduce the surface runoff; Storage systems where runoff volumes are being temporarily stored and slowly released; Treatment systems that facilitate degradation of pollutants in the stormwater; Conveyance systems which is the transfer between the mentioned components and which also can be constructed out of these components. (Woods-Ballard et al. 2015)

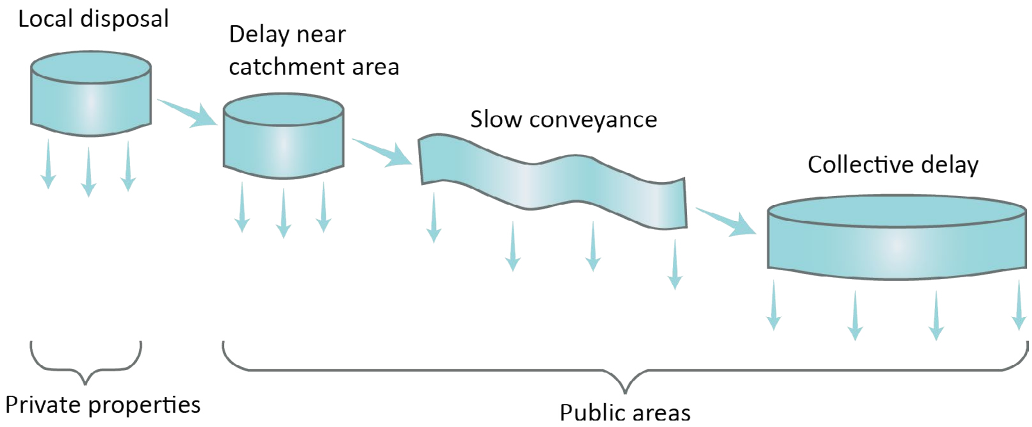


Figure 2.5. Example of how a SUDS-Management train operates (Remade by author, after Stahre, 2004)

2.4.2.2 Role of vegetation

A SUDS design does not correspond to one specific habitat, neither one type of vegetation. A common mistake is to think that the vegetation in these systems should be plants that thrive under wet conditions. However, this is not completely true as the systems will only be filled with water a few times per year and the rest of the time they will be dry. The plants therefore need to survive under both dry as wet conditions. Apart from this, the choice of vegetation should be based upon the site-specific conditions as climate, soil, groundwater table and amount of pollution and salt in the local stormwater. (Woods-Ballard et al. 2015).

By wisely choosing the vegetation there are many benefits with plants that can be utilized in stormwater management. One way is through interception of the rainwater. With its leaves and branches, trees and shrubs catch a lot of water and let it evaporate which consequently reduce the amount of water that reaches the ground (Armson et al. 2013). This delays the runoff peak and reduces the runoff volume. Vegetation in the city also contributes with evapotranspiration and shadow, which decreases the temperature and the heat island effect (Hoyer et al, 2011). The root system of plants also creates channels into the soil which facilitate and thereby increase the infiltration (Bartens et al. 2008). At the same time vegetation is important for pollutant removal of stormwater as it provides efficient treatment through processes of degradation of organic pollutants, uptake of nutrients and heavy metals as well as sedimentation of contaminants and heavy metals (Read et al. 2008). To maximise the effect Read et al. (2008) advices a mixture of species since different plants are efficient for removing different pollutants. To avoid problems with algae in the SUDS, vegetation that requires very nutritious soils should be avoided close to the systems (Malmö stad, 2008). Vegetation can also have a positive effect on urban air quality by filtering the air as well as dispersing and deposing particle pollutants (Janhäll, 2015). To achieve this, Janhäll (2015) mention species with hairy and waxy leaf surfaces to be most effective. A variation of plant species can also contribute to a wide range of habitat types, hence a rich biodiversity (Woods-Ballard et al. 2015). Native species that benefit wildlife should be chosen to the extent possible and invasive species should be avoided (ibid.) Finally, vegetation contributes with aesthetic values that is appreciated in the urban denseness and which also have positive effect on human health since it can relieve mental stress (Gascon et al. 2015).

2.4.2.3 Examples of SUDS

SUDS can be designed in many different ways depending on local requirements. Below the most common systems are explained.

Green roofs

A green roof is a traditional roof equipped with a vegetated system to manage stormwater (fig 2.6 & 2.7). A green roof's ability to absorb and retain stormwater depends on the drainage layer, the substrate, the vegetation, the roof slope, the roof size and the season and climate (GSA, 2011). Depending on the substrate depth, these roofs are classed as extensive or intensive. Extensive green roofs have a substrate layer of <150 mm and are planted with moss-sedum or sedum-herb vegetation while intensive green roofs have a substrate layer of >150 mm and hence can be planted with grasses, perennials and shrubs (Mentens et al. 2006). Intensive green roofs are more effective in reducing the runoff than extensive green roof since their thicker substrate layer can store more water (Mentens et al. 2006; Woods-Ballard et al. 2015). The vegetation on green roofs can also absorb air and rainwater pollutants, resulting in better air and water quality in the city (GSA, 2011). A thicker substrate depth and larger plants provide greater carbon sequestration, but sedum species are mentioned as especially good at absorbing and storing levels of heavy metals (ibid.).

Figure 2.6 showing a green roof in Malmö.

Figure 2.7 showing a green roof in Augustenborg, Malmö.

Rainwater harvesting

During rainfall, stormwater can be collected from roofs or other surfaces and stored in barrels or cisterns (fig 2.8 & 2.9). In this way the runoff volume from the site is reduced (Ahiablame et al. 2013). The good thing is that the collected water then can be used during dry periods for garden irrigation or other domestic tasks that do not require purified water (Woods-Ballard et al. 2015).

Figure 2.8 showing rainwater harvesting in a barrel at a private housing in Wageningen, Netherlands.

Figure 2.9 showing rainwater harvesting in Rotterdam, Netherlands.

Pervious pavements

Compared with normal pavements the pervious pavements allow rainwater to infiltrate through the surface (fig. 2.10 & 2.11). This can be done with porous material as porous concrete or asphalt or reinforced grass or gravel pavements. It can also be done with normal impervious materials but where the joints in between the blocks are widened and optimised to infiltrate the stormwater (Woods-Ballard et al. 2015). Since a major source of the problems with urban stormwater is the large extent of paved surfaces the implementation of pervious pavements can provide a remarkable reduction of runoff volume (Ahiablame et al. 2013). Even over impermeable subsoils with slow infiltration rate the pervious pavement have shown to be effective (Fassman & Blackbourn, 2010). As the water filters through the medium and geotextile layers it also reduces the amount of pollutants discharged to receiving waters (Ahiablame et al. 2013; Fassman & Blackbourn, 2010).

Figure 2.10 showing permeable pavement at a parking lot in Malmö.

Figure 2.11 showing permeable pavement as a path to cross a swale in Rotterdam, Netherlands

Figure 2.12 showing a rain garden in Rotterdam, Netherlands.

Bioretention - rain gardens

Rain gardens are vegetated depressions in the ground where the stormwater accumulates and temporarily pond before evaporating, transpiring from the plants, and infiltrating the soil (fig. 2.12 & 2.13) (Woods-Ballard et al. 2015). In this way the system reduces both runoff rate and volume as well as treats polluted waters if right soil and vegetation is selected (Yang et al. 2013; Davis, 2007; Davis, 2008). Usually bioretention systems are mounted with an overflow drainage so that the water only rises to the desired maximum level before it is discharged to the pipes (Woods-Ballard et al. 2015).

Figure 2.13 showing rain gardens that collect stormwater from a street in Malmö.

Figure 2.14 showing a bioswale in Wageningen, Netherlands.

Bioswales

Bioswales are shallow vegetative ditches that collect and convey stormwater (fig 2.14). In the same way as rain gardens both runoff rate and volume are reduced through evapotranspiration and infiltration (Davis et al. 2012). These systems are especially efficient reducing runoff from smaller rain events while their performance handling larger events depend on the storage capacity and length of the swale (ibid.). Swales also improve the stormwater quality through sedimentation and filtration when the water slowly convey through the vegetation in the swale (Mohamed et al. 2014).

Filter trenches

Filter trenches basically works in the same way as bioswales, but the base of the ditch is filled with gravel (fig. 2.15 & 2.16). In this way the runoff rate slow down and storage capacity and infiltration increase (Woods-Ballard et al. 2015). These systems have shown to be efficient treatment of especially heavy metals and fine sediments, but less suitable when it comes to nutrient removal (Hatt et al. 2007). If the surrounding soil have poor infiltration capacity the trench can be equipped with an underdrain to assist drainage and conveyance towards receiving waters (Woods-Ballard et al. 2015). Filter trenches works best in the end of the management train so that the stormwater has passed through a vegetated bioswale first and in that way been pre-treated of the largest sediment and pollutant load (ibid.).

Figure 2.15 showing a filter trench in Augustenborg, Malmö.

Figure 2.16 showing a filter trench in Höganäs.

Detention basins

A detention basin, also called “flood storage basin”, is a larger depression in the ground that collects the stormwater during bigger rainfalls (fig. 2.17 & 2.18). In that way the runoff rate delays and, depending on design, the runoff volume reduces. The basins can be both vegetated or hardscaped. However, if made entirely hardscaped they only work as temporary storage and do not provide any infiltration or treatment of pollutants as the vegetated ones does. Normally these basins work as multifunctional areas for recreation during dry days or when the precipitation is low. (Nascimento et al. 1999; Woods-Ballard et al. 2015)

Figure 2.17 showing a hardscaped detention basin at a schoolyard in Augustenborg, Malmö.

Figure 2.18 showing a grass-covered detention basin in Höganäs.

Figure 2.19 showing a wetland in Wageningen, Netherlands.

Figure 2.20 showing a pond in Wageningen, Netherlands.

Ponds and wetlands

In comparison with other mentioned SUDS-designs, ponds and wetlands are permanently wet (fig. 2.19 & 2.20). Consequently, they can reduce peak flows but have limited impact on runoff volume reduction since the only reduction occur through evapotranspiration (Al-Rubaei et al. 2016). However, these systems are specifically good in treating incoming stormwater pollutants through biological processes and settling of suspended sediments (ibid.). To avoid turbid and smelly water these systems works best as a final polish of the stormwater in the end of the management train (Woods-Ballard et al. 2015). One advantage with a permanent water body is the positive addition for recreation and amenity in the city as well as increased biodiversity (Ibid.).

2.4.2.4 Biodiversity

"Biodiversity is the variety of life on Earth. It includes all organisms, species and populations; the genetic variation among them; and their complex assemblages of communities and ecosystems."

(SCBD, 2018, online webpage)

Urbanisation can cause a decreasing biodiversity as the vegetated areas are replaced with paved surfaces and the disturbance of people and traffic increases. Human introduction of invasive species is also a major threat (Gurevitch & Padilla, 2004). In extremely dense areas the species-richness almost always decreases while in suburban areas it is not always the case (McKinney, 2008). To turn this trend, SUDS-designs can be a complement in urban areas that contribute to increased biodiversity (Kazemi et al. 2009; Levin and Mehring, 2015). A SUDS-design can be constructed to cover a wide range of habitats, hence a high species-richness. Advantageously, the edges and bottom of swales and basins can be designed irregular and bumpy, hence provide a favourable environment for a variety of plants and animals (Malmö stad, 2008). Especially gravel and leaf litter provide shelter for many species and should not be removed (Kazemi et al. 2009).

2.4.2.5 Health and safety risks with SUDS

Designing with water in urban areas brings some issues with health and safety risks that must be considered.

As explained above, stormwater may be highly contaminated and pose a human health hazard. Sales-Ortells and Medema (2015) investigated this at a water plaza in Rotterdam and found a significant health risk for children playing in the water at the plaza due to contaminations in the water. To prevent this, they recommend disinfecting the basins after heavy rainfalls and to keep the catchment areas clean. Important is also to inform the residents in the surrounding about the importance of collecting faeces from their dogs which is a major source of water contamination.

Water in the city may also pose a safety hazard, especially for small children that risk to drown, but water can also make surfaces slippery and cause falling accidents. Therefore, steep slopes and slippery materials should be avoided. Swedish guidelines recommend gentle slopes with a maximum 1:6 slope and a water depth below 20 cm close to the edges (MSB, 2013). Echols & Pennypacker (2008) also stress the safety precaution to limit the water depth but also to limit the water movement by adding obstacles as terraced weirs and stones as well as giving the swales meandering shapes. They also recommend limiting the physical access to the water. However, at every project the site-specific risks must be identified. To put a fence around every water-body is not always the best option since it blocks the sight and supervision as well as creates an aggravating barrier if someone needs to be rescued (Woods-Ballard et al. 2015). Instead, good lightning, signs and rescue equipment should be placed where necessary to provide a safe environment (ibid.).

3. REFERENCE OBJECTS

3.1 Benthemplein, Rotterdam

3.1.1 Background

Benthemplein is located in the northern part of Rotterdam, in the Agniesebuurt neighbourhood. It is a 5500 m² plaza, surrounded by a college, a graphic design school, a dance school, a theatre, a church, a gym and residential apartments. It is a very hardscaped area and needed some redevelopment at the same time as the Waterplan 2 Rotterdam was confirmed. This made it a suitable place to design the first large-scale water plaza of Rotterdam.

The design-process of the project started with participatory workshops where people from the surrounding buildings shared their opinions and desires concerning the new design. This resulted in a common will about a dynamic square with open space for play, green intimate places to relax and visible water. (Urbanisten, 2018)

The final design was constructed in 2013 and

Figure 3.2 showing the smaller detention basin.

Figure 3.3 showing the smaller detention basin with a stage designed to work as a dance floor.

Figure 3.1. The biggest detention basin at Benthemplein that works as a sport field during dry days.

is a multifunctional space with hard surface detention basins to collect the local stormwater (fig. 3.1 - 3.3).

3.1.2 Design and function

The designers at Urbanisten (2018) describe the plaza as with two main functions; a great experience for visitors as well as efficient stormwater management. Concerning user experience and recreation the plaza delivers lots of place for sports such as football, volleyball, basketball and skating, but also activities as outdoor theatre and dance. The plaza is predominantly hardscaped but still have some green spots with seating to relax.

As it is a water plaza the whole design is inspired by water and focuses on showing the waters way as much as possible. Urbanisten (2018) describes this as a way to make water management and the money invested in it visible to the public instead of hiding it under ground. In that way it contributes with both functionality as an aesthetic value that empowers the design and the users experience of the place.

When the rainwater falls over the surfaces it is first collected in open stainless-steel gutters that transports it further on to the detention basins. The plaza consists of three hardscaped basins; two shallower (fig. 3.2 & 3.3) and one deeper (fig. 3.1). The shallower ones will receive rainwater every time it rains while the deeper one only receives water at heavier rainfalls. Stormwater from surrounding surfaces and roofs outside the plaza are also diverted into the basins from where the water then filters through an underground infiltration system before it slowly percolates to the groundwater (fig.3.4). To maintain public health, the deeper basin is constructed with a system that, after 36 hours, releases the water to the city's open water system at the close by canal Noordsingel. The total water storage capacity in the plaza's basins reach 1700 m^3 and Urbanisten (2018) means that the majority of the plaza will be dry and usable for about 90% of the year and it will only be really wet about once a year and entirely filled about once every 10 year (Urbanisten, 2018).

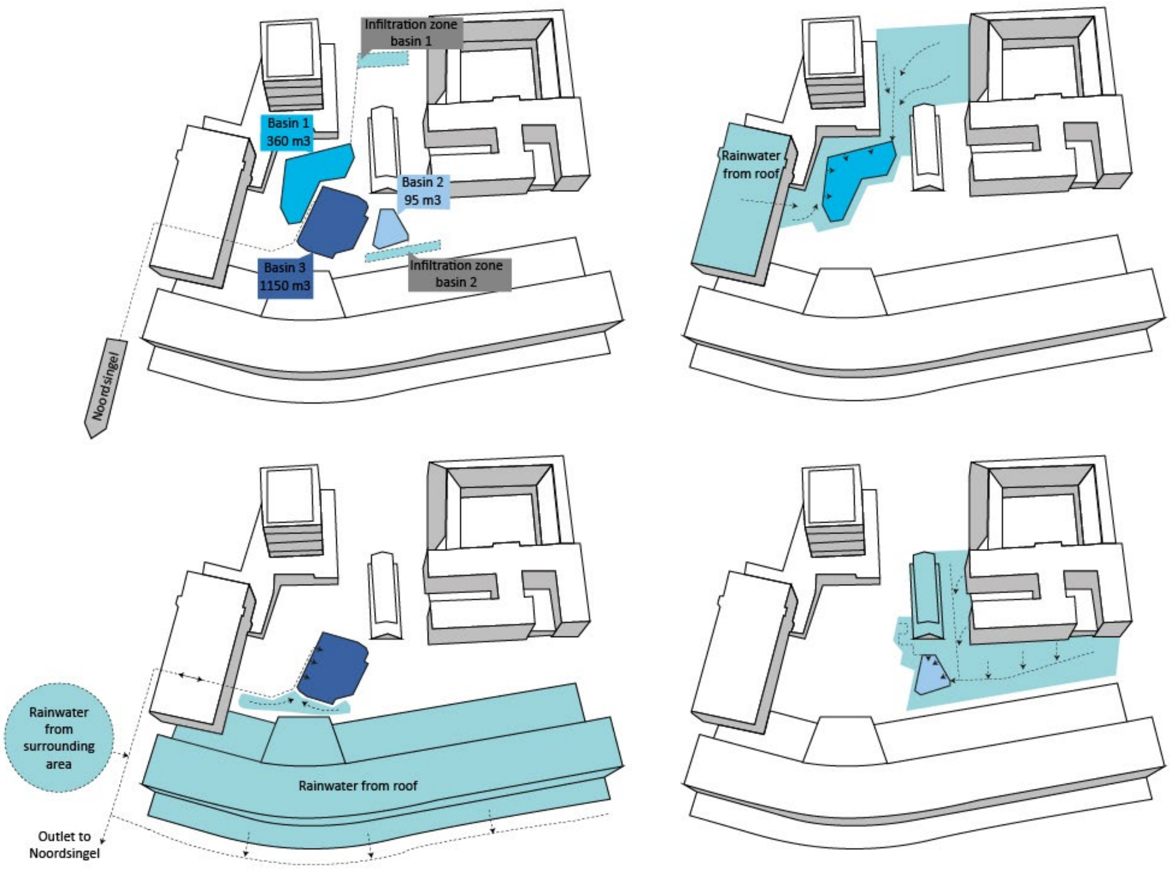


Figure 3.4. Catchment area and water movement to the different basins (Remade by author, after Urbanisten, 2018)

3.1.3 Analysis and reflection

Benthemplein directly strikes you as a different kind of plaza. The blue concrete basins and immersed sports field in combination with stainless steel gutters differs from the usual. It attracts activity and feels like a nice place to hang out for younger people. In night time the basins and gutters are illuminated with white and blue lighting that gives an attractive impression to the place and contribute to a safer feeling (fig. 3.5). However, it has been surprisingly few people at the site both during the visits and observed through the live streaming web-cam. People have been observed hanging outside the school during daytime and outside the theatre at the evenings, but few people have used the square for sport activities. The plaza feels very hardscaped and considering its big size it could have been greener. More vegetation may have contributed to higher biodiversity and better air quality. Aesthetically, more greenery could also contribute to a more welcoming and peaceful impression, even though that is a matter of personal opinion. Conversations with responsible people at Urbanisten and Rotterdam municipality revealed that infiltration was not possible at the site, hence concrete basins was the most suitable solution. They also claimed that the plaza functions the way it was designed to do and can handle the amount of stormwater it is supposed to. At the same time the designers have succeeded very well with arousing curiosity about the water movement over the square. Educational signs help explain the plazas different parts and their purpose. Unfortunately, it didn't rain any of the days the place was visited, and a live experience of the water movement was not possible. Interesting ornaments adorn the plaza, like for example the *water wall* (fig. 3.6) from where the stormwater flows out like a waterfall when entering the detention basin. A big minus that lowered the impression was the amount of rubbish and sediment at the bottom of the basins and stuck in the gutters (fig. 3.7 & 3.8). From the web-cam over the plaza it has been observed that a layer of sediment covers the basins after every rainfall and that it takes several days before this is removed. This even though the stakeholder at Rotterdam municipality explained it to be their icon project and hence top priority to maintain and keep clean.
The SWOT-analysis is concretised in table 3.1.

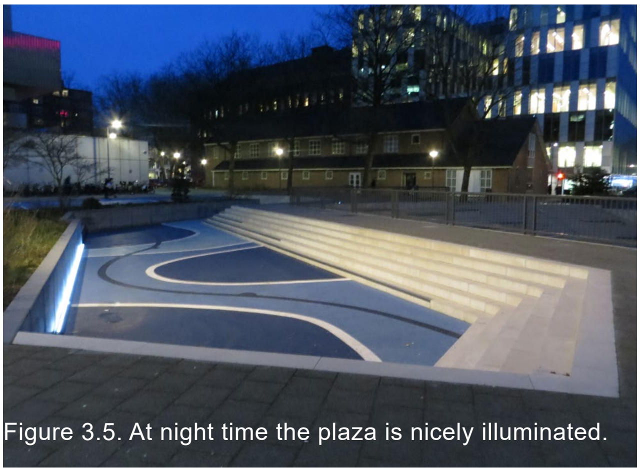


Figure 3.5. At night time the plaza is nicely illuminated.

Figure 3.6 showing the water wall froom where stormwater is entering the detention basin.

Figure 3.7 showing a lot of sediment and rubbish stuck at the bottom of the gutters.

Figure 3.8 showing a lot of sediment and rubbish stuck at the bottom of the basins that in clean condition is colored blue.

Table 3.1 showing the SWOT-analysis for Benthemplein.

STRENGTHS	WEAKNESSES
Lot of place for activities	Hardscaped
Accessible	Lack of vegetation - not contributing to biodiversity
Can store big amount of water	Lots of rubbish
Educational - arouse curiosity	Hard to maintain/clean
Fun	Not used by so many people
Nice lighting at night	

3.2 Tåsinge Plads, Copenhagen

3.2.1 Background

Tåsinge Plads is located in the northern part of Copenhagen, in the Østerbro neighbourhood. It is Denmark's first climate-adapted urban plaza and covers an area of 7000 m² surrounded by residential apartments.

Before the redevelopment in 2014 the neighbourhood had suffered from several basement flooding and Tåsinge Plads was mainly paved with asphalt and used for car parking, except for a small green area mostly used as a dog's toilet (GHB Landscape Architects, 2014). The new design (fig. 3.9 - 3.11) is a green oasis in the neighbourhood that manages - and even welcome - heavy rainfalls.

3.2.2 Design and function

The idea with the plaza is to tell the story of the waters natural cycle and to shape the urban environment based upon the logical behaviour of nature and human beings. The plaza combines advanced stormwater management with lush greenery that attracts people and has become a new local meeting place. The design is a result from several dialogues and sub-projects with residents of the area as well as local artists. (Klimakvarter, 2015)

Figure 3.9. Tåsinge Plads is called an oasis for its lush greenery.

The plaza is designed to let the rainwater travel logically from the highest level to the lowest. This is divided into the three areas; the Sun slope, which is the highest, driest point; the Plaza in the centre; and the Rainforest which is the lowest, wettest point (fig. 3.12). In this way, all water that falls on the square's surface runs towards the lowest point where it accumulates and slowly infiltrates (fig. 3.13).

The plaza in the middle is nicely decorated to emphasize the square's focus on rainwater. This is done with sculptures of rain parasols and water drops which are not just aesthetically pleasing but also fills a stormwater management function. The rain parasols are like huge upside-down umbrellas that collect rainwater and also provide shelter when it rains and shade when the sun shines. The rainwater that falls on the roofs on the surrounding buildings is diverted to a purification system and then collected in a big underground reservoir right underneath the big water drop sculptures (fig. 3.14). These water drops work like playground equipment from where you can pump up the collected water and make it run over the surfaces towards the Rainforest. This feature makes the stormwater visible and able to play with safely.

Figure 3.10. The plaza have several vegetated detention basins that collects the local stormwater.

Figure 3.11. The lowest detention basin is called the "rainforest" and is where all the stormwater finally accumulates.

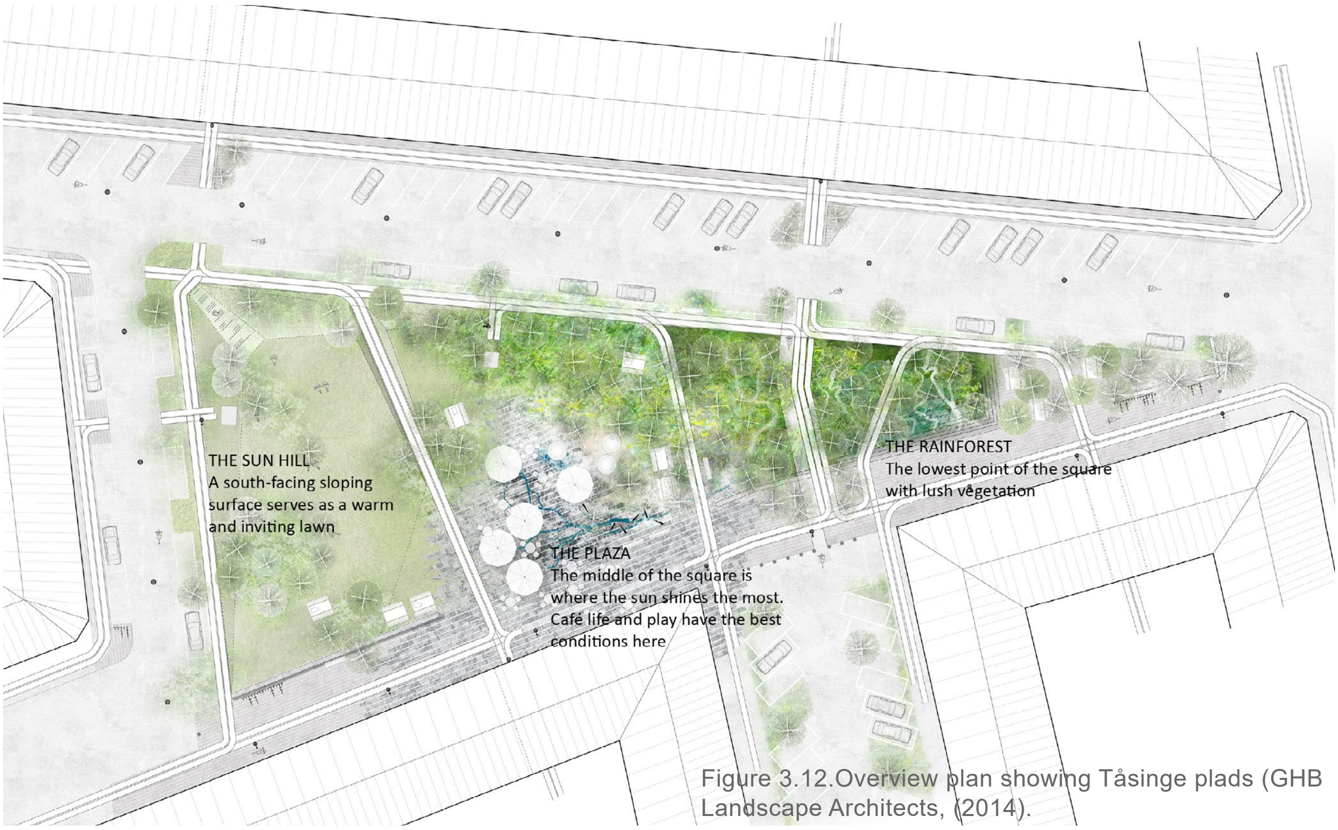


Figure 3.12.Overview plan showing Tåsinge plads (GHB Landscape Architects, (2014).

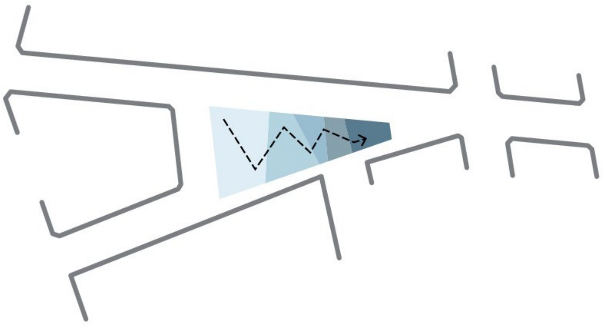


Figure 3.13. Water movement at the square (GHB Landskabsarkitekter & Malmo Landskaber, 2013).

Stormwater from the streets will be managed separately due to the amount of pollution and salt in this water that otherwise may reach and contaminate the groundwater. Instead of leading it further into the plaza it will therefore be diverted into trenches along the street sides where it filters through a special filter substrate.

The final detention basin - the Rainforest, is a combined drainage and delay basin where the drainage time and maximum water level allowed is adjustable. The basin is dimensioned to manage a storm event of 300 mm (GHB Landskabsarkitekter & Malmo Landskaber, 2013). According to Klimakvarter's (2015) calculations the basin will be 10% filled with water about once a year and 30% filled once every 25 years, 40% once every 100 years and it will only be totally filled up once every 500 years.

3.2.3 Analysis and reflection

The plaza is explained as a green oasis between the buildings. Unfortunately, this summer has been extremely dry and most of the vegetation was nearly dead and the "oasis" more yellow than green (fig. 3.15). However, it was easy to imagine how it could look like during wetter times of the year. At the square it felt inviting to sit down under the trees or at the stairs facing the basins. The playful design with the water drops and big umbrellas and wave-shaped bench gave a fun and decorative impression (fig. 3.16 & 3.17). This area is also the most suitable for children to play since the rest of the plaza is dense with vegetation and not offering open spaces for activities. The slopes facing the basins are also quite steep and may pose a danger for small children.

At first sight the square may look just like a regular green square and its water holding ability may be a bit invisible for a visitor that have not heard about the place before. However, the plaza is equipped with educational signs explaining the concept and main functions and after a walk through it you get the idea. Conversations with the designers at GHB Landskabsarkitekter revealed that the plaza even exceeds the expectations and can handle more stormwater than they counted on. They also said that the new design was very appreciated by the neighbours and they had not received any complaints.

Tåsinge Plads was never visited during night time and its lighting could not be observed.

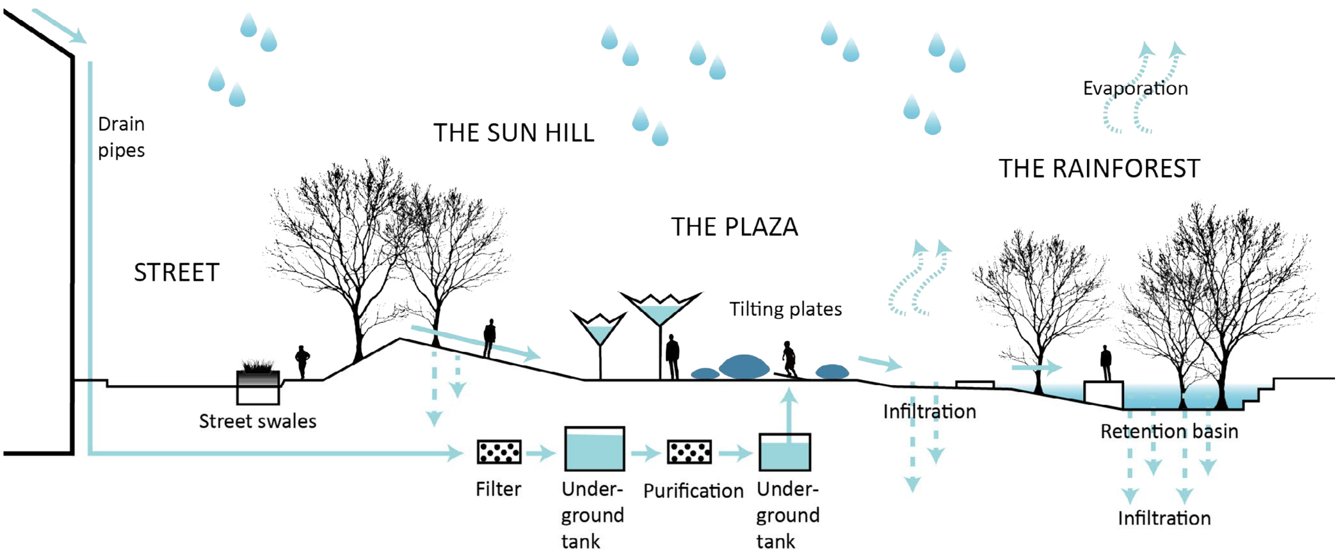


Figure 3.14. Section of the square (Remade by author, after GHB Landskabsarkitekter & Malmo Landskaber 2013).

Figure 3.15 showing the dry street swale.

The SWOT-analysis is concretised in table 3.2.

Figure 3.16 showing the umbrellas and water drops.

Figure 3.17 showing the wave-shaped bench.

Table 3.2 showing the SWOT-analysis for Tåsinge Plads.

STRENGTHS	WEAKNESSES
Green and lush	Limited space for activities
Biodiversity	Hard for vegetation to resist trampling
Decorative and fun ornaments	Steep slopes - can be dangerous
Peaceful	
Educational - arouse curiosity	

3.3 Concluding thoughts reference objects

Benthemplein and Tåsinge Plads show two very different approaches to manage the same problem. Benthemplein is hardscaped and feels a bit stiff and technical while Tåsinge Plads is vegetated and reminds more about natural conditions. Both approaches require advanced engineering but at Benthemplein it is more visible than it is at Tåsinge Plads. Both places seem to value the importance of communicating their message to the public by adding signs that explain the water movement over the plazas. This indicates that the plazas have a pedagogical intention as well, which was also confirmed through the dialogues with both designers. The water movement is more visible at Benthemplein (if it rains) since it runs over hard surfaces and not through vegetation as in Tåsinge Plads. This makes Benthemplein better at communicating the message even during dry days and without reading the signs. Tåsinge Plads may look like an ordinary green neighbourhood square. However, Benthemplein lack the perspective of biodiversity and miss out on that message. Benthemplein detention basins are more adapted for sport activities during dry days when Tåsinge Plads is vegetated and more suitable to just sit down and admire. Maybe dogs and children can play spontaneously in the vegetation as well, but the place does not invite for sport activities as Benthemplein does.

Both places have fun ornaments that add a lot of aesthetic value and increases the curiosity awakening at the places. At Tåsinge Plads the ornaments feel impressive and really add character to the place when at Benthemplein they are subtler. Benthemplein instead let the colourful basins and open gutters stand for the aesthetics, which is impressive as it is. However, to be able to see the colourful bottoms of the basins it requires clean surfaces. Just as all public places, both plazas have problems with trash as well as sediment after rainfalls. At Benthemplein it is more visible against the concrete surfaces than it is at Tåsinge Plads in between the vegetation. Tåsinge Plads have the advantage that the vegetation makes the place appears fresh and green (or yellow if dry as this summer) even if it has some sediment at the bottoms. Benthemplein however directly turns into an entirely grey surface when the sediment covers the blue surfaces in the basins. One advantage with this hardscaped solution may be that it can be easier to clean a concrete surface than a vegetated one. It however may require more frequent maintenance.

To conclude, both places have their strengths and weaknesses, and which one is the most suitable option depends upon the conditions at the site. No matter what, both places definitely serve as multifunctional plazas that manage the local stormwater as well at provide recreation for the neighbourhoods and can be seen as good examples of existing water plazas.

4. CASE STUDY SÖDERVÄRNSPLAN

4.1 Background

Malmö is facing large scale growth that will imply a densification of the city (Stadskontoret, 2017; Malmö stadsbyggnadskontor, 2010). This puts a high pressure on the already stressed sewer system in the city. As shown in figure 4.3 (p. 41) the large areas of combined sewer systems in Malmö is a problem and result in especially vulnerable areas that tend to flood after heavy rainfalls. Södervärnsplan is placed within one of these areas and flooding have been common in the surrounding neighbourhoods. Södervärnsplan however provide an open space without too many obstacles underground that make it suitable for implementing SUDS. With its hardscaped surroundings the place was considered suitable to achieve the objective of this research.

4.2 Terrain and geology

The terrain of Malmö is very flat (fig. 4.1), and in addition, most of the surface consists of dense moraine clay soils with low infiltration capacity (fig. 4.2) (Malmö stad, 2008). Thus, it is of great importance to create waterways that collect and convey the stormwater runoff on the surface, away from buildings and infrastructure. The municipality strives towards reducing the paved surfaces in the city and increasing the amount of vegetation and big trees in order to increase the evapotranspiration (Malmö stad, 2018).

Figure 4.1. Surface model showing the terrain elevation of Malmö. The elevation in the city centre shift between 5 and 15 meters above sea level with lower closer to the beach and higher more inland (By author).

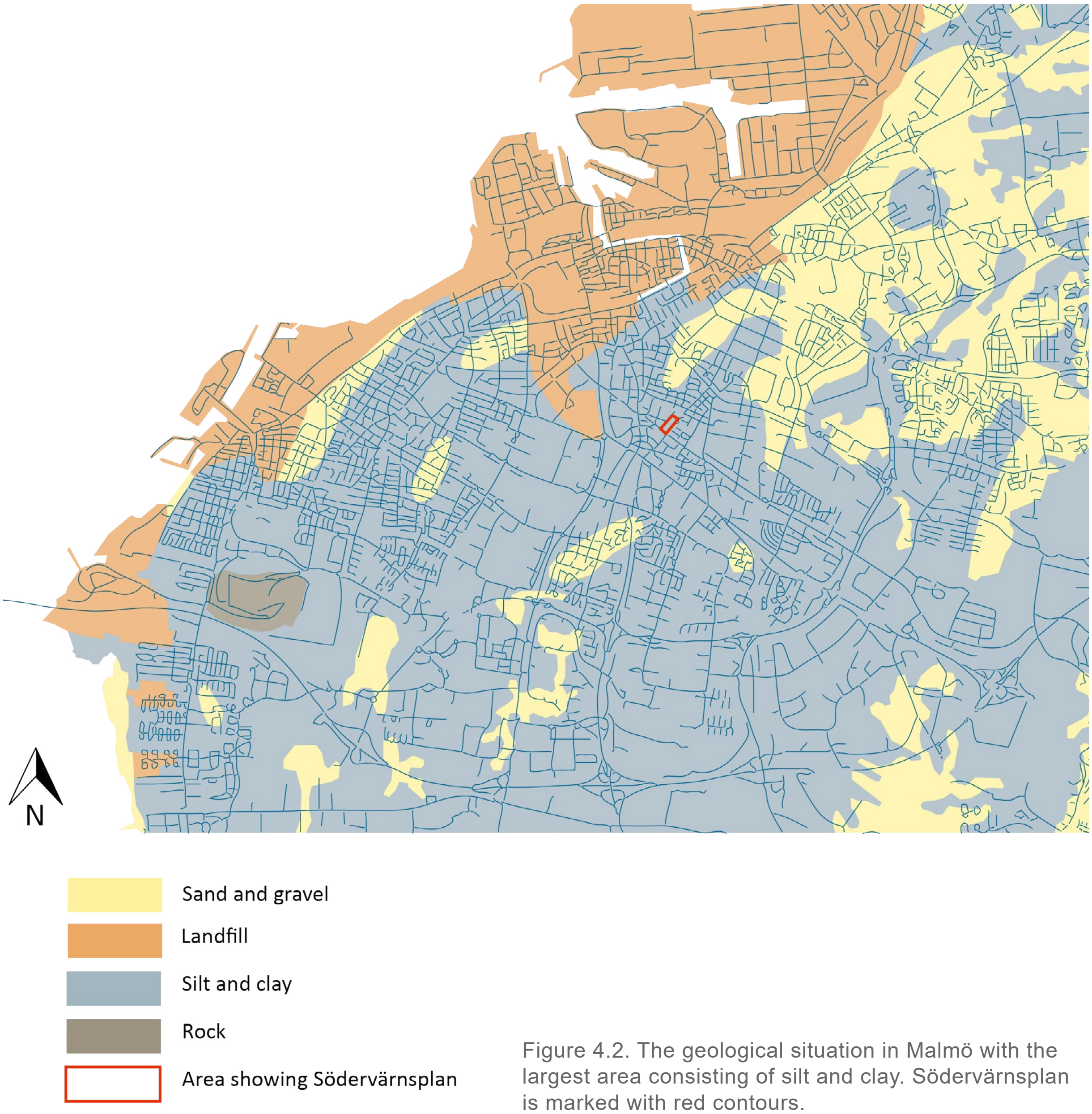


Figure 4.2. The geological situation in Malmö with the largest area consisting of silt and clay. Södervärnsplan is marked with red contours.

4.3 Water management in Malmö

After the industrial revolution Swedish cities got rapidly urbanised and a combined sewer system for waste- and stormwater was the recommended approach. However, from the 1950's this has been changed to a current standard of separate systems (Semadeni-Davies et al. 2008).

In Malmö the city consists of both combined and separate sewer systems (fig. 4.3). Mainly the older central parts are still a combined system while newer settlements have a separate system or a combination of both. According to VA SYD (2017) urban flooding mainly occur in the areas where a combined sewer system is operating but problems occur within the separate systems as well. Figure 4.3 also shows the areas that flooded after the rainfall in August 2014 and it is clear that many of these areas is within the area with combined sewer system.

The capacity of the pipes and receiving waters is already limited, and are put under further strain by new constructions that connects to the system (Malmö stad, 2008). Hence, it is a necessity to reduce the flow of stormwater run-off that reaches the pipes.

The municipality considers it a high cost to reconstruct the existing sewer-system and that it would cause physical disturbance in the city (Malmö stad, 2018). Instead, they recommend complementing the existing sewer system with

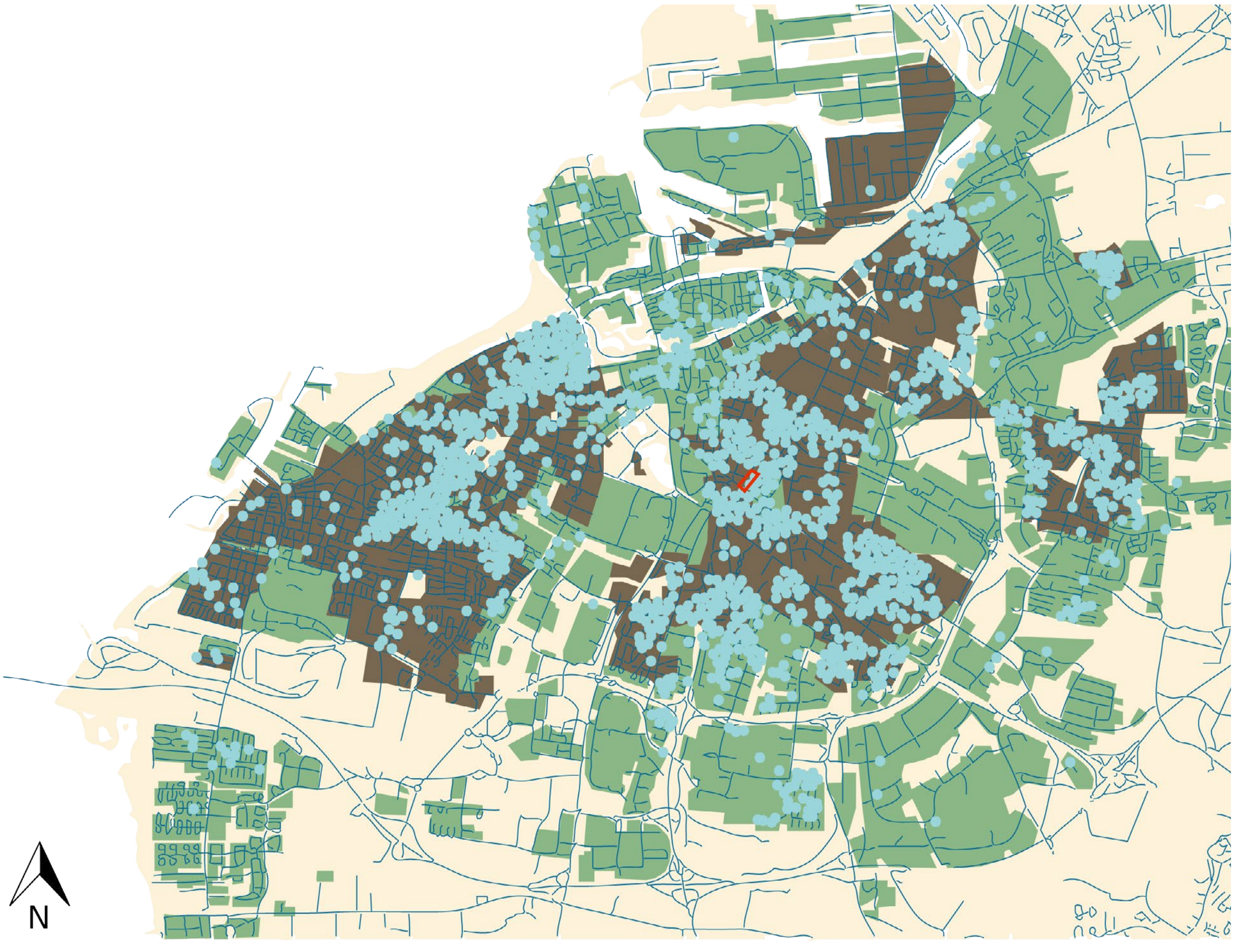


Figure 4.3. Separate sewer system (green) and combined sewer system (brown) in Malmö. The blue dots represent every reported flooding in August 2014. Södervärnsplan is marked with red contours. (Remade by author, after VA SYD 2017)

open stormwater systems that delay and treat the water as close as possible to where it falls. At the same time, they promote this as a strategy that adds aesthetic, pedagogical and ecological values to the environment.

According to Malmö stad (2008), open stormwater systems that aim to collect and convey stormwater (e.g. bioretention swales, filter strips, rain-gardens, detention basins or ponds) should be designed as follow (fig. 4.4):

- The slopes should be shallow with a slope ration between 1:4 – 1:20.
- At 50 cm distance from the shoreline the water depth should not exceed 20 cm.
- Maximum water depth of the construction should not exceed 1 m.
- The construction should not be fenced but safely constructed and available for children.
- Vegetation should be selected based upon site specific conditions to favour biodiversity and water purification.

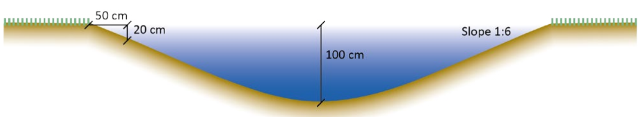


Figure 4.4. Conceptual figure showing Malmö Stads guidelines for construction of open stormwater systems (By author).

4.4 Södervärnsplan

4.4.1 History

The construction of the water tower at Södervärnsplan was completed year 1916, 54 meters high. It managed to alone provide the citizens of Malmö with water for about 30 years but was taken out of service in 2015 and has been empty ever since (Sydsvenskan, 2015-06-27).

Figure 4.5 show the square in the beginning of 1930s when it was just an open space with lawn and gravel. In the late 1930´s a paddling pool was constructed right outside the water tower. The pool got the name “The Southern sea” (Söderhavet) and was very popular for families during hot summer days (fig. 4.6). Due to bad conditions and new regulations for water quality the pool was removed in 2010 and replaced with a sports field (Sydsvenskan, 2015-06-27).

Figure 4.6 showing the paddling pool at Södervärnsplan year 1941 (Photo source: HD-Sydsvenskan, with rights to use).

4.4.2 Existing design

The area that today is called Södervärnsplan covers 6000m² and is surrounded by cotoneaster hedges and fences (fig. 4.7). At the northern edge an asphalt parking lot hides underneath the tree-tops of six big tilia trees. The area that surrounds the water tower consists of gravel and some benches and waste baskets. In the middle part, one big salix tree is planted and the sports field with artificial grass is placed. The sports field is enclosed with fences and surrounded with a concrete path. The southern

Figure 4.5 showing the water tower at Södervärnsplan year 1934 before the paddling pool was constructed (Photo source: HD-Sydsvenskan, with rights to use).

igure 4.7. Map showing existing design at Södervärns-lan (By author).

part of the park is covered with lawn and some shrubs and bigger salix trees. Along Nobelvägen and Spårvägsgatan, lines with smaller tilia trees are growing next to the sidewalks.

Figure 4.8 – 4.12 shows how the place looks like.

4.4.3 Analysis and reflection

The lively and popular Södervärnsplan as shown in the picture from 1941 (fig. 4.6) is not the place that meets you today. Today it feels neglected and gives an empty and abandoned impression. The hedges and fences that surrounds the park (fig. 4.9 & 4.12) makes it enclosed in a way that prevents you from entering spontaneously and if you entered it makes you feel trapped. It may be suitable for the dog owners that can let their dogs run free within the fences, but otherwise it has a negative impact on the atmosphere of the place. The whole gravel surface that surrounds the water tower is an empty and useless space (4.8). In combination with the hedges that surrounds the area, and the 54 meters high water tower, you feel very small standing at the gravel surface and you do not feel invited to sit down at

Figure 4.8 showing the empty gravel surface surrounding the water tower.

Figure 4.11 showing the sport field in the middle of the plaza.

Figure 4.9 showing the area right to the water tower with the cotoneaster hedge and walking path next to Nobel-vägen.

Figure 4.12 showing the fence surrounding the park.

Figure 4.10. Södervärnsplan standing at the southern lawn and looking at the water tower.

the benches. The sports field is the best part of the park and feels modern and useful for children and youth in the surrounding neighbourhoods. Good lighting at night time make it possible to play until late at the same time as it makes it feel a bit safer. The fences around the sports field may look a bit boring, but are considered important for safety reason. The southern lawn with big weeping willows feels refreshing considering the rest of the park being paved with concrete or gravel and the big roads surrounding the area. At the lawn it feels more inviting to sit down, and the water tower can be admired from a more comfortable distance. Unfortunately, there is no benches to do so which is considered very unaccessible for people that do not want to or cannot sit on the grass.

Not many people have been observed in the park the times it was visited. The place seems to be used mostly by younger people that play ball in the sports field or dog owners who let their dogs do their needs in the park. At night time, the place feels rather unsafe and seems to be a place for homeless and alcoholics. The major roads bordering the park makes it noisy from traffic and may be one reason people avoid the place.

Due to the lack of rain during the period for the observations, it was not possible to visit the park during or after rainfall. Thus, how stormwater operates at the place today was analysed from maps of the elevation. The result show that runoff will come from north and pass Södervärnsplan when flowing south towards the lower area Södra Sofielund (fig. 4.13). Today the surfaces are slightly higher than the surroundings and most stormwater will take other directions instead of flowing into the park. The open areas however offer opportunities to remodelling the surfaces to derive the runoff from the surrounding streets into the park for slow conveyance and temporary storage.

To investigate the opportunities for adding SUDS at Södervärnsplan, the existing situation of pipes and wires underground was analysed (fig. 4.14). The result show that most

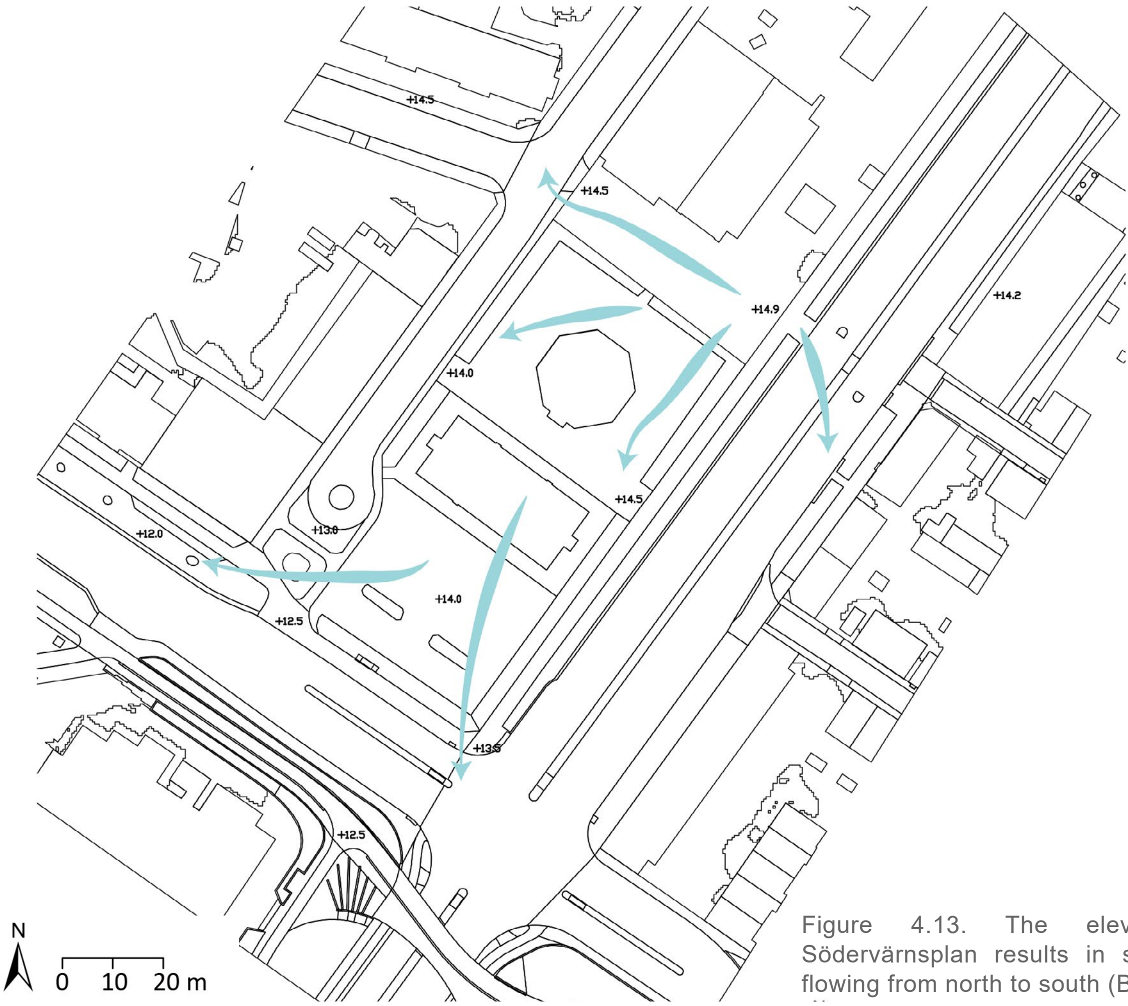


Figure 4.13. The elevation of Södervärnsplan results in stormwater flowing from north to south (By author).

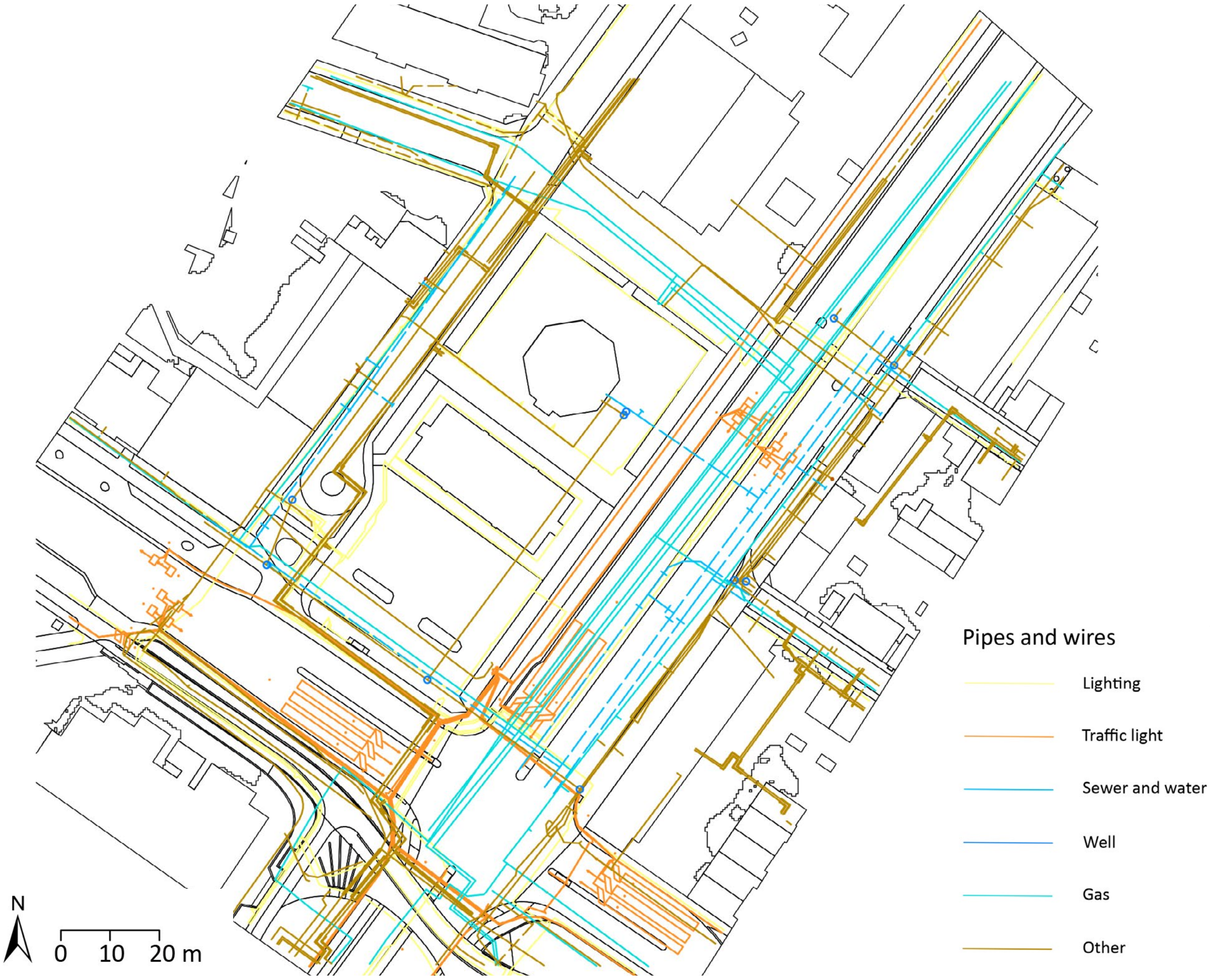


Figure 4.14. The pipes and wires in and surrounding Södervärnsplan (By author).

of the pipes and wires are placed under the streets and there are plenty of space inside the park that can be remodelled without too much disturbance and redirections.

The SWOT-analysis is concretised in table 4.1.

Table 4.1 showing the SWOT-analysis for Södervärns-plan.

STRENGTHS	**WEAKNESSES**
Nice multisport arena	Not welcoming
Open spaces for activities	Enclosed
Big trees	Neglected
Attractive water tower	Feeling unsafe
	Lack of identity
	Surrounded by high traffic roads
	Noisy
OPPORTUNITIES	**THREATS**
Open spaces to develop into SUDS	Polluted stormwater from the roads
Not too much pipes and wires underground	Risk of flooding for surrounding buildings

5. DESIGN PROPOSAL

5.1 Intention and concept

The new design proposal aims to deliver a multifunctional water plaza at Södervärnsplan that can delay runoff, temporarily store and to some extent treat the local stormwater. In that way, the plaza could mitigate the consequences of flooding for the surrounding neighbourhood and improve water quality for receiving waters. As the literature indicates a combination of SUDS-designs being the best approach to achieve optimum hydraulic and treatment performance for stormwater, the intention is to apply this strategy to the proposal for Södervärnsplan. Due to the local soil conditions, infiltration is limited at the place and cannot be fully relied on. Hence, solutions that reduce peak flows by slow conveyance systems and temporary storage are most suitable. Furthermore, Södervärnsplan will serve as a pedagogical example that educate about sustainable stormwater management. Thus, open systems that make the flow path visible is preferred over underground solutions. Water will be the ecological phenomena revealed at the place as propound by Galatowitsch (1998). Highlighting the concept of water will reconnect with the history of the place and its former identity in a more meaningful way than today's design. The idea is to create an inviting place that people want to stay in instead of just passing by. Just as before, kids will be able to play with water at Södervärnsplan again, but this time in a more sustainable and educative way than the former paddling pool. The new design will improve the amenity of the place and contribute to higher biodiversity.

5.2 Design process

Parallel with the literature review, document studies and site-visits, a lot of sketching were performed to try out different solutions for how to design the best water plaza for Södervärnsplan (fig. 5.1). Inspired by Benthemplein and Tåsinge Plads open solutions seemed like the best approach to manage stormwater for a curiosity awakening design, higher biodiversi-

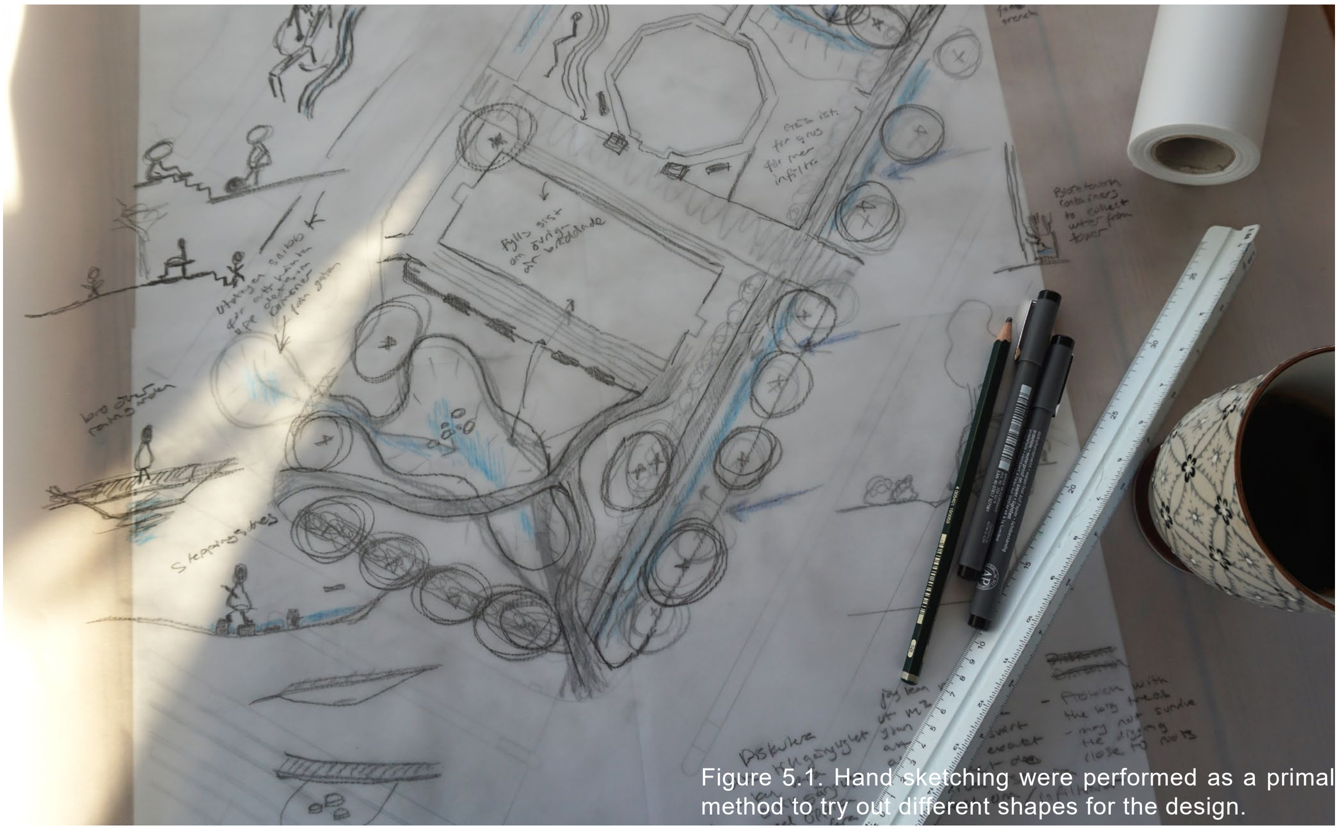


Figure 5.1. Hand sketching were performed as a primal method to try out different shapes for the design.

ty and evaporation. Hence, different ways to add swales, filter trenches and detention basins were sketched. In order to improve biodiversity and amenity it was decided to add as much greenery as possible and make the SUDS vegetated instead of hardscaped. To increase the available space for greenery, different solutions where the sports field was removed and replaced with vegetated basins was tried out. These solutions were however finally dropped since the sports field is considered to provide such a valuable place for activities that people seem to appreciate in the existing design. The literature review and observation of Benthemplein also indicates that multifunctional activity areas as a sports field is an important feature in successful water plazas. Hence, it was decided to keep the sports field, and in order to have some distance to the bigger roads the placement was decided to remain the same. To add a SUDS function, inspiration was gathered from the sports field at Benthemplein, and the field was decided to be lowered so that it operates as a hardscaped detention basin that can collect stormwater when it rains. As the designers at Urbanisten and Rotterdam municipality explained, infiltration was not an option at Benthemplein which was the reason why they chose hardscaped SUDS. As mentioned by Malmö stad (2008) infiltration in Malmö is low, and after looking at the soil conditions around Södervärnsplan that consist of clay it was decided not to rely entirely on infiltration. This led to one more reason to add a hardscaped basin at Södervärnsplan as well. The basin is expected to provide useful storage when it rains a lot and the soil not allow more infiltration. Dry days the sports field will be usable for sports just as it is today. To enter the basin, stairs with generous tread depths was designed to also work as comfortable seating for visitors resting from the sports activities or cheering their friends.

Later on in the design process, more detailed sections were sketched to try out different depth and slopes for the trenches and basins (fig. 5.2). Too steep slopes were avoided to limit the safety risk as well as facilitate maintenance. The guidelines for slopes and depth presented by Malmö stad (2008) as explained on page 41 was followed to propose reliable solutions.

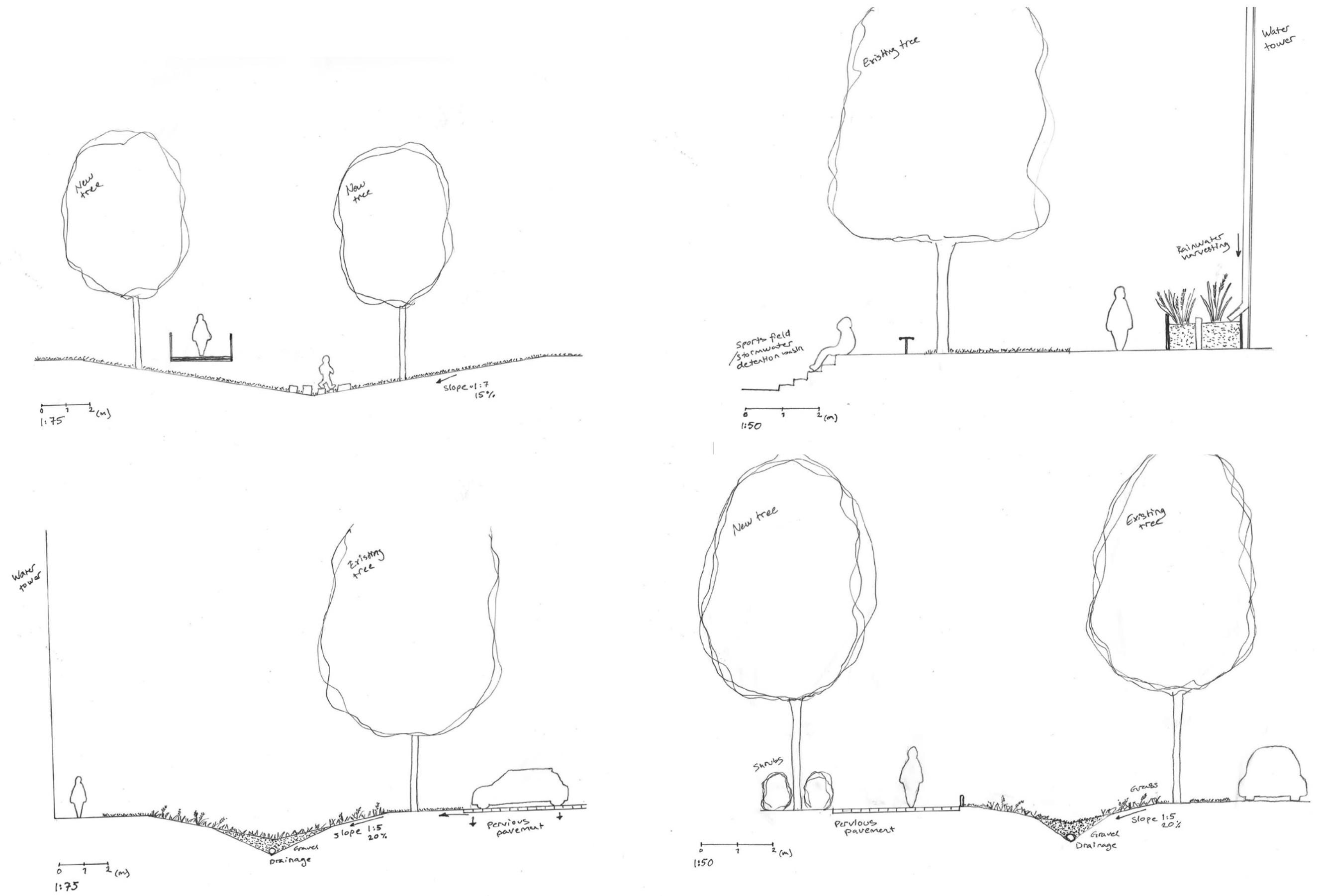


Figure 5.2. Sections to try out new filter trenches and detention basins.

Figure 5.3. The physical model of Södervärnsplan made it easier to grasp the spatiality and try out different designs.

To do something about the unwelcoming atmosphere of the existing design, new entrances and walking paths was sketched. The intention was to increase the possibility for people to more spontaneously enter the park and by adding new seatings invite people to sit down and stay a while. To further increase the experience value and attract more visitors, solutions to come closer to the water were sketched. This resulted in a new playground for playing with water, stepping poles at the bottom of the detention basin to jump over the water, and bridges crossing the SUDS so that the visitors can look at the water from above.

To get a feeling for the dimensions and spaces at Södervärnsplan, a model in scale 1:200 was constructed (fig. 5.3). The main part was made of carton and the ground surface was then covered with modelling clay *Plastilina*. The plastilina simplified the process of trying different solutions of elevation and where to place the retention systems as swales and basins (fig. 5.4 - 5.6). Together with the analysis of existing heights at Södervärnsplan a new plan with modified heights was sketched to get new functional flow paths that divert the water into the purposed SUDS.

Figure 5.4 showing how the model was used for trying out the effect of adding new trees and a filter trench along Nobelvägen.

Figure 5.5 showing modelling of a detention basin and testing whether or not to add trees in it.

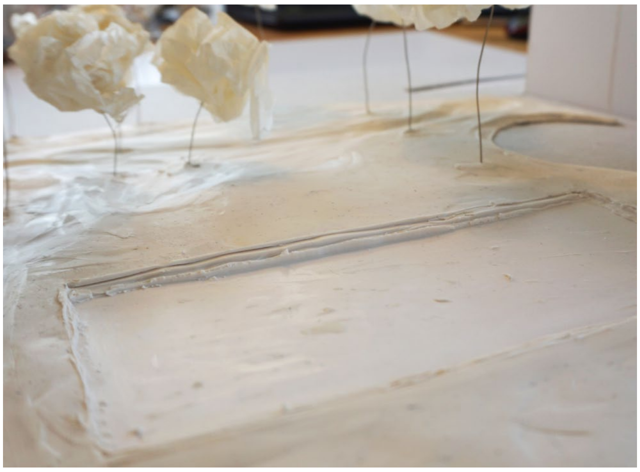


Figure 5.6 showing modelling of the sports field detention basin.

The model was also used for playing around with new vegetation and try out where to place new trees. By making small humans out of wire and placing them in the model, the scale of the place was easier to grasp and it became more obvious that new trees could really increase the amenity. Inspired by Tåsinge Plads a vegetated detention basin was designed in the southern area of the park. With the physical model different shapes were tried out but finally resulted in a smooth and dynamic shape in order to contrast the rectangular sports field basin. It was also tried out to add different amount of trees inside of it, but in order to not create a too shady area it was finally decided to only add three new trees. In order to facilitate maintenance, ideas where the basin was covered with perennials was finally dropped and replaced with a grass-covered solution. The grass-covered solution also added more opportunities for children running and playing at the slopes of the basin or people sunbathing or having picnic.

5.3 Final proposal

The new design proposal for Södervärnsplan (fig. 5.7) deliver a multifunctional water plaza that offer more greenery, places for play and SUDS to manage the local stormwater.

At the northern parking lot, the former asphalt surface has been replaced with pervious pavement to allow infiltration. Excess water flows into the bioswale that stretches all over the northern part of the park. During dry days the swale will be filled with perennials to look at and after rainfall it can temporarily flood. Stormwater from the swale will also flow into an underground tank placed under the new playground besides the water tower. In the playground children will be able to pump up water and use it in the playground equipment. In this way, the former gravel surface that made a very boring impression is gone and the northern part of the park now has got higher recreational and biodiversity values as well as stormwater quantity and quality values.

Due to the health risk of playing with stormwater presented by Sales-Ortells and Medema (2015), the idea is to filter the most contaminated water from the roads through filter trenches. Along with Nobelvägen at the eastern side of the park a filter trench collects the stormwater through curb cuts in the gutter along the street. In this way the stormwater from the street that most likely is polluted gets pre-treated before reaching the detention basins. To enable enough space for the trench, the former walking path is moved a bit more into the park. Together with new trees and shrubs the new path along the filter trench is expected to be a pleasant walk.

The new design contains two detention basins. One is the former sports field that now is lowered one meter and the other one is a grass-covered depression in the southern part of the park. Normal days the basins will be dry and functional for recreation and sports but after heavy rainfalls they collect and temporarily store the stormwater. A new path crosses the grass-covered detention basin as a bridge, enabling easy crossing, as well as the possibility to get a closer view of the water. In the bottom of the basin stepping poles make it possible to walk or play in the basin even when filled with some water.

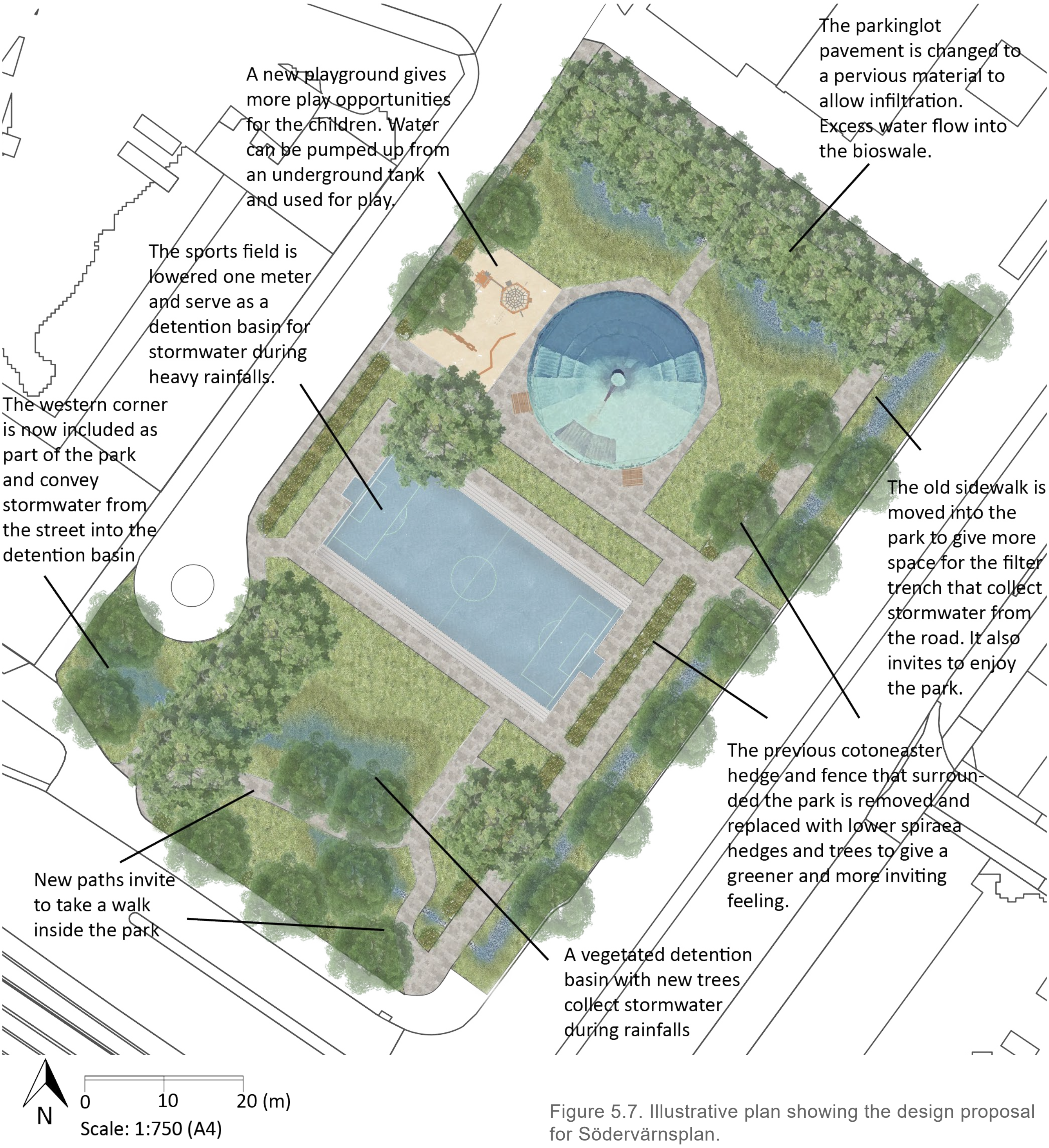


Figure 5.7. Illustrative plan showing the design proposal for Södervärnsplan.

Figure 5.8 show the presumed water movement over the plaza. The stormwater from the bioswale and filter trench is first diverted into the grass-covered detention basin and it is only when that one is filled to a certain level, that the stormwater enters an overflow drainage and start filling up the sports field basin. In this way the sports field will be dry as long as possible and only filled with water after really heavy rainfalls. It is also a way to improve the water quality before reaching the sports field and in that way reduce the risk of children getting sick from playing in the water. The western corner of the park is today outside the fences, but in the new design it is included as a part of the park. The corner collects stormwater from the street and divert it through a filter trench to the grass-covered detention basin.

The decision to propose open SUDS instead of underground pipes and magazines contributes to the curiosity awakening and pedagogical aim of the plaza (Stahre, 2004; Galatowitsch, 1998; Sprin, 1998). To understand the concept and flow path even during dry days the plaza should be equipped with signs as shown at Benthemplein and Tåsinge Plads. In this way, Södervärnsplan has the potential to become a pedagogical water plaza where visitors can learn about the water cycle and sustainable stormwater management. Like Thayer (1998) said it is like bringing back to surface what for so many years in urban areas have been tried to hide underground. In this case it is water that is the highlighted ecological phenomena made visible for people to observe. Hopefully it raises reflections about rural versus urban landscapes and the importance of natural processes for healthy ecosystem and life. Together with a sign that informs about the history of Södervärnsplan and the water tower, the plaza is expected to better connect with its history

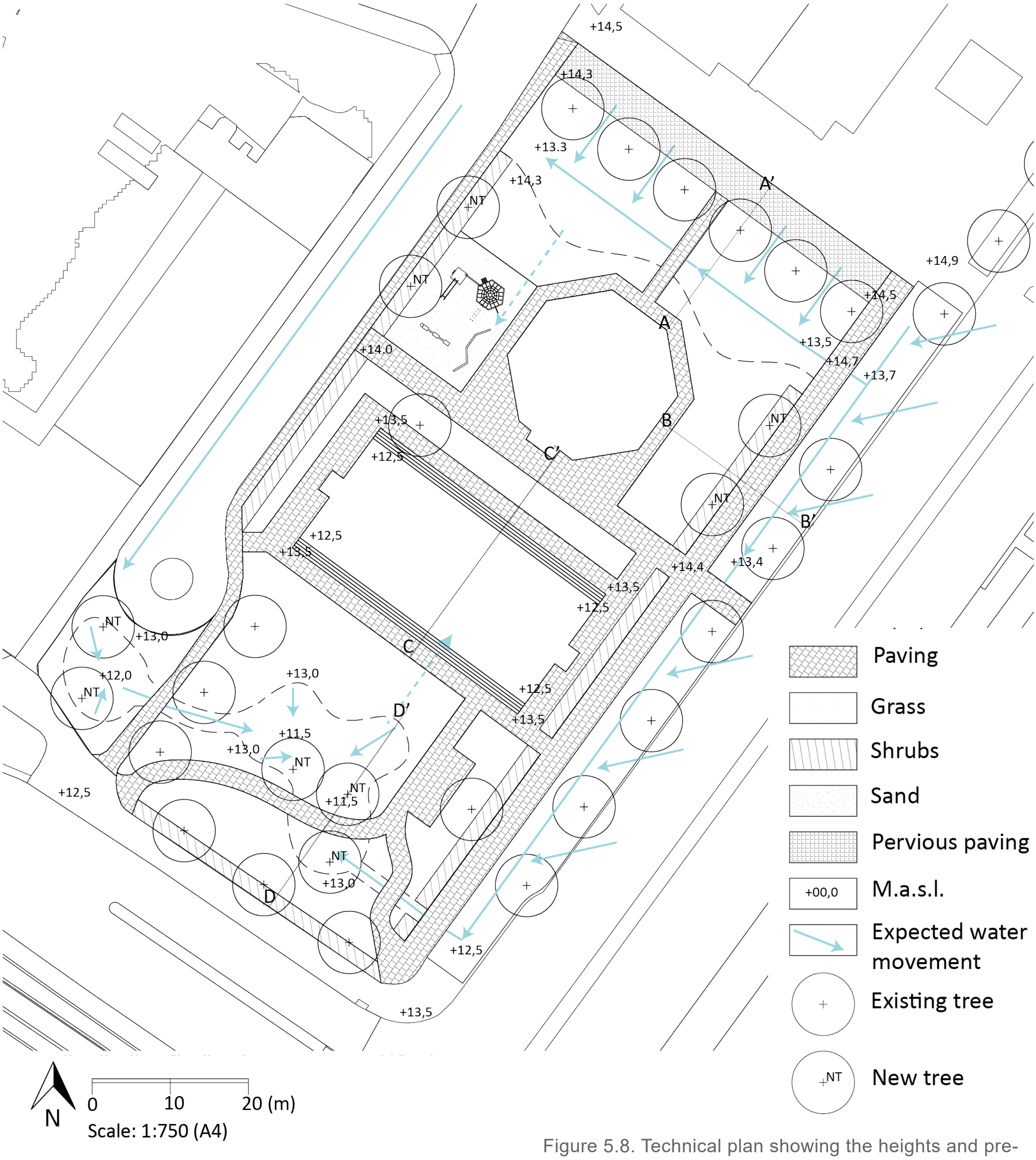


Figure 5.8. Technical plan showing the heights and presumed water movement over Södervärnsplan.

and have a more meaningful approach than today's design. The water tower that today is empty and without function could serve as a perfect place for opening a pedagogical centre where school classes and other groups can come to learn more about water.

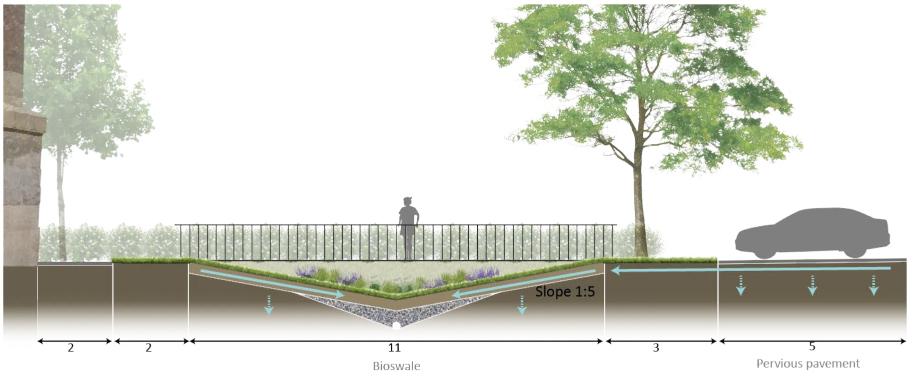
Figure 5.9 is presenting four sections showing the main systems added for managing the stormwater at Södervärnsplan. Section A-A' show how the water can penetrate the pervious pavement and infiltrate the soil. A slight slope divert the excess water into the bioswale where it slowly conveys and filters through the perennials. Here it also gets opportunity to infiltrate and evapotranspire. From a bridge the visitors can look at the bioswale from above. Section B-B' show the filter trench along Nobelvägen and how stormwater from the street enters the trench by first filtering through the vegetation at the slopes and then slowly convey and filter through the gravel at the bottom of the trench. New trees turn the walk into a small alley of lime trees to walk under. Section C-C' show the hardscaped detention basin/sports field that can be filled with water after heavy rainfalls but used for sports when dry. Section D-D' show the vegetated detention basin where stormwater can accumulate and temporarily store after heavy rainfalls. It is also allowed to infiltrate the soil when possible. From a bridge over the basin, visitors can look at the water from above, and at the bottom of the basin, stepping poles provide play opportunity.

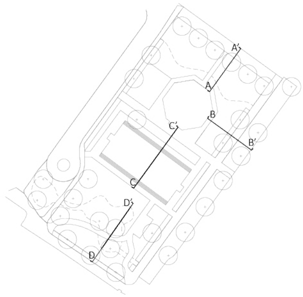
The final proposal facilitates slow conveyance, treatment and temporary storage of stormwater. Hence, runoff rate is reduced. Reduced runoff volume is desirable as well, and infiltration will occur to possible extent but with the systems equipped with drainage and overflows that can convey excess water as recommended by Woods-Ballard et al. (2015).

The design proposal for Södervärnsplan have a green approach and suggest new trees, shrubs and perennials. It is expected that this will result in a more inviting and pleasant atmosphere. New vegetation is also assumed to contribute to higher biodiversity. In addition, the uneven surfaces from the swales, basins and gravel filters together with fluctuating water levels should provide more micro-climates than today's design (Kazemi et al. 2009; Levin and Mehring, 2015). A permanent water-body as a lake or river would have greater impact on both biodiversity as amenity but was not an option due to lack of space. After rainfall the water that collects at the plaza will contribute with amenity and play opportunity for visitors (fig. 5.10) (Echols & Pennypacker, 2008). The fences and big hedges that today surround the park are removed and replaced with lower hedges and some new trees. Two new entrances in the southern part of the park also increases the possibilities for people to enter the park instead of walking around it (fig. 5.11). This is expected to result in a more inviting impression and a greener appearance that promote amenity.

The implementation of SUDS may contribute with some problems of accessibility since many systems involve depressions in the ground. At Södervärnsplan this is solved with hardscaped paths through the whole park and bridges over the swales and basins. This enables safe crossing but also possibility for a closer look at the water even for people disabled to get closer by themself. Good lighting increases the accessibility as well as the perceived sense of security for everybody walking through the park at night time. Benthemplein is a very nice example of good lighting that is both functional and beautiful. At Södervärnsplan good lighting is expected to make the place feel more secure than it does today.

SECTION A-A´





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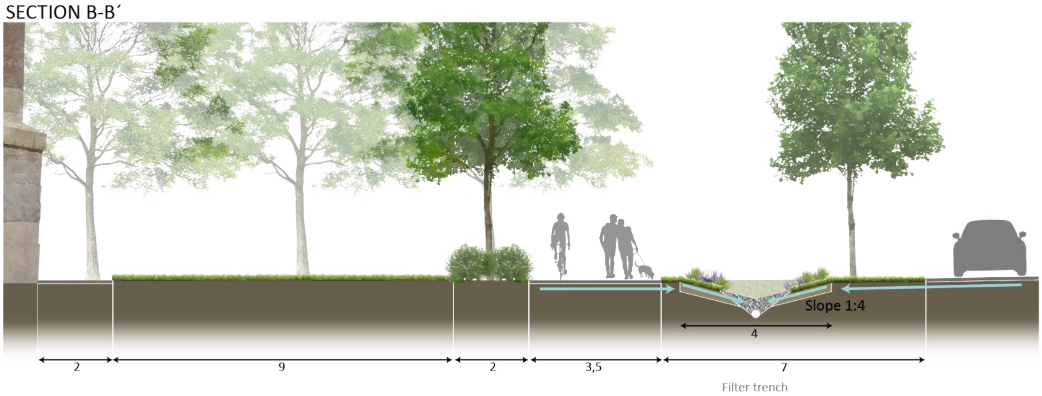
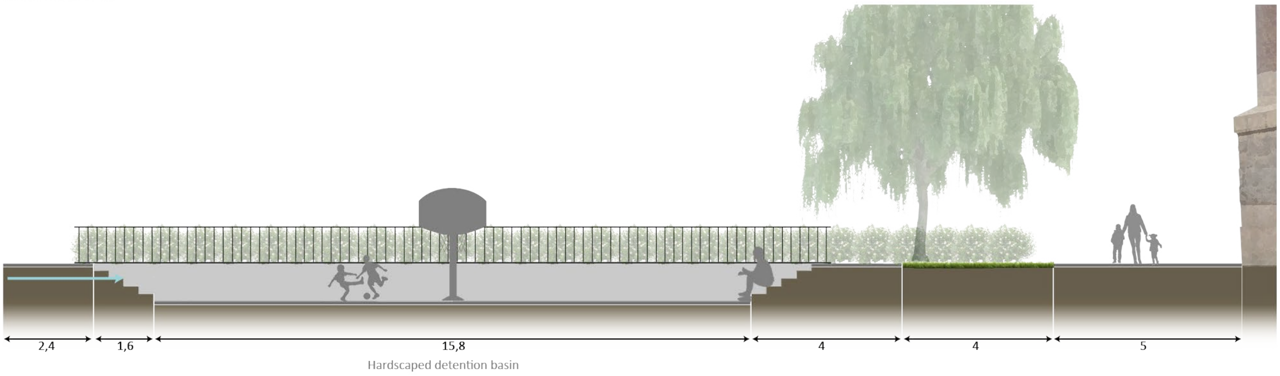
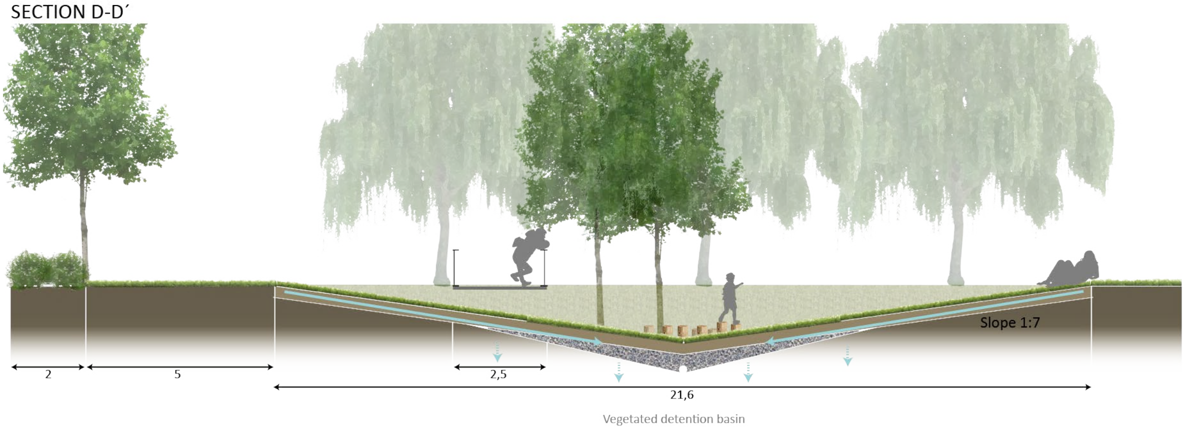


SECTION C-C´



SECTION D-D´



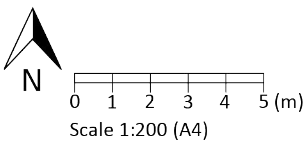


Figure 5.9. Sections showing the main systems added for managing the stormwater at Södervärnsplan.

Figure 5.10. A bridge over the vegetated detention basin provides easy crossing and possibility to look at the water from above. At the bottom of the basin children can jump on the stepping poles and play with the water. In the background, children are playing in the sports field detention basin.

Figure 5.11. Two new entrances at the southern edge of the plaza provides easier access and new pleasant walking paths through the plaza.

6. DISCUSSION & CONCLUSION

6.1 Discussion

After experiencing several cloudbursts and floods recent years it can be concluded that there is a global interest in discussing solutions for how increased precipitation should be managed in urban areas.

The objective of this research has been to investigate the concept of water plazas and sustainable stormwater management in urban areas based on the main research question:

- How can sustainable stormwater management in shape of water plazas prevent flooding, relieve the existing drainage system, create awareness of the problem and contribute to greenery and recreation for people at Södervärnsplan in Malmö as exemplified in the city of Rotterdam and Copenhagen?

In urban areas there seems to have been a negative trend to densify and hardscape to an extent that have left no space for natural processes (Spirn, 1998). People have relied entirely on the existing systems to the extent that they have been taken by surprise when storms led to devastation. Although the importance of green areas in cities for human health and well-being have been known for a long time (Gascon et al. 2015), it seems to be first in recent years, together with the noted importance of green and blue solutions for a well-functioning urban climate that such implementations has gotten real response in city planning. What Spirn said in 1998 about working with the nature instead of against it, is still highly relevant.

The literature review presented an assortment of published research relevant for the topic. It revealed a wide and complex context surrounding the urban stormwater issue. The climate change progress is uncertain and will have different impact on different locations worldwide. Apart from the climate, topography and geology varies and every city structure is a unique matrix of infrastructure, buildings and greenery. This leads to the fact that there is no easy answer for how to adapt cities to climate change and become flood proof. The SUDS-manual from Woods-Ballard et al. (2015) with its over 900 pages is a good way to start but also a good example of the complexity showing several solutions and combinations of methods to apply depending on the current scenario at the place you are designing for. Consequently, planning and designing for urban stormwater management require expertise in many areas, thus an inter-branch project group that involves all these professions. Stahre (2004) mean that there have been difficulties making this work in reality due to attitudes and financial disagreements and each profession has preferred to continue the traditional way. This may have been one fundamental problem for implementing these types of stormwater solutions before. That attitude however seems to be in progress of change considering all new literature about the topic and constructed examples of SUDS that can be seen worldwide. The great attention climate change has received recently has certainly played a big role in arousing interest and understanding from people and authorities that new solutions are a must. It has resulted in new policies from international to local levels; such as the Paris agreement COP21 (UNFCCC, 2014), the European Water Framework Directive (WFD, 2000) Waterplan 2 Rotterdam (Municipality of Rotterdam, 2007), Copenhagen Cloudburst Management Plan (City of Copenhagen, 2012) and Cloudburst plan for Malmö (Kommunstyrelsen, 2017) etcetera. To conclude, the attitude towards SUDS seems to be in a positive state at the moment.

As mentioned by Fletcher et al. (2014) sustainable stormwater management goes under different terminology worldwide. Same seems to apply the concept of water plazas which only appear under that name in the Dutch literature. The Dutch also shifts between the terms *water plazas* and *water squares* when talking about the same concept. The literature review however revealed that it appears as a concept in other countries as well but without a decided terminology. The city of Malmö describes them as multifunctional activity areas that temporarily floods during heavy rainfall (Kommunstyrelsen, 2017) and in Copenhagen they are described as stormwater system and storage facilities that serve a double purpose as recreational facility for skating and ball gaming (Hvilshoj & Klee, 2013). To conclude, the term water plaza is still a bit vague today and whether it should be called water plazas, water squares or why not water parks are up to taste and national customs.

It has been noted that the word multifunctionality has been repeated in connection with water plazas and similar concepts in the literature and during the dialogues. When densification is a fact, urban spaces may have to serve multiple purposes in order to fit all needs. The result of this research indicates that the wide range of shapes that water plazas can adopt may be one of its main strengths. Water plazas can be used as regular plazas with what ever other function is desirable as long as they serve a stormwater management purpose and provide storage and delay of stormwater. How visible and obvious the stormwater management should be can vary depending on how important it is considered to be to communicate the message to the public. Thus, it is a concept transferable to all kind of urban plazas. Considering the variety of SUDS available to choose from, water plazas in all scales and shapes should be constructible.

In Malmö, the literature revealed that the city planners now strive towards replacing many paved surfaces with green ones to improve the city climate (Malmö stad, 2018). At the same time, they consider it too expensive to replace the sewer system with new pipes, thus SUDS is proposed as a complement that can relieve the old sewer system. During this research it however has become clear that implementing SUDS in an existing urban environment is not always easy. First, finding an open space in dense city structures where you can remove the paved surfaces is not easy. Second, pipes, wires and tree roots all try to fit underground and consequently it gets problematic trying to find spaces for excavating depressions for SUDS without having to redirect existing pipes or damaging existing vegetation. Considering all benefits a water plaza could bring to the urban environment this however may be insignificant.

The study of the reference objects provided valuable visual impressions of how water plazas can look like and which functions they can have in the city. As discussed in chapter 3, Benthemplein and Tåsinge Plads show two very different designs that nevertheless share the same purpose. Comparisons of them both clearly showed pros and cons with both more hardscaped as vegetated solutions and the reason selecting one over the other must be based upon site specific conditions. By visiting the places, it also became clear what does not work as good as one would prefer, something the literature cannot provide. At Benthemplein this mainly refer to the maintenance that seemed to fail. A plaza like this has cost a lot of money to design and construct, hence money must be budgeted for maintenance as well. If not, both function and attractiveness may diminish as well as it may pose a health risk. This does not just apply for Benthemplein but for all water plazas and SUDS. Filtering systems requires cleaning to avoid sediment clogging and function as supposed to. Conventional plazas do not have these systems and consequently, implementation of SUDS may imply new tasks for the maintenance staff. This could be one reason why the cities lack resources to maintain the systems properly as seen at Benthemplen and reported by Echols (2007). Sales-Ortells and Medema (2015) recommend disinfecting SUDS basins after every rainfall. After seeing Benthemplein, this however not seems cost-effective and practically manageable. The sports field basin at Södervärnsplan will therefore only receive stormwater when necessary after heavy rainfalls and the added filtering systems are expected to filter the water before reaching the basins and in that way reduce the health risk. Open water bodies in the city will always imply some health risks as well as safety risks, but putting up fences around them does not seem like a good solution. In Malmö and many other cities where open canals without any fences flow through the city centre one can assume that such water systems should pose a bigger safety risk. Thus, people should know how to act with water. By implementing safety precautions as shallow water depth and gentle slopes, the risks at Södervärnsplan are reduced.

At Tåsinge Plads bad maintenance was not as visible in terms of litter and sediment but what was visible was the complete drying of the vegetation. One reason to this was undoubtedly the unusually hot summer but it also indicates the importance of selecting vegetation that can cope with hot and dry climate, something common in urban places and which may get even worse with the effects of climate change (Seager et al. 2010; UN-Water, 2010; WMO, 2018).

The result of this research indicates a complex structure of conditions both above and below ground that affects the stormwaters runoff path, rate and volume. Thus, it requires detailed investigations to calculate where flood risk is most exposed and where actions most effective. One thing that may be disputed with Södervärnsplan as case study is its elevation (fig. 4.1, p.39). Södervärnsplan is not located in the lowest areas of the city. However, it has been concluded that sometimes the lowland is situated within a private housing area or dense city structure that simply does not have much space for installing SUDS or it can be unsuitable for other reasons. Then a solution that manage the stormwater higher up the flow path may be effective to prevent flooding lower down the flow path. This is what may be the case at Södervärnsplan. If well planned, the plaza should be able to delay the runoff so that Södra Sofielund not will be as badly affected by cloudburst and flooding as it was in 2014. Important to comment is also that water plazas and SUDS is not only about finding the most effective way to drain stormwater rapidly. Most effective in Malmö may be to just oversize the underground pipe systems and divert all stormwater to the canals and out in the sea. However, such solution would not contribute with amenity, biodiversity and treatment which is just as important as reduced runoff rate and volume when designing water plazas and SUDS.

The final design proposal for Södervärnsplan is a conceptual design showing how a water plaza at the place could look like. It is expected that the new design should be able to relieve the existing drainage system by delaying and storing stormwater in the proposed filter trenches and detention basins. Claiming that the plaza would prevent flooding in surrounding areas is too much to say based upon this research. The result of the literature study and analysis of the reference objects however indicate that the implementation of SUDS result in prevented flooding. Thus, it can be assumed that the flood risk at Södervärnsplan and Södra Sofielund should be reduced. To what extent is however impossible to say and it is emphasized that a more detailed investigation of the city structure and local hydrology and geology is needed in order to develop final construction plans and calculate the plazas full potential.

6.2 Conclusion

Based on the results of this research, following can be concluded:

- Water plazas provide a multifunctional concept that can serve an important piece of the puzzle to climate adaption and flood prevention in urban areas.

- A water plaza at Södervärnsplan would provide a more sustainable stormwater management that through the implementation of different SUDS could delay, store and purify the local stormwater. In that way it is indicated that the existing sewer system would be relieved and flooding prevented. It would also imply an interesting design that could arouse curiosity from the visitors to learn more about stormwater management. In combination with new vegetation it would bring more greenery and recreational possibilities to the people visiting Södervärnsplan.

- The adaptability of water plazas to be designed with multiple purposes and in all scales and shapes results in a concept that can be adopted at urban plazas in other cities and countries as well.

6.3 Reflection of methods and work process

I started this project with some superficial knowledge about the topic but mainly a strong enthusiasm and will to learn more. Throughout the work it however became clear that urban stormwater management is a huge and complex topic. As discussed earlier, the variation of used terminology worldwide and the fact that water plazas is a relatively new term also complicated the search for information. This resulted in more time spent at knowledge acquisition and writing of literature review than expected. However, the reading was necessary to gain enough understanding to grasp the topic and be able to analyse the reference objects as well as develop the design proposal. It also turned out to be time consuming trying to get in contact with informants for the reference objects and case study. First intention was to get face-to-face interviews with people responsible for each project but in the end it turned out to be dialogues over e-mail. Both Benthemplein and Tåsinge Plads are today internationally recognized places, and designers as well as stakeholders do not have time for all students and journalists trying to get in contact. The fact that I could not freely discuss the objects with the designers obviously affected my research in the way that I did not obtain as detailed answers for my questions as I wished for. It is also possible that the answers they gave me were slightly biased and revealed the positive aspects more than the negative. Consequently, I had to seek more information in publications and less time remained for the design process. Thus, the proposal did not get into as much detail as intended from the beginning. My lack of detailed technical skills concerning hydrology has also resulted in a very conceptual design that rather shows an example of how a water plaza at Södervärnsplan could look like than a final solution with optimised water storage and treatment capacity.

As pointed out by Creswell (2014) it is also important to emphasise my personal impact on this research. All the analysis of places and material are based upon my personal interpretations derived from my educational background and knowledge acquisition within this research. The analysis would have been different if made by another person and at other moment. The design process is also a highly individual process where the decisions is affected by my personal interpretations and beliefs of what is most suitable and attractive.

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