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Approaching sustainable stormwater management

- investigating the hydrologic cycle for sustainable landscape design

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- investigating the hydrologic cycle for sustainable landscape design

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Contents

Abstract

Abstract

The global population is known to be increasing, by which urbanisation is expanding and demanding more space. Many issues occur through the spreading of impermeable surface in which some of the more pressuring compartments lie within hydrology, such as access to freshwater, spread of pollution and flooding. Our future presumes to bring climate changes more radical than we have experienced so far, presenting extremes of aridness and rainfall.

As landscape architects take a large part of the urban landscape design, a large portion of urban issues can be approached by the same. For a landscape architect to create an enlightend design proposal regarding stormwater systems and management in an urban setting, knowledge of what make a water system sustainable and why is required. That is, what the relations between our urban design and the natural (urban) hydrologic cycle are. Solutions can be achieved in many ways, but the foundation has to be cast from the knowledge of interactions between the hydrologic cycle and an urban area, as well as the comparison and learning from the natural hydrologic cycle.

Analyses has to be carried out along with pilot installations of projects with the aim of creating sustainable solutions. Therefore also evaluations of already implemented installations with a sustainable approach towards water management are of value to gain understanding of and learn how to think and approach similar problems as a landscape architect.

Introduction

Research question

What are the issues within the natural flow of the hydrologic cycle in relation to urban areas, and what measures can be taken within landscape architecture design to aid it?

Aim

Emphasize complications that may arise within the hydrologic cycle during development as well as with sustainable stormwater systems, and construct models to show how landscape architects may approach and work with them to mitigate the negative effects.

Objectives

- Research the hydrologic cycle and its effects on humans and the environment.
- Research current sustainable concepts regarding stormwater, presenting pros and cons within the field.
- Apply ideas for improvement in an application area with infiltration difficulties to use it as a tool for understanding of the subject.

Introduction

Background
We are in need of more sustainable stormwater systems in urban areas than we have today, as our current use and discharge of water leads to spread of pollution and alternations in the hydrologic cycle, negatively affecting us directly as well as indirectly. Increased population, urbanisation and the failure of changing developed countries populations' living habits are all part in the unsustainable development. In future climate changes it may be vital for our cities to be sustainable for survival, thereof water is a key ecosystem service to approach.

To be able to make enlightened decisions as a landscape architect whilst working with water management, it is vital to understand the hydrologic cycle, what the negative impacts are and how to work with it to achieve a more natural water cycle to increase sustainability.

Method
The project investigates the processes and the structure of the hydrologic cycle. It is divided into three parts: The literature study (divided in two sub-parts), presentation of application site and case studies, and finally the discussion of what has been discovered as well as an analysis of how the discoveries could be used in a sustainable water management project.

The first part of the literature study describes what sustainable stormwater management and systems are and their importance, as well as considerations and issues within the subject, as these are the means landscape architects can use to mitigate negative effects on the water cycele caused by anthropologic developement. It additionally look over how stormwater is considered and managed in Sweden, as this is the location for the application site.
The second part of the literature study presents the structure of the hydrologic cycle, how it functions and its connections to the environment, and its relation to human activity.

To concretise what a landscape architect should consider whilst working with water and the water cycle, some solutions found at the application site has been analysed and discussed. In an attempt to present how a current system might improve in regard for mitigating negative anthropologic effects on the hydrologic cycle, ideas from relatively modern case studies approaching the issue of flooding has been analysed and finally traced onto the application site.

Literature study
As the project aims to investigate the processes and structure of the hydrologic cycle in order to emphasize potential complications constituted by urbanisation, the first part of the thesis is a fundamental literature study investigating such processes based on both on regular as well as sustainable stormwater management. Used search engines are Google scholar, ScienceDirect and Research Gate. Certain references have been found referred to in other articles. Keywords have been alternated between english and swedish to provide as extensive research possible.

Application site and case studies
In order to bring further understanding of how to make use of provided information in the literature study, Augustenborg is used as an application site. The site is chosen due to its reconstruction in the 1990's when the new design aimed towards making it less prone to basement flooding and thus also a little more sustainable. Looking at and learning from site redevelopment as a landscape architect is valuable as it provides the architect with knowledge of approaches that may and may not work well in what context. In turn this provide insight in how to design a similar project and what to think of.

Introduction

An analysis through the use of the IWA-model is carried out to inform understanding of the site as well as the following analysis in part 3.

Choosing Tåsinge Plads in Copenhagen and Benthemplein Water Square in Rotterdam is mainly due to their recent development with a high focus on sustainable stormwater management and their difference in material approach, but also the similarity Malmö, Copenhagen and Rotterdam share in temperature and rainfall.

Information and material has been gathered through article research, site surveys, conversations, email correspondence and matetial inquiries with municipality officials, project design offiicials as well as with lecturer at SLU.

Discussion, analysis, design proposal and conclusion

The discussion has received a modest situation within the thesis in order to provide space for the analysis, which is of more value as it has a better connection to both conclusion design proposal. The design proposal in turn is not a design solution in the sense. It is rather a collection of the ideas constructed in the analysis, and provides a light idea of what the area could look like with adapted approaches. This vague proposal is created due to the limitations regarding site factors this thesis has the potential of showcasing (see *Restrictions*).

Restrictions

Having Augustenborg is already a developed site specifically focused on sustainable stormwater management, it limits the scope of focus for this thesis. Starting from the beginning at a site lacking hydrologic aid would also present the need for other considerations a landscape architect has to regard (basic factors i.e. circulation, social aspects, culture, history etc.). However, starting at a site where many of these considerations have recently been regarded allows for almost complete focus on the issue at hand. The already establised stormwater solutions can be critically evaluated through the scope of aiding the hydrologic cycle (not only from the perception of humans) and improvements can be put in comparison for educational purposes.

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Information foundation

The information foundation presents the information upon which the discussion is built. It aims to provide knowledge and understanding of what sustainability is, how it is connected to the hydrologic cycle, and most importantly: how the hydrologic cycle works and how it is connected to humans and the environment - why we need it to function.

Importance of Sustainable Stormwater Management

The maintenance of water has become increasingly important within and outside cities globally. Immense cloudbursts, and the effect of them, has in recent decennias drawn attention to the issue of stormwater management also in Sweden, since according to Svenskt Vatten (2016) the expansion of current underground pipeline stormwater systems will not be functional in the long run as the widening of pipelines cannot compare to surface disposition systems' potential of holding and transporting large volumes of water. The work with urban drainage has extended further, not only concerning health protection (polluted water) and the mitigation of flooding, but also enviromental, economic, social and sanitary issues (Fletcher *et al.*, 2015; Hatt *et al.*, 2009).

The general apprehension of how sustainable stormwater management *should* be achieved is the concept of making use of stormwater as a resource, rather than dispose of (Fletcher *et al.*, 2013; Calkins, 2012). Water can be used for enhancement of communities, to benefit biodiversity as well as reduce certain costs. A major goal is to ”restore natural hydrologic function to our landscapes” (Calkins, 2012).

The best approaches of *how* to achieve a safe and sustainable stormwater management is however constantly in debate, due to the complexity of the field (Fletcher *et al.*, 2013; *Sage et al.,* 2015). Presumably the issue of how to achieve the goal can be traced to the fact that all locations have individual issues, possibilities and prospects. To reach a similar result the issue has to be approached individually for each location. The subject touches many professions, and the science/technology research of stormwater management continues to be an area of interest and research (Fletcher *et al.*, 2013).

Terminology

The term as well as use of Sustainable Stormwater Management is being developed simultaneously across the world, and the outcome is a variety of terms sharing the same foundation, but with slight divergences due to the individual needs of the country naming the term (Fletcher *et al.*, 2015). Also the individual interpretation of the term leads to a variety of implementations and uses of systems and technology. Thus the outcome of a sustainable system may turn out differently and with different results, even though the designers have referred to the same term in their product (Fletcher *et al.*, 2015).

This thesis does not aim to follow a specific term's objectives, but instead consider the effects a solution may have on the hydrologic cycle. Hence the term used for systems considered sustainable (which may or may not inflict negatvie effects on the water cycle) is not e.g. SUDS or LOD, instead it will only be referred to as ”Sustainable Stormwater Management”, which could be considered one of the most neutral terms for the subject since it does not refer to a specific term of use. The vague use of the term therefore need to be connected to the foundation upon which the word ”sustainability” rests upon in this thesis (see ”*Definition of Sustainability*”, p. 10).

It should also be stated that in this thesis the term ”sustainable” in ”sustainable stormwater management systems” is something that is *better* than current regular stormwater systems from a sustainable point of view, and not necessarily *completely* sustainable, nor *the best* sustainable option. It is rather a fairly sustainable option in comparison to many others. This because we are still far from developing a completely sustainable system - instead we have to continue researching and comparing various systems on their way towards a sustainable solution.

Definition of Sustainability

It is today globally known that a key component within environmental policy of new development is the concept of sustainability. Novotny *et al*. (2012) support the conclusion of the concept not to be a process, but rather an objective and a quality, whilst *sustainable development*, which we are practicing today, in turn is a ”*process toward achieving and then maintaining sustainability*” (Novotny *et al.*, 2010, p. 80). Calkins (2012, p. 2) has composed a summary, aimed towards the construction of landscape, from the United Nations World Commission of Environment and Development Brutland Report, Our Common Future (UNWCED, 1987), stating: “the design, construction, operations and maintenance practices that meet the needs of the present without compromising the ability of future generations to meet their own needs”. This means the design of an area has to take into consideration not only one focus point, i.e. preventing flooding, but add to this a range of focus points working together which drives the process of making decisions for the design forward (Fletcher *et al.*, 2015).

Resilience

Resilience is by Novotny *et al.* (2010) described as ”the fourth dimension of sustainability”. The term can be described as a system’s potential of ”bouncing back” after disturbance. If a system is resilient, distrubances does not cause it great negatvie effects - instead it can ”bounce back” and avoid suffering heavy impacts from the disturbance.

Walker *et al*. (2010, 62) discusses the term which they define as ”the capacity of a system to absorb disturbance, undergo change, and still retain essentially the same function, structure, and feedbacks - the same identity.” As the meaning of the word can be apprehended differently depending on profession and what context it refers to, they conclude the mentioned definition need an additional statement/consideration to be complete within the subject of water: ”Resilience (...) refers not to the speed with which a system will bounce back after a disturbance so much as the system’s capacity to absorb disturbance and still behave in the same way” Walker *et al*. (2010, p. 62). In other words, how long it takes for an area to e.g. recover from heavy flooding is not as important as the fact whereas an area can recover completely after disturbance.

Consideration of resilience in urban areas is therefore of importance (Novotny *et al.*, 2010) as resilience stands for systems and constructions which on its own accord can withstand changes in its surrounding without caving.

Achieving future sustainable and resilient cities are of high significance as successful implementation of the concepts can aid the hydrologic cycle running naturally.

Influential factors

Factors such as local characteristics, spatial-, and temporal considerations all play part in a healthy and positive stormwater management, therefore it is highly important that the stormwater system is flexible (Barbosa *et al.*, 2012). The flexible stormwater system should approach flood control, water quality and erosion in order to form a sustainable unity (Barbosa *et al.*, 2012).

Law and administrative considerations has to be regarded (Barbosa *et al.*, 2012), as well as the field of responsibility for an area or a system. People of responsibility are often many and can be spread between a number of professions and owners. This regards people within the construction- and planning professions, but also people who lives and/or operates within the regarded location (Svenskt Vatten, 2016).

Objectives for sustainable stormwater management approaches

Cited from Fletcher et al., 2013, p. 268:

”1. Manage the urban water cycle in a sustainable manner (considering both surface water and ground water, along with flooding and impacts on erosion of waterways)

2. Maintain or return the flow regime as close as possible to the natural level

3. Protect and where possible restore water quality (of both surface and ground waters)
4. protect and where possible restore the health of receiving waters

5. Conserve water resources (consider stormwater as a resource rather than a nuisance)

6. Enhance the urban landscape and amenity by incorporating stormwater management measures which offer multiple benefits into the landscape.”

As can be seen, Fletcher *et al*. strongly refer to connecting the fundamentals of a site design to the hydrologic cycle in order to obtain increased sustainability. It includes the decrease of *extracting* freshwater from recipients and instead *utilise* local runoff and perhaps precipitation, as well as reducing our pollution of waters.

Benefits of optimally designed sustainable stormwater managament

Cited from Calkins (2012, p. 75-76).

- ”Reduces onsite and downstream flooding
- Reduces flooding caused by combining detained runoff
- Lowers the site and regional stormwater systems cost
- Lowers peak storm flow frequency and duration
- Reduces soil erosion, stream siltation, and downstream scouring
- Reduces nonpoint source and thermal pollution
- Replenishes groundwater
- Supplements domestic water supply
- Restores low stream base flows
- Improves aesthetics
- Enhances recreational opportunities
- Provides for wildlife habitat
- Improves safety
- Maintains appropriate soil moisture”

Calkins describe what a sustainable stormwater system and management can (or preferably should) achieve. Outcomes of aiding the natural flows of the hydrologic cycle (through systems that increase resilience, reduce pollution, and provides for natural water processes as can be seen in the list) benefits both humans and ecosystems.

Stormwater in Uban Space

Novotny *et al* (2010) pronounces cities to play a major role in sustainable development due to the threats to nature it holds during their increasing expansion. Even though half the worlds population is currently residing in cities, it is predicted to increase further in the future, demanding extensive expansion and increasing the risk of urban sprawl (Fletcher *et al*., 2013; Novotny *et al.*, 2010). The main load of pollution springs from and around cities: people working in the city center tend to live outside it: requiring the commuting to and back from work as well as to other activities; industrial production; food and water brought from a distance etc. Not only is pollution able to contaminate water created by this, but also large amounts of energy is needed for the various activities (Novotny *et al.*, 2010). In areas across the world even the water supply is currently decreasing, and will continue to, due to urban sprawl and growth of population (Calkins, 2012).

Impermeable surface of urban development restrict the ground’s natural infiltration possibilities, thus hydraulic catchments has to handle extensive surface runoff which it may not be designed to handle (Fletcher *et al*., 2013). The exploitation degrees in relation to original natural surfaces decide the increase in stormwater runoff.

If no detention area or facility is implemented in new development it will result in a changed runoff pattern: e.g. the new construction of a parking area not including a detention area would result in a 10 times increase of stormwater runoff (Svenskt vatten, 2016).

One consequence following increasing runoff is, amongst others, erosion which may widen flow areas, and can injure sensitive biotopes (Svenskt Vatten, 2016) which in turn can affect local ecosystems. The main issuse does however tend to refer to the pollution of surface waters due to heavy precipitation.

Extreme precipitation cleanse areas and surfaces, thus becoming the source of transportation for pollution simultaneously (Svenskt vatten, 2016; Barbosa *et al*., 2012). Depending on its route, e.g. along roofs, traffic surfaces or parkland it will gain various pollution concentrations. Surface pollution can, beyond direct pollution from e.g. cars and car tires (spiked in winter), excrement from animals or remains of cigarettes, arise by polluted air leaving particles and leftover products from a number of building materials (Svenskt vatten, 2016). This water, along with water from potential flooded polluted ground, may reach recipients (Svenskt vatten, 2016). Contaminated runoff may have disastrous effects of receiving waters, which in turn may have negative effects on aquatic life. This in turn have impacts on ecosystems, ecoservices and public heath when using or consuming the water (Gaffield *et al*., 2003; Goel, 2006).

Consequently, the increase of hard surfaces during urbanisation worsen the pollution spread since it collect contaminants which is washed away during snowmelt and precipitation and lead to recipients (Gaffield *et al.,* 2003).

Effects of impermeable surfaces

Impermeable surfaces reduce moisture within and on top of soil. This affect groundwater recharge, baseflow of streams, degradation of water quality (resulting in higher costs for treatment), and the increase of surface runoff (Calkins, 2012; Han *et al*., 2017). Change of water levels and moisture in soils also affect habitats, temperature as well as local climate (Calkins, 2012). Geomorphic changes occur when impermeable surfaces affect the hydrologic cycle, resulting in hydrologic changes. This may enlarge water channels, impact sediments and degrade habitat quality. This in turn has a negative domino effect on several other systems which in turn has negative impacts on ecosystem services (Fletcher *et al*., 2013), as will later be explained further.

Fletcher *et al.* (2013) argues the urban hydrology not to be excessively dissimilar to natural hydrology. The complexion of the issue rather lies within the current urban water system, and the multiple objections and interactions this system has with the hydrologic cycle onsite. The designing of more sustainable urban hydrologic solutions is further complicated by the patchwork of designed land surrounding a city, i.e. agricultural fields and other developments.
Nonetheless, Svenskt Vatten (2016) stresses the keeping of a sustainable stormwater management system in Swedish urban areas, as it would severely decrease both pollution of water recipients and damages during heavy precipitation.

Stormwater Management in Sweden

The traditional solution to manage stormwater in Sweden, the directing it into the underground sewage systems, first started in the 1860's and has since been altered according to modern technique of the time it was installed and improved. All since the first sewage systems were installed, sewage system has been in constant development. Until mid-1970's stormwater was considered an issue to be solved by discarding it into nearest recipient, thus a combined sewage system (fig. 1) was used (Svenskt vatten, 2016). Since then, the knowledge of pollution and its effect on recipients has gradually improved, and today the stormwater management system is made increasingly visible. The increasing knowledge of the multiple positive effects visible water has on people's wellbeing is amplifying the use of open water management and combinations of sustainable solutions (Svenskt Vatten, 2016; Cettner *et al.*, 2014).

It is today by Svenskt Vatten recommended to have a "divided double system sewage" (fig. 2) able to drain stormwater from the stormwater pipe upwards to the surface without endangering nearby development. New stormwater management systems should compose a slow flowing open water system combined with underground piping systems. The latter are dimensioned with certain resiliences, and if/when exceeded the remaining runoff is collected as surface water in lowly situated locations (Svenskt vatten, 2016).

Current demands for construction

The current demands, according to and cited from Svenskt Vatten (2016, p. 40), on functions for new stormwater management are:

- ”Drainage of hard and other surfaces shall be constructed to minimize injuries of buildings and facilities
- Maximize detention of stormwater to reduce peak flows and discharge of pollution
- Facilities of detention shall be implemented in domestic as well as in public space when needed for flooding
- Stormwater shall be purified according to the sensitivity of various recipients
- Surface systems shall be able to handle extreme precipitation to avoid injuries on buildings and facilities”.

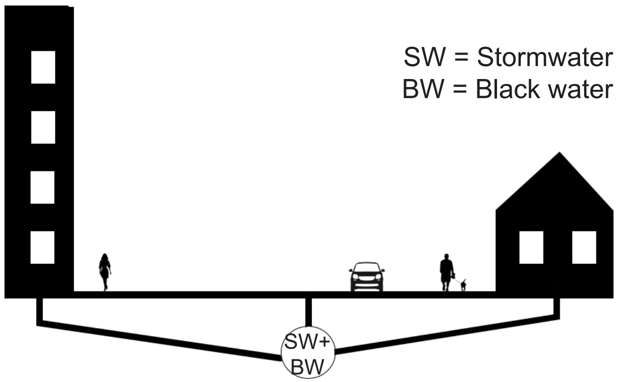


Fig. 1. Combined sewage system.

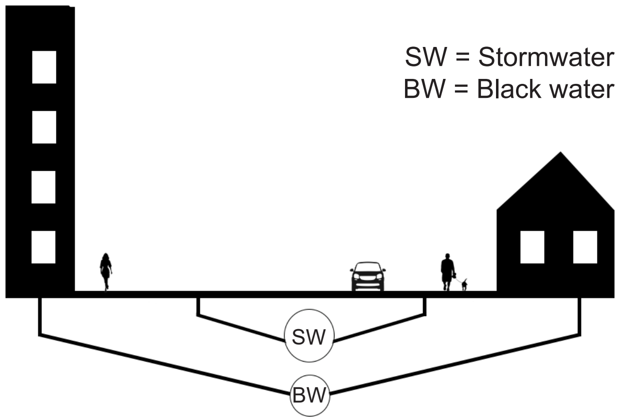


Fig. 2. Divided double sewage system.

Sustainable Stormwater Management in Sweden

Svenskt vatten (2016, p. 28) describe the term ”Sustainable Stormwater Management” as “creating prerequisites for stormwater management to mimic the natural system of handling rainfall, from the first falling raindrop reaching ground until the last reach receiving water” in order to “extensively slow down and reduce stormwater runoff from communities, (...) thus the risk for destruction of buildings and polluted stormwater reaching the recipients due to flooding is reduced” (Bäckmann, 2017).

As previously mentioned, the approach of implementing the concept of or even improving sustainability within stormwater management systems has become increasingly used in Sweden, usually in the form of surface water. Sweden does not regularly suffer from extensive flooding, although there has lately been a few flooding scenarios i.e. in Malmö that has resulted in high costs materially and emotionally, individually as well as for society (Malmö Stad & VASYD, 2016). Thus mitigating runoff and making it slow is of great value. However, the management of average precipitation in Sweden is of just as high importance since this currently turns into an issue of pollution spread more regularly than flooding caused by clodbursts, although calculations of climate change presume this issue to increase in the future (SMHI, 2016). Instead the major focus currently lie within the preventing of contamination to spread through runoff and the mitigation of fast runoff (Svenskt Vatten, 2017).

Policies & legislations

As Sweden is currently missing a national strategy or stormwater management policy, as well as a “Plan of Action” regarding the work of adapting to climate, the main responsibility of achieving results lie within the municipalities and private property owners - although departments and authorities naturally are extensively involved in the work as well (Svensk Försäkring, 2015; Svenskt vatten, 2016). Universally, a strong collaboration between a variety of people in the municipal organisation possessing expertise in the subject need to, according to Svenskt Vatten (2016), construct the foundation to be able to create a sustainable society. This idea statement is supported by people within the field globally; e.g. Barbosa *et al.*, 2012 and Malmö Stad & VASYD, 2016.

Promoted solutions

From early 2000’s sustainable stormwater management has become increasingly used. In Sweden the aim overall is to achieve a slow runoff. Extensive infiltration to slow down and reduce runoff, the placement of correct topographic development to avoid damages during flooding, and an easy access for stormwater to surface water during extreme cloudbursts are the most promoted solutions. Slow runoff through sustainable systems (i.e. wetlands or dams) is promoted as heavy precipitation may cause the release of ground material (erosion) which may harm sensitive recipients and habitats. A dam for example provides good prospects of detaching particle bound pollution through sedimentation (Svenskt vatten, 2016).

Promoted stormwater systems

Svenskt Vatten (2016, p. 29) presents their suggestions of how to approach stormwater management in Sweden:

- ”Green roofs (detention of stormwater)
- Green sunken areas around parking space (detention of stormwater)
- Safe topographical location of buildings in relation to street (preventive measure to keep a sustainable stormwater management)
- Open surface water for runoff (preventive measure to keep a sustainable stormwater management)
- Open drainage route (preventive measure to keep a sustainable stormwater management)
- Raingarden (preventive measure to keep a sustainable stormwater management)”
- Provide space for flooding areas (Svenskt Vatten, 2016, p. 23)

Sustainable Stormwater Management Solutions

There is a vast collection of sustainable stormwater management solutions. Depending on site character and context, different solutions are applicable. The general apprehension of how to design sustainable stormwater systems is to use a range of solutions approaching the same and different issues onsite, concerning both various and similar aims, in order to be able to target all that is needed onsite (Barbosa *et al.*, 2012). This should build a strong, functional and lasting stormwater management. Calkins explain the use of distributing runoff between infiltration, evapotranspiration and discharge, as peak flows are reduced and may prevent flooding to some extent. She proclaims average storm events to be able to reach predevelopment levels regarding peak flows through this multi-use solution (Calkins, 2012).
As stated before, the concept of sustainable stormwater management is still under heavy research; therefore solutions well promoted today may not be as well received tomorrow. However, it is important to start and keep implementing the solutions today in various settings to be able to analyse the outcome of them for tomorrow's research.

One common objective within the various innovative approaches, i.e. LOD and SUDS, is to manage the runoff as near the source as possible in order to keep the system as similar to the natural hydrological cycle as possible, as well as to decrease pollutant discharge onsite (Sage *et al.*, 2015). This can be achieved many ways - too many to state all in this thesis. Therefore only a few will be presented overall, some in this part, others in the case studies.

Drawbacks for sustainable stormwater management

As previously mentioned, the concept and use of sustainable stormwater management and systems is in constant development (Fletcher *et al*., 2015). Sustainable systems of today are far from completely sustainable, and therefore the question is whereas current sustainable systems should be referred to as sustainable at all. It can be discussed whereas many constructions claiming to be sustainable actually have achieved their aim and objectives, as well as the aim and objectives of the term/ concept the producers are claiming to be using. Fletcher et al. (2015) adheres the importance of comparing the vision to the actual outcome critically, to identify the success or failure of each project.

Economic sustainability

Economy is usually the main factor of not implementing sustainable stormwater systems in development. As development is dependent on economy, designers have to regard the cost in comparison to aims and wishes. The general apprehension is, according to Liptan & Santen Jr. (2017), that grey infrastructure is cheaper than green. Thus grey infrastructure is carried out to a further extent than green sustainable infrastructure. Liptan states this apprehension to be incorrect - it is possible to construct sustainable cities which both in a short- and long-term perspective is cheaper, thus economically sustainable. This is supported by Malmö Stad &VASYD (2016) argues the economic costs for e.g. repairing damages and provide for emergency departures extensively exceed the costs for preventing flooding. Svenskt Vatten (2016) refer to personal interviews from Gothenburgh that it would be a higher cost to e.g. cleanse surface waters *after* contamination instead of *preventing* contamination happening, which is further supported by Calkins (2012). Sometimes the issue rather sits with the functionality after a "sustainable" solution is implemented, instead of the actual construction of it. According to Calkins (2012), the *use* of treated stormwater, rather than the treatment of it, is considered the greater challenge. The level of water quality from onsite wastewater treatment is dependent on what sequence of wastewater treatment it has run through. Sequence is chosen depending on what level of quality the owner aims to achieve. E.g. treated stormwater to be let out in surface water has to be of a higher quality than treated stormwater to be used for irrigation. Additionally components have to be considered to be able to design use for treated effluent for land application. This prove the importance of needing a sustainable solution to work on all levels from beginning to the end in order to be economically valuable and sustainable.

What economic sustainability actually means and the argumentation which may arise cannot be discussed in this thesis. The mention of it is nonetheless of importance to all sustainable solutions as economy and economic value each play a major part of sustainable development - as the human world is based on economic evaluations and comparisons, whilst natural systems are difficult to evaluate the cost of.

The importance of water for people

Water, especially freshwater, is a vital part of our everyday life in Sweden. We drink it, we flush, shower, cook and clean with it, it is used for agriculture and in industries – the list can be made long. Yet, although only approx. 3% of all water in the world can be considered freshwater, in Sweden we are not at loss of it even though we use approx. 140 l/person every day (Svenskt Vatten, 2017).

The importance of water for the ecosystems

Of course, not only humans are dependent on water. Water quality issues and stormwater runoff affect and disturbs many ecosystems, of which we are both dependent and part of. Water play a complex part in nature, and is part of interrelated systems affecting and changing each other. In excess of water other parts of the systems are flora, fauna, air, soil and atmosphere - to name a few. Nonliving elements, i.e. water and air interacts with living organisms i.e. vegetation and soil organisms creating provisioning, supporting, regulating and cultural benefits for people (Calkins, 2012).

The impact on ecosystems does not only affect the living organisms in them, but also the nonliving elements interacting with them, and thus the people aided by the chain of ecosystem services. Furthermore the effect of ecosystems in one area has the potential of affecting another area far away from the originally impacted ecosystem (Calkins, 2012).

Healthy ecosystems, of which we often take for granted, also have economic value. The ecosystem services we (often unknowingly) are provided with, for example by wetlands, would cost us a susbtantial amount of money to do ourselves (Calkins, 2012).

Benefits from Ecosystem Services

Cited from Calkins (2012, p. 6):

- ”**Provisioning**: i.e. the production of water, clean air, food, medicines
- **Supporting**: i.e. pollination, waste decomposition, nutrient recycling
- **Regulating**: global and local climate regulation, erosion control, disease control
- **Cultural:** health, spiritual, recreation, relaxation”

Water and Climate Change

The average temperature is estimated to increase worldwide in coming years. Climate models measuring the relation between increased heat and increased humidity reveals that future weather becoming more extreme can be expected: dry areas becomes drier and wet areas wetter, the latter along with hydrological extremes (Todd *et al*., 2011). In Sweden extreme precipitation is predicted to occur over more days than currently, and with heavier loads of water (Malmö Stad & VASYD, 2016; Svensk Försäkring, 2015).

The Hydrologic Cycle

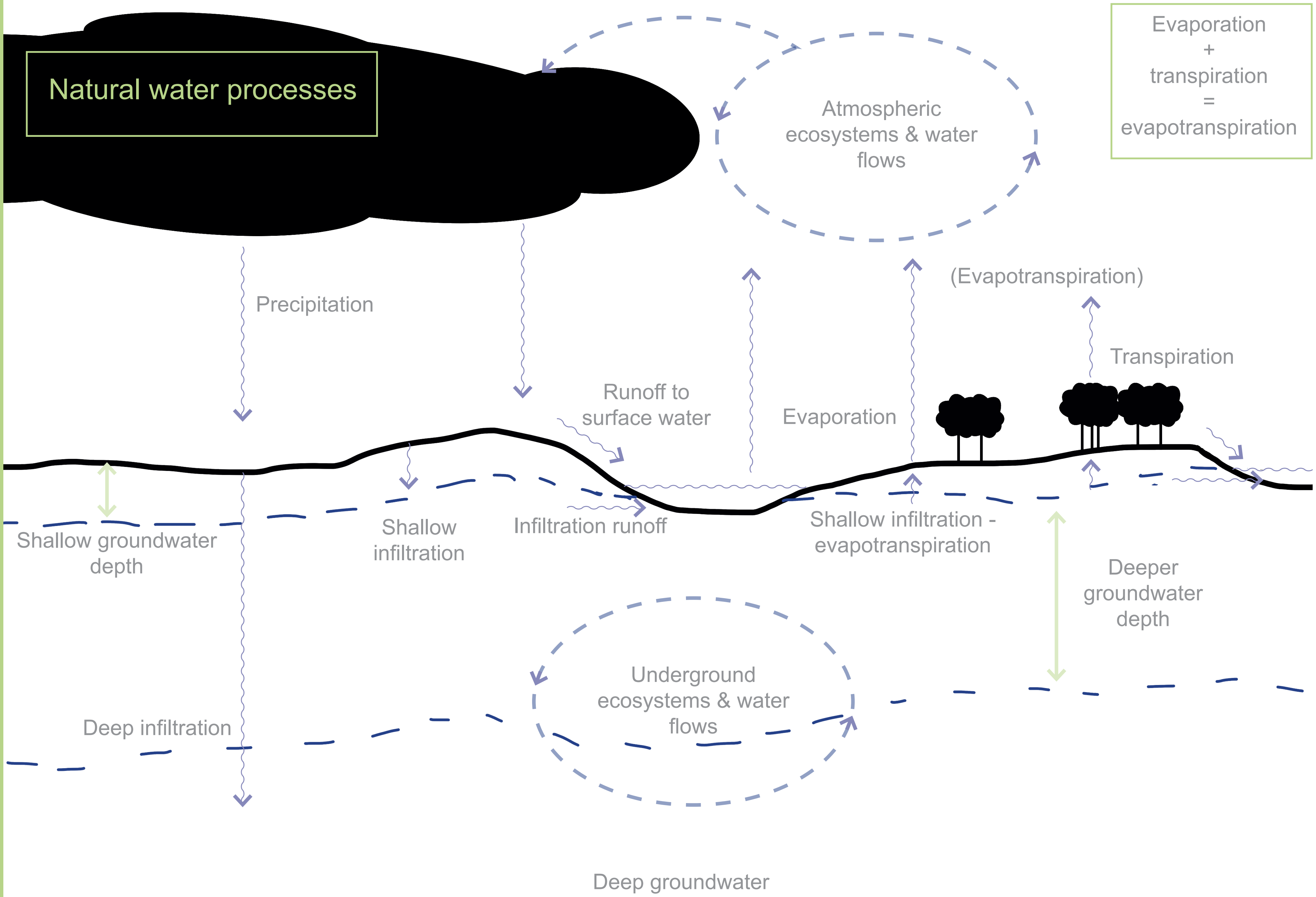


Fig. 3. Water flow is steady in all directions, balancing underground-, ground- and atmospheric ecosystems and water flows.

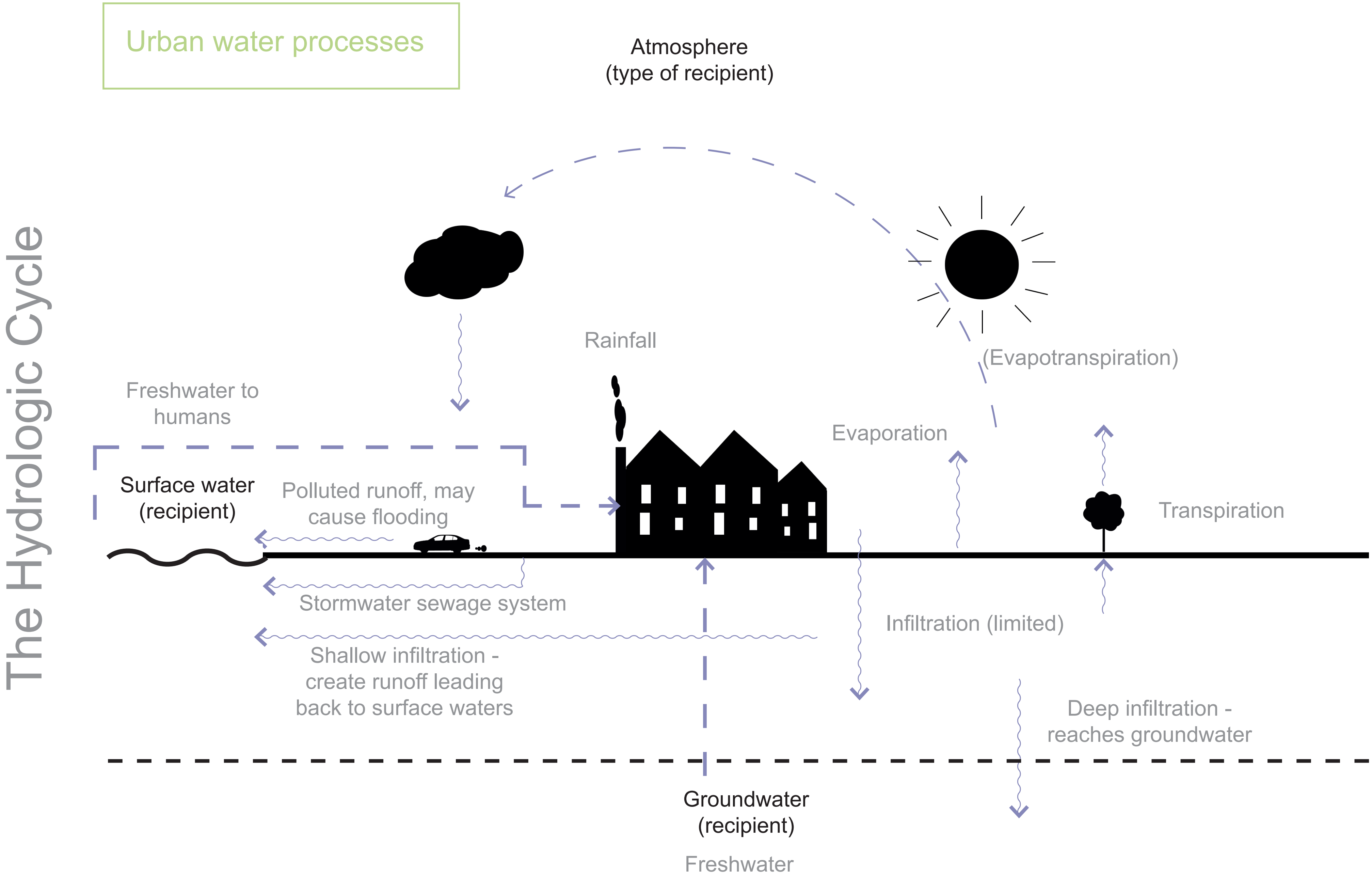


Fig. 4. The urban water cycle and processes work similarly to the natural water processes, but the urban context limits and alters it. Smaller amounts of infiltration reaching groundwater whilst humans extract freshwater from it, and higher amount of pollution reaching recipients are some of the outcomes from the alternation.

Bringing water back to the hydrologic cycle

The hydrologic cycle control the freshwater around us. It is constituted by interactions between geology, climate and, of course, all of our waters. The cycle perform a complex system of precipitation and evapotranspiration, flows and watersheds. This dynamic system is of vital importance for life on earth (Liptan & Santen Jr., 2017). Calkins (2012) stresses the keeping of the hydrologic cycle flowing naturally is a major part of sustainable stormwater management. Hydrological changes, often anthropologically caused, may amongst else result in pollution of freshwater sources and ecosystem alternations. An overview of the interactions and effects will be described* in this and following sections.

As can be read previously, in section ”*The importance of water* for *the Ecosystems” p. 17*, impacts made on one ecosystem may affect another ecosystem further away. Kent *et al.* (2016) describes the hydrological ecosystem(s) to work the same way. When altering the water cycle in one area upwind through land use change, e.g. by covering it in impermeable paving, it will have effects on the precipitation in another area downwind, since the upwind ecosystems need to change behaviour as they receive less moisture from the surface. This in turn may affect the vegetation growth, groundwater and surface water refill, evaporation providing precipitation etc. (Keys *et al.*, 2016), fig. 5. This since all waters affect eachother and everything using the affected water is affected as well. It is the part of the hydrological system that immediately affect us that we currently have an extensive knowledge of, which can be seen in the simplified hydrologic cycle on the previous page, fig. 3 and 4. Ecosystems we need further information of are the ”subsurface ecosystem” (subsurface flow processes) (Fletcher *et al*., 2013) and the ecosystems working in the atmosphere (the effects of and on vapour) (Keys *et al*., 2016) as can be seen in fig. 3 and 4. These gaps increase the difficulty of creating better, more sustainable drainage solutions and further adds to the complexity of the field.
To prove the point of knowledge gaps, two examples of fairly promoted stormwater systems will followingly be described.

The first example of a knowledge gap within the subsurface ecosystems and water flows is the solution of effective irrigation systems (fig. 6).
Effective water irrigation is during research found to be an effective approach within agriculture. This is however challenged in an article made by Ward & Pulido-Velazquez (2008). They stated that a more effective irrigation, where plants do not have the same possibility for evapotranspiration and underground runoff to occur, prevents aquifer (surface and groundwater) recharge and have negative effects on valuable return flows. This in turn has the potential of creating other issues within the hydrological cycle, i.e. compose devastating results on all ecosystems relying on the water flow and/or water levels. Collecting and conserving water upstream reduces the water downstream, which in arid areas can become a matter of water rights due to increased draught downstream (Ward & Pulido-Velazquez, 2008). Thus it is not only a question regarding issues within the hydrological cycle, but has also become a politic issue of rights to and possibility of having freshwater.

Ward & Pulido-Velazquez (2008), describes the continuous anthropogenic adjustments to have impacts on water flows. The water conserved to be spread out evenly through the effective irrigation system, across a field or other surface, has the potential of negatively affect the natural water flows through water depletion, since the small water amount may never reach the groundwater. “Adoption of more efficient irrigation techniques reduces valuable return flows and limits aquifer recharge” (Ward & Pulido-Velazquez, 2008).

This example presents a stormwater solution meant to enhance the efficiency of our crop production (or potentially other

*As the system is highly complex, and all interacting factors affect one another, this thesis is limited to present only an overview of the subject.

The Hydrologic Cycle

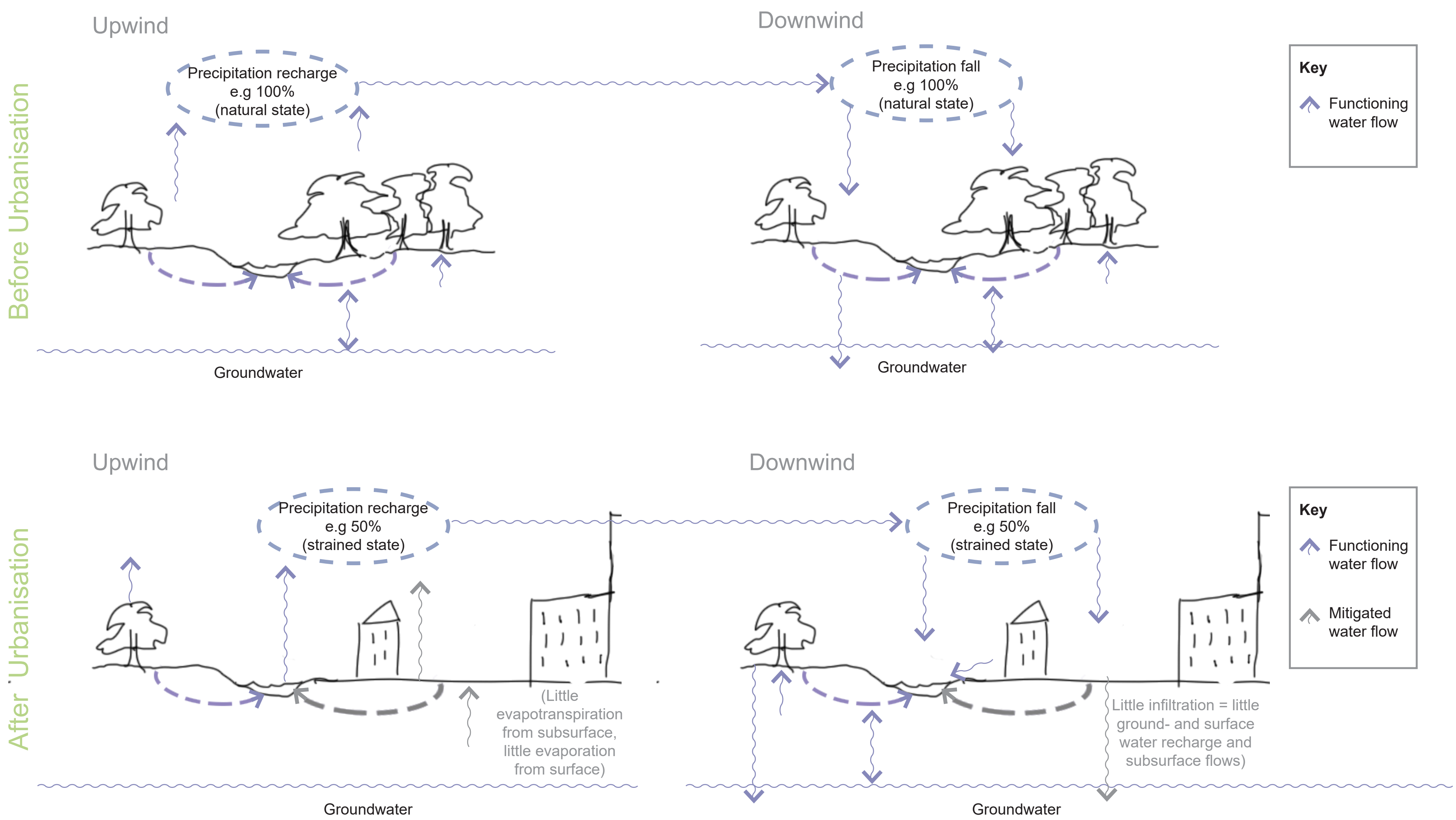
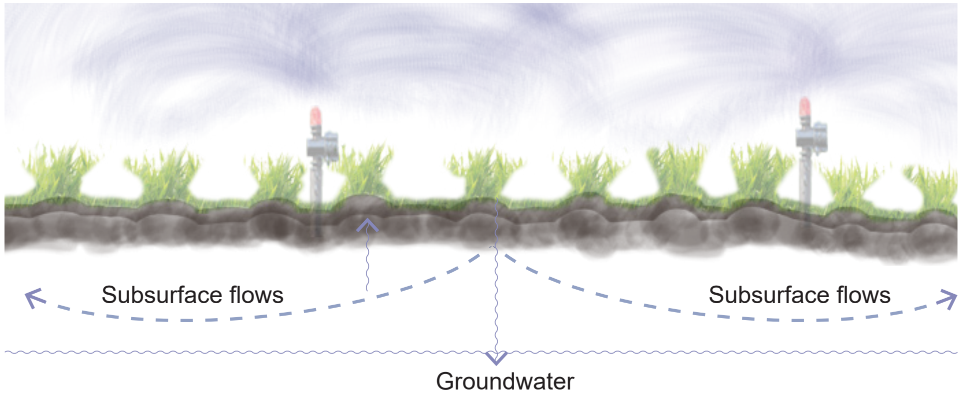
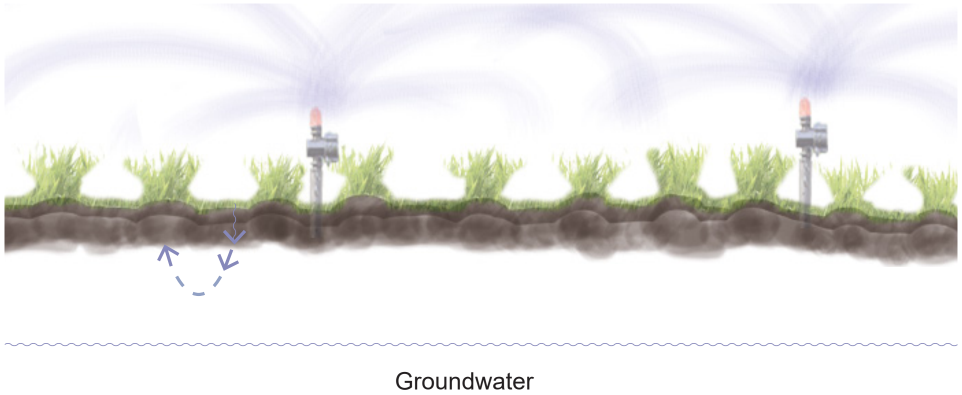


Fig. 5. Precipitation falling in one area has to have been collected in an area upwind. Lets pretend recharge of precipitation in one natural area is always 100%. After urbanising half the area, spreading impermeable paving and removing natural surface waters, precipitation recharge decreases to e.g. 50%. The natural area still has its water processes, but they are affected by the change in land use in the area across the lake. Subsurface water flows, important for recharging and levelling surface- and groundwaters, are in urban areas mitigated. Thus only the subsurface processes underneath the natural area upwind are functioning in comparison to the processes underneath the urban area. As the urban area upwind however decrease evaporation and precipitation recharge, the precipitation downwind is decreased and provides less water than it should. This may have visible effects on vegetation growth as well as in groundwater recharge. Surface water volumes may however be both overcharged and polluted in some areas, whilst half drained in others, due to urban runoff. Change in recipients water levels and vegetation growth can in turn affect habitats and ecosystems.



Rich irrigation can aid the hydrologic cycle, providing it with the water it lacks to let the subsurface flows progress naturally and recharging groundwater. The infiltration results are in a way similar to infiltration areas.



In dry periods, small amounts of water in irrigation systems let the water evapotranspirate before reaching the groundwater. Thus it does not aid subsurface flows to flowing naturally.

Fig. 6. Potential impact from using effective irrigation.

green area) in order to save freshwater whilst reducing runoff. If we are to believe Ward & Pulido-Velazquez, this second anthropological interference in the natural hydrological cycle (the first one was to make the site a crop field in the first place, reducing the site's possibility of keeping water through vegetational roots) has the potential of disturbing all ecosystems and recipients connected to the underground water flows and groundwater, through the reduction of freshwater collection in the cycle.
Ultimately, the solution where the effects are not obvious to us does the exact opposite of the aim for the solution construction. Freshwater is lost and the loss brings additional losses with it due to alternations within the hydrological cycle.

The second example regards a debate of a stormwater system also made to save freshwater as well as reduce runoff onsite - stormwater harvesting.

Stormwater harvesting has during this thesis' research been found to be used in many situations. It is used to save freshwater and mitigate flooding as it reduces runoff volumes (Fletcher *et al.*, 2013). The harvest can either be kept in e.g. enclosed barrels or underground reservoirs, or in open retention basins. Collected stormwater can e.g. be used in irrigation systems or for flushing toilets, which reduces the use of freshwater (Calkins, 2012). As the stormwater is systematically drained from its retention basin, the basin gains further potential of reducing peak flows and runoff volumes.

The use of this solution is questioned by Gwenzi & Nyamadzawo (2014) who discusses the use of e.g. large-scale water harvesting systems lacking the professional knowledge and understanding of the subject. They consider the unique location of every urban area including factors i.e. climate and surface material, and thus stress the use of further research within urbanised catchments as every site has an individual hydrologic cycle. If using systems in sites where the compability is not fully evaluated, issues on site as well as on ecohydrological processes downstream may occur.

They have researched large-scale water harvesting systems on rooftops. They consider the ideal inventory for implementing this kind of system in an urban area should, according to Gwenzi and Nyamadzawo (2014), include the analysis of a hydrological model and field measurements. Understanding the individual water flows and processes onsite, and how they affect one another as well as their surroundings, will help the designer mitigate potential drastic changes in the water cycle which otherwise often happen during urbanisation. Fletcher *et al.* (2013) and Han *et al*. (2017), support this by stating the need for using hydraulic models for water storaging to prevent negative influences. In other words, no matter what kind of water system a designer aims to build, trying to understand how the construction may affect natural and urban water processes at a local as well as far reaching level is of importance to mitigate negative changes within the hydrologic cycle.

In the report made by Gwenzi and Nyamadzawo, they further conclude the complexity of the effects water harvesting has on evapotranspiration as well as on groundwater recharge. As each site is individual and has its own unique hydrology, the meddling/tampering with it my cause significant issues, such as described above. Their investigation presents many processes counteracting with each other, which is why heavy investigation and analaysis has to be carried out on a site before the construction of a water harvesting system (Gwenzi and Nyamadzawo, 2014). The encouragement of practicing further research within the field is supported by Fletcher *et al*. (2013).

Once again the aim is to save freshwater and in the meantime be able to reduce runoff, for example from rooftops if implemented in lage-scale. However, the prevention of evapotranspiration may change the habit of precipitation, which in turn may affect both groundwater recharge and ecosystems depending on the rainfall. Thus it can be stated that in many cases it is of uttermost importance to bring the water back to the hydrologic cycle, and not try to collect it, in order for it to flow as naturally as possible.

Drawbacks

Although there is a range of information of the area today, it is still not researched enough, which can be concluded from the two presented examples. Further research must be carried out within the field to find out how the cycle is affected through antropologic changes, and what the outcomes may be.

The importance of surface water

It is well known that stormwater is a large contributing factor of the pollution of recieving waters. Pollution does not only affect the polluted recipient and its habitats, but also water sources and their ecosystems connected to it as well as water downstream (Valett & Sheibley, 2009), as surfce waters may be connected either by streams or through groundwater (fig. 3). Since surface water is connected to groundwater, the risk is high of both becoming polluted. As both ground- and surface waters are used for freshwater in Sweden, this is a major issue (Svenskt Vatten, 2017). To achieve an effective stormwater management system, it is of importance to understand the interactions between the waters (Sophocleous, 2002).

Interactions between surface- and groundwaters

Surface- and groundwater interacts within the hydrological cycle through infiltration, recharge and discharge processes of water (Valett & Sheibley, 2009; Sophocleous, 2002). The water exchange these processes make provides for and maintains hydrological ecosystems and habitats, and occur between aquifers linked to above-ground water bodies. Alternations in the interactions has the potential of changing the processes of ecosystems, and environmental conditions have throughout evolution been dependent on these exchange processes (Valett & Sheibley, 2009). Thus the ground-and surface water interactions can be stated to be of highest importance for our ecosystems to function properly.

Urbanisation may cause alterations in the water exchanges due to extensive cover of impervious surface. Mitigated baseflows and flashy storm flows are two results from the loss of recharge of ground water from precipitation (Valett & Sheibley, 2009). A streamflow destabilised due to excessive runoff may affect nutrient, sediment and hydrological loads, which individually may result in the decrease of health and stability of receiving waters, disconnection of water from floodplains and erosion (Calkins, 2012).
As precipitation works as a transport system for surface pollution, and climate change is presumed to increase precipitation volumes (Barbosa *et al.*, 2012), additional issues due to urbanisation are an increased concentration of containment and nutrient levels, degradation of a diverse collection of animal species whilst instead promoting the dominance of tolerant species, and a flashier hydrograph (Walsh *et al.*, 2005).

Of course, the relationship between the ground- and surface waters in relation to the geology, topography and climate onsite also play part in the system and interactions, which is stressed by both Sophocleous (2002) and Alley (2009).

Stormwater quality

The variety of pollutants that can be found in stormwater is vast, and the contamination level can usualy be traced back to land use and season (Barbosa *et al.*, 2012).

Stormwater heavily contaminated by metals or micropollutants can have deathly effects on living organisms in surface waters, whilst less contaminated water may cause increasing or chronic effects (Barbosa *et al.*, 2012).

Barbosa *et al*. (2012) explains that the stormwater quality + the volume of stormwater, in comparison to the volume of water + the quality in the receiving waters, decides the impact polluted stormwater has on the receiving waters (See fig. 7).

Thus depending on the water volume in a recipient and the mass of pollution that enters it, the recipient can either suffer from gross or slight contamination. The outcomes varies depending on grade of contamination, but no matter if it is more or less pollution in a recipient it still has effects on the life within it.

Stormwater quality + Stormwater volume

In relation to the recipient's

Water quality in recipient + Volume of water in recipient

=

Impact the polluted stormwater has on the receiving recipient

Fig. 7. How polluted the recipient become when stormwater is added to it depends on the added stormwater's quality and volume, as well as the recipient's current water quality and volume of water. How great the additional pollution is determines the impact on the water system and connected ecosystems. Information adapted from Barbosa *et al*. (2012)

Drawbacks

Since there is a high potential of addressing hydrological issues anthropogenically caused, much research is carried out within the field of how to avoid the disturbing and polluting receiving waters. It is however still by Valett and Sheibley (2009) concluded that much more investigation is needed within the subject in order to achieve the aim of completely mitigating hydrological issues caused by humans.

The importance (and potential) of infiltration

According to Calkins (2012) infiltration is (as can be seen in figure 3 and 4), along with evapotranspiration, a substantially important ecologic process. It is therefore also one of two (the second being evapotranspiration) of the most important objectives within sustainable stormwater management. Both processes are increasing within sustainable stormwater management design, as they often have the possibility to occur within open stormwater systems. These in turn are increasing in popularity both as they are considered realistic solutions, not only desired solutions in a world yet to be designed, as well as aesthetically pleasing (Calkins, 2012).

Infiltration is the source of recharging groundwater - without it there is no groundwater. In natural conditions approx. 20-30% of precipitation infiltrates. After development all from 0% to 30% of precipitation may infiltrate (Calkins, 2012).

The maintenance of high infiltration for long periods of time is of grand importance for for groundwater recharge (Rice, 1974). Site conditions, i.e. soil permeability and the potential of clogging, constitutes the main factor of the potential and success of infiltration (Fletcher *et al.*, 2013). Permeable soil let water seep through, whilst simultatneously erratically removing certain pollutants (i.e. high levels of oil and metals) (Ellis, 2000).

Clogging, on the other hand, is by Rice (1974) explained to occur when the pore diameter in soil is decreased, making the soil less permeable. This mitigates the infiltration, and keeps the water above ground. There are three classifications for clogging: chemical, physical and biological.

- Chemical clogging is due to dissolved salts (sodium) that chemically interacts with soil and water, minimising the pores.
- Physical clogging occur when small particles in the soil blocks the pores.
- Biological clogging decrease the pore diameter through bacterial growth, either by the bacteria itself or its by-products.

Clogging in relation to sustainable stormwater management systems after some time is not uncommon, i.e. in swales or underneath permeable paving, and the issue as well as the potential redemption has to be researched further (Ellis, 2000).

Infiltration-based and retention-based techniques

Fletcher *et al.* (2013) stresses the two focus applications within stormwater management technologies to be:
- Water quality treatment
- Mitigating hydrologic changes

Key elements of a natural flow regime in a catchment are infiltration-based techniques (to use in impermeable areas) and retention-based techniques (to work with volumes and peak flows) combined in order to be successful (Fletcher *et al.*, 2013).

Infiltration-based techniques help charging groundwater and subsurface flows which has the potential of restoring base-flows. Examples of this kind of systems are rain gardens, swales, permeable paving, basins and infiltration trenches.

Two examples of *local* infiltration-based systems are 'Enhanced infiltration basins or trenches' and 'Swales'. According to Calkins (2012), an enhanced infiltration basin or trench is made to recharge groundwater and reduce runoff volumes. It infiltrates collections of water into the direct and surrounding soil through coarse and well-graded clean aggregate which purposefully forms large voids (ca 40% void space) for water to infiltrate to. Runoff diverted to the infiltration area is cleansed from e.g. sediment and pollution to avoid groundwater contamination. Soil onsite has to have the adequate infiltration rate and potential (supported by Fletcher *et al.*, 2013) to cope with the precipitation rate. Preferably the trench or basin should be approximately located to the runoff source (to reduce cost and speed of water), be aesthetically enhanced since vegetation rarely is used and be no larger than one acre – there should rather be multiple infiltration areas across site. Today these types of infiltration solutions can only help during small storm events.

Swales on the other hand has the potential of handling larger storm events if designed with correct vegetation. It has a good potential of cleansing water from pollution and sediments before leading water to e.g. infiltration areas. The system infiltrates locally, and can therefore be placed in certain areas at a generally impermeable site for local infiltration. Properly constructed swales normally can handle a 25-year event (Calkins, 2012).

Retention-based techniques retain stormwater, resulting in either the attenuation of outflow or reduction of water through evapotranspiration. Examples of systems are lined and draining raingardens, ponds, an assortment of water harvesting facilities (i.e. tanks or storage basins), wetlands and vegetated roofs (Fletcher *et al.*, 2013).

Fletcher *et al*. (2013) explain that retention-based technologies tend to only reduce their water levels through evapotranspiration and the potential harvest, not through infiltration. Therefore their potential of reducing runoff is limited to their size. Thus retention-based technology can be used for three purposes:
1. Retain water to evapotranspirate (if possible) and returned to the hydrological cycle slowly.
2. Retain water which *may* be used for harvesting (if possible and if needed).
3. Used for attenuation of water providing detention, provide for a slow outlet and constitute a space for water volumes.
Hence also systems without potential for infiltration may have a positive impact in areas where heavy precipitation causes high peak flows, since water volumes can be collected in retention-based systems and mitigate the flow (Fletcher *et al.*, 2013).

The importance of groundwater

Groundwater is a vital water resource for both human and vegetation. It's absence has the potential of composing major impacts on recipients i.e. wetlands and lakes. Thus flora and fauna living within or nearby those recipients are dependent on the availability and quality. During dry periods the groundwater is vital to sustain streamflows (Alley, 2009).

In Sweden freshwater is fetched from ground- and surface water (Svenskt Vatten, 2017), hence its availability is of greatest value. Withdrawal of water has to be compensated by additional flows, since it alters the natural flow system. This compensation is by Alley (2009) described as achieved through some combination between three bullet points:

- Increased recharge through addition of water
- Decreased discharge through smaller withdrawals
- Only water that is additionally stored through an increase of water flow in the system is withdrawed

Recharge

Alley (2009) tells there are two types of recharge for groundwater: natural recharge and human-induced (artificial) recharge. Natural recharge occurs naturally

within the hydrologic cycle. It can be localised or diffuse (although groundwater tends to gain refills from both simultaneously): localised meaning recharge through the infiltration from surface waters to groundwater; and diffuse meaning recharge through the process of infiltrating through the vadose zone (from the land surface to the water table) after precipitaiton.
Human-induced recharge occurs either consciously e.g. by using injection wells or spreading basins, or unconsciously as a consequence: e.g. by using irrigation systems.

Most of the infiltrated water does however tend to evaporate or transpirate to plants rather than recharge groundwater, since it fastens in the soil zone. The amount of water reaching the groundwater is generally dependent on factors affecting the diffuse recharge i.e. local weather and climate, topography and vegetation, as well as the water table depth (Alley, 2009; the latter supported by Han *et al*., 2017) - which makes calculations of the recharge percentage difficult.

Influential factors

Recharge processes of groundwater are complex due to the many influential factors. It is not only the diffuse recharge that is influenced by surrounding factors. Anthropogenic modifications can be negative as well as positive (Han *et al*., 2017; Alley, 2009).

Alley (2009) and Han *et al*., (2017) explain that negative activities are e.g. deforestation, urbanisation (increase of impervious surfaces) and drainage of important water collectors i.e. wetlands. This result in an increased runoff volume and speed, preventing natural infiltration to occur and mitigates groundwater recharge on a local level (whilst increasing stormwater runoff).

Some positive activities on the other hand are installations of stormwater recharge systems i.e. artificial wetlands (Alley, 2009), as well as the rich irrigation of agricultural land (Ward & Pulido-Velazquez, 2008). Although artificial recharge systems aim towards increasing the the groundwater levels in order to make amends for human water withdrawal, there are complications. Is infiltrated water polluted, the groundwater quality is endangered, posing issues i.e. illness for everything living using the water (Calkins, 2012). Common contaminants are salts, nutrients, metals, pathogens and pesticidies - which one(s) that becomes the contaminant(s), as well as the quantity of pollution, depends on the substance's potential of infiltrating through the specific soil onsite (Calkins, 2012).

Considering purification of groundwater after contamination is heavily difficult and expensive, it is by Calkins (2012,) adviced to prevent pollution of groundwater happening to begin withw through purification of runoff before it is diverted towards an artificial infiltration system.

Care does nonetheless have to be taken regarding how contaminants are being dealt with. Even though they are removed from the runoff through e.g. soil infiltration, they are instead cought between the soil particles within the water particles, which may cause other issues instead (Calkins, 2012).

Summary of influential factors

The influential factors described in the text are here summarised for a simplified overview:

- Anthropogenic modifications
- Space available underground for groundwater recharge
- Anthropogenic and natural changes due to climate change
- Land subsidence
- Aquifer depletion
- Groundwater's response to surface's hydrological changes (often anthropogenic)

Approaches for recharge

Recharge of groundwater through e.g. stormwater management technology is significant for controlling its availability (Calkins, 2012; Han *et al.*, 2017). Runoff from impermeable areas can be lead to infiltration galleries or retention basins. This changes the location for infiltration; from diffuse recharge to a fast local recharge (Alley, 2009; Han *et al.*, 2017).

The research in this field is still challenged. All alterations to natural recharge and decharge rates of the hydrological cycle may for example have many heavy impacts on surrounding eco-environment (Han *et al.*, 2017), of which is known relatively little. The knowledge and understanding of the connection between the groundwater recharge and vegetation, and the effects land change has on groundwater, is of vital importance for future water management and sustainable land (Han *et al.*, 2017). Hence it has to be acknowledged that to achieve a functional sustainable water management method, without disturbing our ecosystem, we need to fully and effectively understand the natural processes of groundwater and its recharge, its relationship with vegetation and its impact on the surroundings in order to be able to continue using groundwater as our future natural water magazine through recharge processes.

Effects of groundwater recharge

Calkins (2012) states a list of what groundwater recharge through stormwater infiltration can do:

- Prevent lowering of groundwater levels
- Supplement domestic water supplies
- Restore stream base flow
- Help maintain wetlands and riparian areas
- Prevent wells and springs from going dry
- Reduce land subsidence
- Prevent saline water intrusion
- Provide treatment and storage for reclaimed surface water for possible reuse
- Provide additional uses for land otherwise used for detention basins
- Reduce the cost of typical regional stormwater management systems
- Maintain a watershed's existing drainage patterna
- Help increase recharge of underlying aquifers
- Restore the annual water budget

The importance of evapotranspiration

The final part in the hydrologic cycle to be presented in this thesis is the component of Evapotranspiration.

As mentioned previously, the process of evapotranspiration (constituted by evaporation and transpiration) is important for the natural water system, along with infiltration. Recharge of water resources through precipitation made by land evaporation (also known as moisture- or evaporation recycling) is vital to both water resources and ecosystems (Ent *et al.*, 2014).

Natural factors regulating evapo-transpiration's abiotic and biotic processes are e.g. climate (air temperature), reduced soil moisture, vapour pressure and elevated atmospheric CO2 (Katul *et al.*, 2012). Anthropologic factors are for example land use changes that alter the premises for the upwind ecosystems which may cause changes within the evapotranspiration processes. This can cause alternations in precipitation, resulting in regulations in the natural water flow (e.g. recharge of groundwater and surface water levels) which finally has an impact on humans, animals and vegetation e.g. access to freshwater (Keys *et al.*, 2016).

Evaporation has for a long time been

ignored as being a part of an ecosystem, and has been considered neutral to ecosystem services. Thus vaporation of water has only been considered as water loss, in some cases even harmful, e.g. within agriculture where it is considered water loss when the crops do not receive all the water for growing (Keys *et al*., 2016) which is why the effective irrigation system was invented in the first place (see section *"Bringing water back to the hydrologic cycle",* p. 20).

Drawbacks

As stated previously, the hydrologic system is incredibly complex, and the precipitation from different parts of the evapotranspiration process (evaporation, transpiration and interception) varies depending on site conditions (Ent *et al*., 2014). Calculations of how the natural factors affecting the efficiently of evapotranspiration processes, as well as to what degree, is still being researched. As factors within the evapotranspiration process is affected by its environment as well as by the other factors within the hydrologic cycle, the research within this field is difficult, and further knowledge has to be gained also in this field (Katul *et al*., 2012).

Examples of stormwater systems promoting evapotranspiration

- Ponds and wetlands (although the evaporation process is only to a small limited amount) (Fletcher *et al*., 2013).
- Vegetation. Leafs promote not only evaporation from precipitation landing on the leaf surface, but also provide transpiration where water is exuded from the leafs pores (Katul *et al.,* 2012). As vegetation additionally holds water underground as well as absorbs it, the runoff in the area decreses. In natural conditions, where forest cover much of the land surface, surface runoff of a site is calculated to be approx. 1%, whereas it in developed sites is approx. 20-30% (Calkins, 2012).
- Vegetated roofs. Functions almost like as a retention area as infiltration does not reach the groundwater. It may however be part of a system that let runoff from the roof infiltrate on the ground. If the vegetation is suitable for climate and situation, and the greenery covers the complete catchment area, then the roof can retain up to 65% of precipitation (Fletcher *et al*., 2013) - which enhance runoff mitigation in the area approximate to the roof/buillding.
- Water-efficient water features. These are water features (e.g. fontains, reflective pools, other water constructions in urban landscapes mainly used for aesthestetic purposes) connected to a site's stormwater system. The main aim for the system is to decrease the use of freshwater in the landscape by using purified stormwater collected onsite in the water feature instead of freshwater - which is often used otherwise (Calkins, 2012). Hilaire *et al.* (2008) explain that water in motion evaporates faster than stationary, especially during hot weather. Therefore using water features with moving water can be a source for decreasing stormwater (probably to a small extent) onsite through slightly enhanced evaporation. The water does however have to be purified to an extent as people might want to engage with it (Hilarie *et al*., 2008).

2

Application site
Case studies

This section presents information of the application site and the inspirational case studies. Ideas from the latter will be used, adapted and applied onto the application site. Presented information will cast the foundation for the Application site analysis in Part 3.

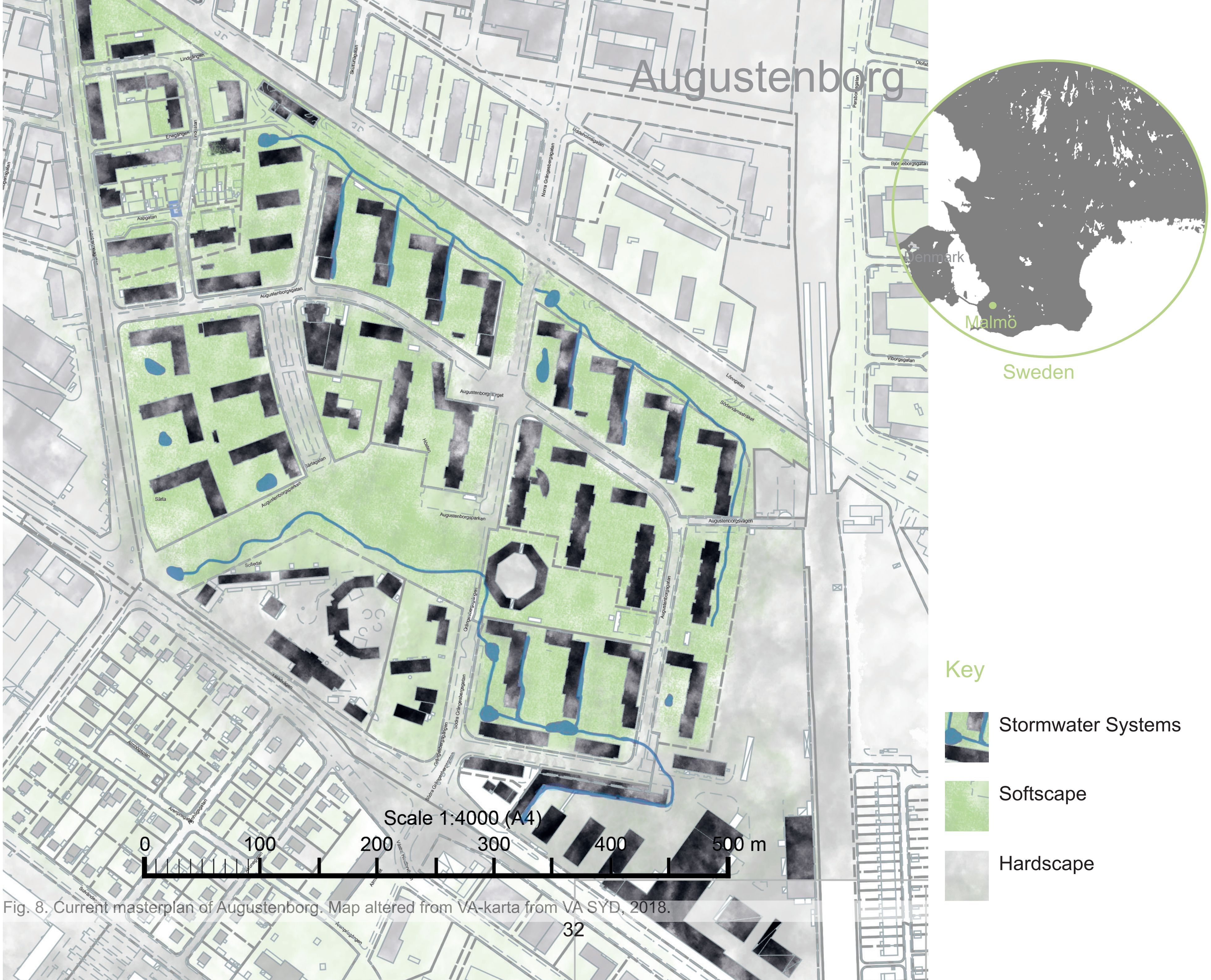


Fig. 8. Current masterplan of Augustenborg. Map altered from VA-karta from VA SYD, 2018.

Ekostaden Augustenborg
(The Eco City Augustenborg)

Location: Malmö, Sweden
Construction start date: 1998
Aim: The overall aim was to make Augustenborg into a settlement ecologically, economically and socially sustainable (Stahre, 2008). Water wise it was to mitigate basement flooding in the area (Beckmann, 2018; Stahre, 2008) as well as to show how sustainable stormwater solutions (of that time) can be constructed and used in an urban context. As the project is a so called ”Pilot Installation/Establishment”, the technical solutions are bound to be more expensive and not as funtional as projects built later (Folkesson, 2018).

Augustenborg is located in the eastern part of Malmö in Skania, Sweden. There is a slight topographic change leading down from southeast to northwest (fig. 9), leaving some potential for local water issues downstream. The domineering soil is moraine clay (fig. 10), limiting the natural possibility for infiltration in the area (p. (Sveriges Geologiska Undersökning, 2015). Malmö Stad & VASYD (2016) pronounce in their compendium ”Skyfallshantering in Malmö” (”Cloudburst management in Malmö”) the aim to make Malmö resilient and able to handle cloudbursts whilst through multifunctionality add value to the environment.

Background

Augustenborg was after it’s construction in the 1950’s a popular area to live in. As it was still common to construct combined sewage systems at the time (Svenskt Vatten, 2016), this system was installed in Augustenborg (VASYD, n.d.).
In the 70’s fewer people wanted to live in the area. One reason was that the housing and facilities were out of fashion. 10 years on the area had become one holding many problems. This could possibly be the result of a decrease in social self esteem and loss of identity onsite. As an aim to increase its popularity again and highten its social status the site was reconstruced and modernised (Stahre, 2008; VASYD, n.d.).

The concept for the reconstruction was to reconnect to the history of the site and its days of glory - the 50’s. Beckmann (2018), presume the vegetation is quite low key in many parts of the area, as the ideal garden design in the 50’s was not thickly wooded and leafy. Further information regarding the vegetation design has not been found during research for this thesis.

Topography

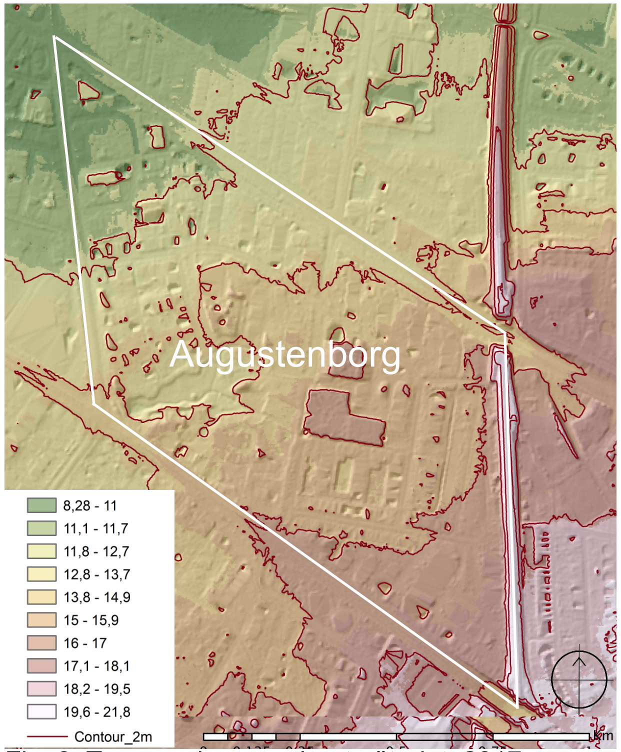


Fig. 9. Topography map. Lantmäteriet, 2017.

Soil

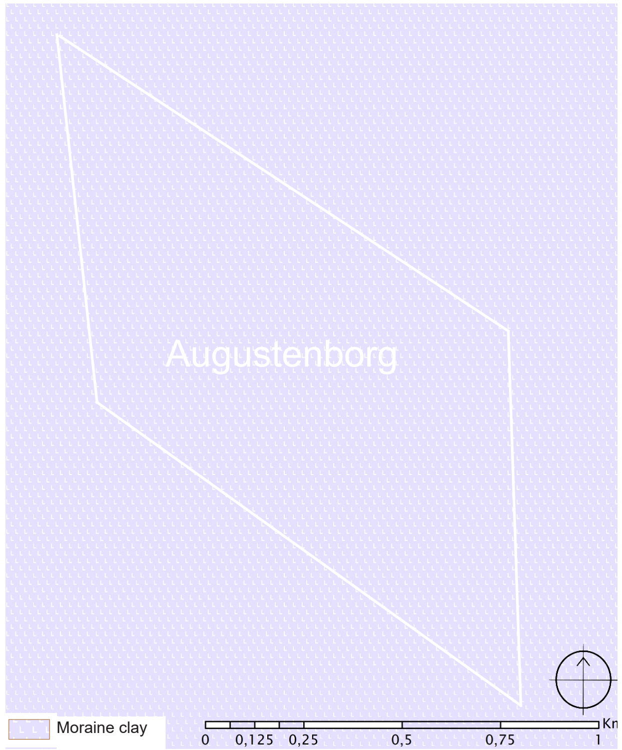


Fig. 10. Soil map. SGU, 2017.

Design aim

The aim for the reconstruction of the socially strained Augustenborg in 1998 was to create a space with improved ecological, social and economic values (VASYD, n.d.). The Eco City project was thus made of a range of sub-projects.

The main aim for the stormwater system is to delay and reduce the water. The goal is to reduce and detain approx. 70% of the stormwater onsite before the remains is diverted to the sewage system (VASYD, n.d.).

Design objectives

The objectives to achieve the aim are:

- To mitigate stormwater flowing into the combined sewage system
- To collect most possible stormwater in a new, open stormwater system
- To model the new open stormwater system through the combination of a variety of local, technical stormwater solutions
- To model the shallow stormwater system to keep stormwater within the site to the uttermost extent
- To model the open stormwater system in order for residents to find it as a positive and exciting experience in the urban environment
- To create prerequisitions for an enhanced biodiversity

(Beckmann, 2018).

The designed stormwater solution

The open stormwater management system is one of the sub-projects within the Augustenborg area. Most open stormwater systems had at the time been installed within new design projects, where they could be considered from start and thus be developed in the design project along buildings etc. The unique approach within the Augustenborg project was to adapt the new stormwater system to the already present condition of the site. The stormwater system therefore had to adapt completely to the condition of the built site (Beckmann, 2018).

As the area before the reconstruction suffered greatly from basement floodings, caused by the overload of the combined sewage system (fig. 1 and 2) during cloudbursts, the pressure on it had to be eased (Stahre, 2008). Therefore the sewage system was not only to most extent replaced from combined to divided double sewage system, but additionally stormwater was diverted to an open stormwater system connected to the sewage system (VASYD, n.d.) - just as recommended by Svenskt vatten (2016). Water is not only diverted from ground surfaces but also from some of the roofs, as can be seen in fig. 15 (VASYD, n.d.).

There are two open stormwater systems onsite: the Central Drainage Corridor (fig. 15) which was built first and is the larger system, and the Lönngatan Drainage Corridor (fig. 16). Both include a variety of retention-based solutions, slowing down the water flow which additionally gained the feature of reducing the water volume through evapotranspiration - although the latter was not intended (Beckmann, 2018). Both corridors are constructed to keep the runoff in the system for as long as possible (Stahre, 2008; VASYD, n.d.). This provide more time than before for the water to be in circulation which in turn provide time for pollution to fall to the bottom of the system. The created slam is removed systematically by a collaboration between MKB, VASYD and the Augustenborg School. The goal of making the water ”slow”, is simultaneously achieved as the drainage corridors is aiming towards keeping the water in the system. Water only reaches the sewage systems when the open stormwater system is filled to the brim. Hence only smaller amounts of water reaches the sewage system, unless it is an extreme cloudburst. As the water reaches the sewage system it is transported and emptied into the sea. The water is not reused as it is not considered clean enough to be further purified in the water purification plant. As Sweden currently has asset to voluminous freshwater sources the reuse of stormwater was not considered a neccessity when designing this system (Beckmann, 2018). This approach towards water management and sustainability could however be questioned and discussed.

One of the reasons for using a variety of retention solutions is to inspire people and provide a pilot foundation to help research and development forward (VASYD, n.d.). The contamination removal achieved onsite is therefore limited and only a positive side-effect (Beckmann, 2018).

A thick layer of rubber sheet is placed underground, presumably across quite large areas of the site to reassure the prevention of basement flooding* (Beckmann, 2018; Folkesson, 2018). Thus it can be presumed that little surface water can infiltrate to the groundwater in these locations (Folkesson, 2018). As the soil on site mainly is made of moraine clay infiltration is difficilt to enhance onsite as constructors need to be absolutely certain flooding will not occur (Beckmann, 2018). To reduce the water it therefore either has to evapotranspirate, or be removed. Removal of water from site, in this case diverting it from site to the sea, only occur when the water volume exceeds the barrier level within the stormwater system. As the system is made to keep water onsite, the water can only enter the stormwater diversion system if reaching a certain level of height, e.g. as seen in fig. 11 and 12.

Evaporation and transpiration are fairly achieved onsite due to the open stormwater system and vegetation. Some of the vegetation, e.g. in the mini-wetlands, has been designed to slow the flow of the water which also achieve some purification and evapotranspiration. Even though the hydrologic cycle was not taken into much consideration during the design work, evapotranspiration is thus still achieved onsite, but as a positive side-effect rather than aim (Beckmann, 2018).Having this said, no calculation has been made regarding the amount of water having been reduced through evapotranspiration onsite, neither for the volume of water mitigated through the open stormwater system (Beckmann, 2018). Beckmann (2018) does however show a GIS-map presenting residents stating their buildings not suffering from basement flooding anymore. This map, carrying the error that not every resident has been asked, shows that the area does not suffer from basement flooding anymore. The only area that has reported being flooded since the reconstruction is the Augustenborg School and park. This due to its low topographical location.

The central drainage corridor follow the logic of water and topography - the water follows the topography downwards from the eastern part of Augustenborg to its final station at the Augustenborg Park (fig. 14).

Having stormwater flowing along the surface has additional value besides the reduction of water volumes diverted to the sewage system and the return of water to the hydrologic cycle. Surface water also provides for e.g. ecological as well as aesthetic values (VASYD, n.d.) - features just as important to keep sustainable in order to create a fully sustainable site.

*The location and size of the rubber sheets have not been possible to access.

Fig. 11. Low water level.

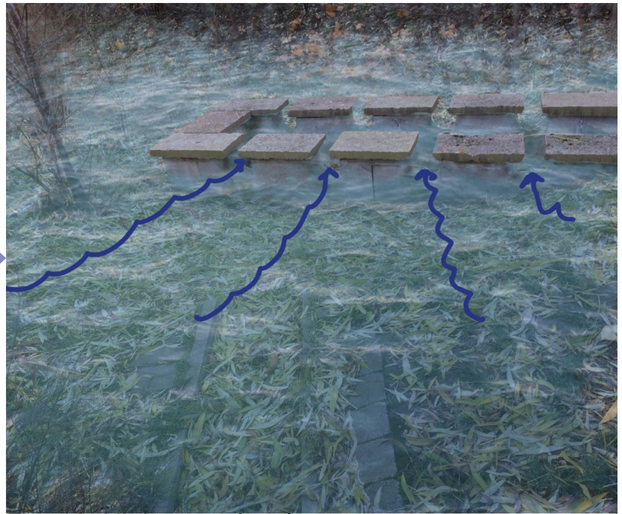


Fig. 12. High water level.

Application Site / Main case

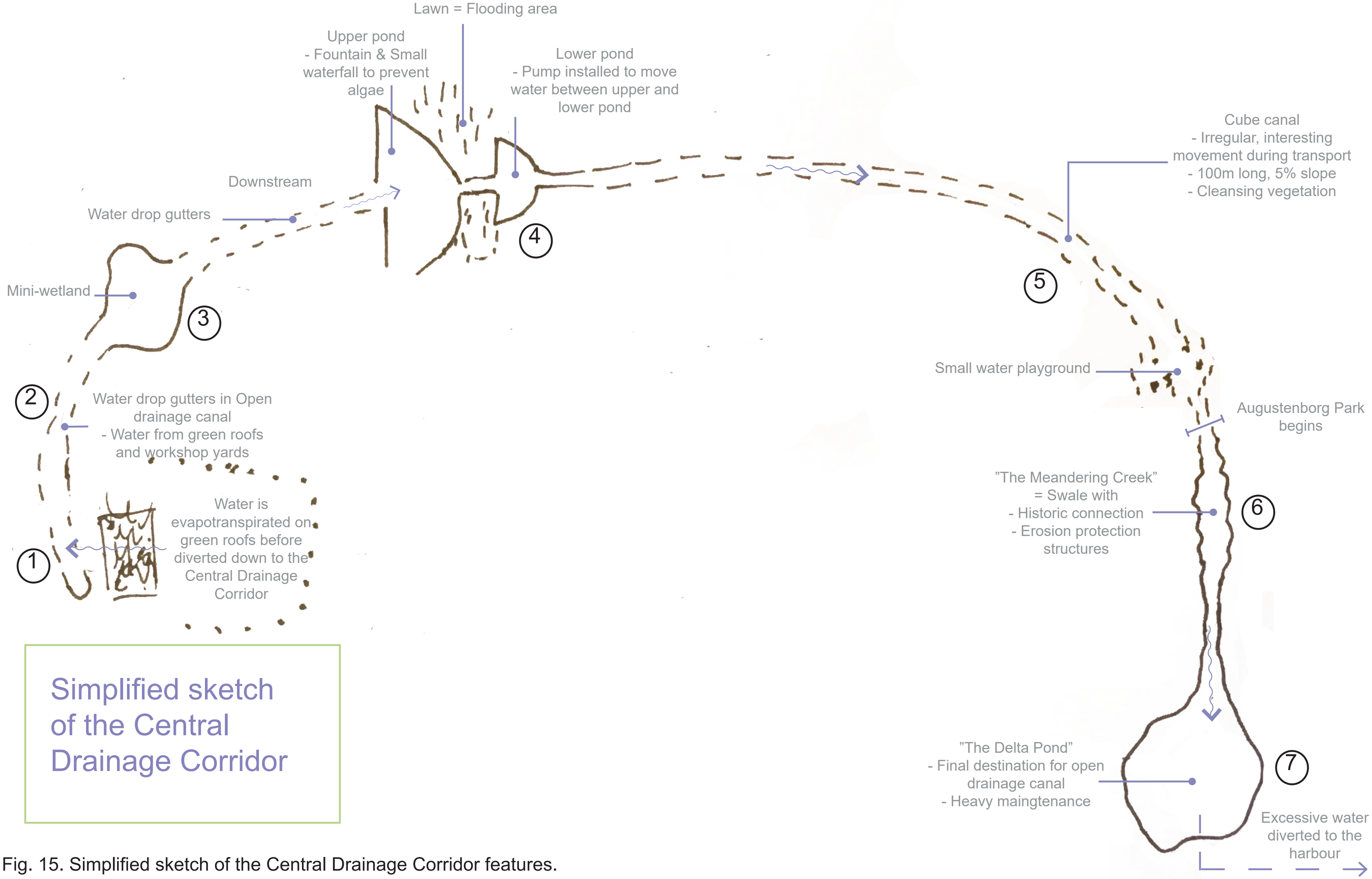
Fig. 13. Water corridors. Map altered from VA-karta from VA SYD, 2018; number location gathered from Stahre, 2008, p. 43.

Fig. 14. Water direction of the system follow the natural topography of the site. Map altered from VA-karta from VA SYD, 2018.

Key

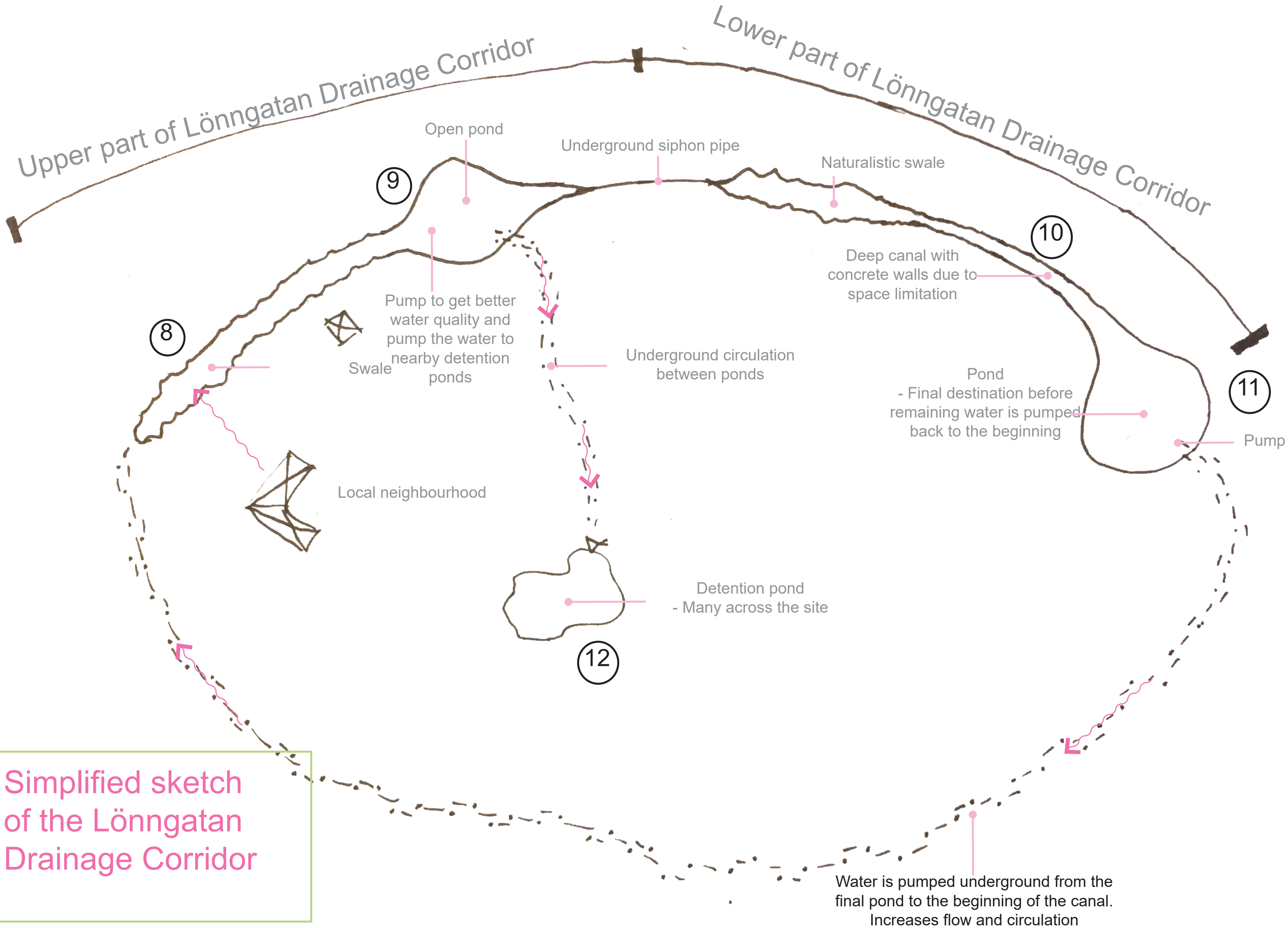
Central Drainage Corridor

Lönngatan Drainage Corridor



Simplified sketch of the Central Drainage Corridor

Fig. 15. Simplified sketch of the Central Drainage Corridor features.



Simplified sketch of the Lönngatan Drainage Corridor

Fig. 16. Simplified sketch of the Lönngatan Drainage Corridor features.

Simple site inventory

To gain an understanding of what the neighbourhood looks like and what feature is located where, this simple site inventory is presented. The numbers shows parts of the drainage corridors (conncected to the previously presented corridor sketches), and the letters some of the features most obvious when walking through the site.

Fig. 17. Water Drop Gutter.

Fig. 18 Double Pond, upper part. An aesthetic feautre during and after normal precipitation.

Fig. 19. Double Pond, lower part. During cloudbursts this area and surrounding wetland is allowed to flood.

Fig. 20. Ending of the Double Pond. Water has the potential of flowing into the canal would the water volume be too exessive.

Fig. 21. Part of the Meandering Creek running through the Augustenborg Park.

Fig. 22. The Delta Pond in the Central Drainage Corridor.

Fig. 23. Final step in the Central Drainage Corridor. When the water level is too high, the water passes through the opening at the end.

Fig. 24. Part of the Lönngatan Drainage Corridor.

Fig. 25. The only square in Augustenborg.

Fig. 26. Small fountains can be found in some of the ponds. Made to enhance circulation and oxygenate the water (Beckmann, 2018; Folkesson, 2018)

Fig. 27. Also larger fountains can be found, having the same purpose as small fountains.

Fig. 28. Playground and recreation area. Lowered topography, probably to function as a retention area.

Fig. 29. Playground and recreation area. Topography in level with buildings.

Fig. 30. Stormwater drainage within one of the housing areas.

Fig. 31. Water channel surrounded by wetland-like plants.

Fig. 32. Upwards elevated drainage channel. When the water reaches a certain level, it will pour through and into the drainage corridor.

Fig. 33. Deep, concrete part of the drainage corridor.

The IWA Model

IWA is a shortening for the ”International Water Association”. The association is, according to its own website, the ”largest international network of water professionals” aiming towards creating a more water wise world (International Water Association, 2018) through resilient design and planning (International Water Association, n.d.). The presented principles are created to achieve the goal of creating water wise cities standing upon a firm foundation of a collaborative process between fields of responsibility (International Water Association, n.d.).

Using designed principles from a fairly credible source could potentially enhance the analysis of the thesis when looking at ”best option”-solutions. The strength of the IWA-principles is the (presumed) thoroughness from stage 1 to 4, from site to politics. The principles further provide an understanding of the complexity of achieving a truly sustainable stormwater management. Although the hydrologic cycle is here not mentioned, the meeting of each principle contributes to a more natural water management which in turn support a healthy water cycle.

To the right 4 principles are stated which makes the foundation to the IWA’s approach of how to achieve a successful water balance in any space. Further information can be found in the *Appendix* p. 75-77.

P r i n c i p l e s

1
Regenerative Water Services

- ”Replenish Waterbodies and their Ecosystems
- Reduce the amount of Water and Energy Used
- Reuse, Recover, Recycle
- Use a Systematic Approach Integrated with Other Services
- Increase the Modularity of Systems and Ensure Multiple Options”

2
Water Sensitive Urban Design

- ”Enable Regenerative Water Services
- Design Urban Spaces to Reduce Flood Risks
- Enhance Liveability with Visible Water
- Modify and Adapt Urban Materials to Minimise Environmental Impact”

3
Basin Connected Cities

- ”Plan to Secure Water Resources and Mitigate Drought
- Protect the Quality of Water Resources
- Prepare for Extreme Events”

4
Water-Wise Communities

- ”Empowered Citizens
- Professionals Aware of Water Co-benefits
- Transdisciplinary Planning Teams
- Policy Makers Enabling Water-Wise Action
- Leaders that Engage and Engender Trust”

Principle information (above) cited from the International Water Association, n.d., p. 3.

Analysis of Augustenborg with the IWA-model

The following principles present ideas and proposed ”regulations” leading from local (blue) to regional and political (purple) adaptations, created by the International Water Association. Considering the knowledge and implementation of sustainable systems are not optimal today, it is not possible that the Augustenborg project can comply to all the presented principles. Comparing a site to composed principles such as the IWA-model can however provide the designer with informtation of sustainable errors onsite, ideas for how sustainability can be improved as well as arguments for how to bring issues achieving sustainability onsite to a political level.

Aiding the hydrologic cycle and achieving water sustainability goes hand in hand at many levels, which is why this model is of importance for this thesis. Following analysis and comments for each principle has been aimed to give answers both to the water cycle and sustainability to show the connections.

The importance of presenting the IWA-principles is to stress the complexity of the field sustainability, and to what extent and level the subject has to be considered in order to create sustainable neighbourhoods. See Appendix (p.75) for an explanation of each principle which provides the foundation to the following answers and discussions.

Replenish Water Bodies and their Ecosystems

Replenishing water bodies, including those we extract our freshwater from, is an important process as the reduction of water in water bodies alters the natural flow system which may result in negative consequences for ecosystems depending on certain water levels and water flows (Alley, 2009). Reducing water in one water body may affect and mitigate all water processes in connection to the water body - creating imbalances in the water cycle.
The level of replenishment of water bodies has not been investigated as the balance between the gathering and replenishmet of freshwater in recipients is not considered in this thesis. Presumptions instead has to be made. As less infiltration is allowed onsite due to the rubber textile sheet, and as enhanced infiltration areas are not installed, it can be presumed the replenishment of local groundwater is not carried out to its current possible extent. Thus potential water flows reaching surface waters connected to the groundwater are not positively affected either. The only water body gaining extra water from Augustenborg is the sea.

Regarding the effect the stormwater systems in Augustenborg has on ecosystems can be reflected on. As excessive stormwater onsite is diverted to spill out in the sea without further purification than the limited amount achieved in the open stormwater system, some pollution is bound to be let out in the sea. However, as presented by Barbosa *et al.* (2012), the level of pollution in a recipient is relative to the volume of water within the recipient. As the sea is a very large volume of water, contaminants from Augustenborg could be considered non-existent. On the other hand, would every neighbourhood let out a smaller amount just like Augustenborg does, the affect is no more simply a drop in the sea, but rather a stream of contamination.

Reduce the Amount of Water and Energy Used

The area does not keep water storages for reuse through eg. irrigation, in order to reduce the amount of water used onsite. Storage has been avoided as dimensioning of storage tanks is difficult to calculate, and as the current system meet the construction aim (mitigating flooding), there is no need for further changes (Beckmann, 2018). Beckmann (2018) believes the reason for not aiming to save freshwater in the landscape around Augustenborg was because Sweden generally has a large storage of freshwater, and therefore saving it was not reflected upon as important enough.

Energy is used for the water pumps and fountains that are installed to increase circulation and oxygenate the water (Stahre, 2008). Minimising the use and need of energy within the system has been

considered during design development which is made evident from the choice of using topography and thereby gravity onsite instead of using pumps for diverting stormwater to the open stormwater system which directs the water to the final outlet (in the Delta Pond) in the Central Corridor. For example, one reason flooding still occur in Augustenborg Park is the choice of not elevating the parkland area further downwards as made in some of the playgrounds (fig. 28). This would have required implementing more pumps and thus more energy to pump the water from the lowered topography up to the sewage system instead of letting it flow to its natural lowest point as it does today (fig. 34).
Water directed to the Lönngatan Corridor flows naturally until it reach the Pond, from which it (with pumps) is redirected back to the beginning of the first swale.

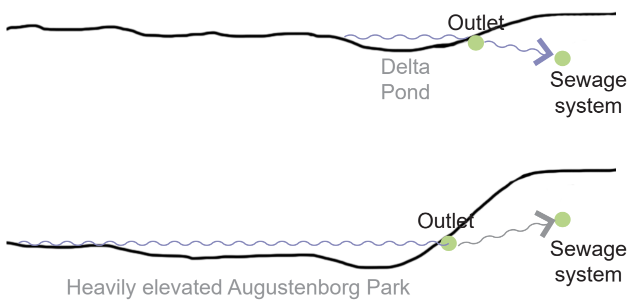


Fig. 34. Water in the top image can reach the sewage system inlet from the outlet in a natural manner. Water from the outlet in the bottom image cannot reach the sewage system inlet naturally, but would have to be pumped upwards to flow into the sewage system.

Reuse, Recover, Recycle

Sweden has an extensive access to freshwater. It has potentially therefore been argued needless to reuse stormwater as a mean to save freshwater when AB was built - since it is easier using a system we are used to, we use it. Thus, during the design process of Augustenborg the focus was placed elsewhere, in this case the mitigation of flooding (Beckmann, 2018). Learning to reuse and recycle stormwater within our neighborhoods would on the other hand prepare us for future changes in e.g. climate - as even though we can consider ourselves having much freshwater today, it is not unlimited. We should be able to handle a draught, aided by our sustainable stormwater management when we are exposed to it.
More importantly for this thesis, the reusing of water onsite could presumably also mitigate anthropologic changes in the water cycle. Reusing both stormwater and used freshwater lets us extract less from ground- and surface waters which reduce our impact on the natural water processes, mitigating them from progressing naturally due to their reduced state. Less extraction from freshwater recipients whilst instead learning how to save it also let us prepare for future changes.
Further using precipitation in the location it has fallen may aid the hydrologic cycle's natural processes as evapotranspiration (and infiltration where possible) occurs where it is supposed to, and not in another area to where the stormwater has been redirected.

The recovering of energy from water is not achieved onsite (Folkesson, 2018), once again probably as this was not aimed for in the design. Recycling of water, i.e. watering plants in the neighbourhood with stormwater (which also might serve as a plant nutrient depending on what the stormwater is carrying), is not carried out. As the water is flowing in an open stormwater system the plants nearby has the possibility to use it. This could be considered a form of recycling but to a limited amount.

Use a Systematic Approach integrated with Other Services

A systematic approach has not been achieved onsite as issues and services water can bring has not been considered and/or gained. Reusing stormwater in a variety of ways to save freshwater, as well as making use of its potential as an energy source could have achieved this principle.

Increase the Modularity Systems and Ensure Multiple Options

There are multiple storage options within the open stormwater system for the water (double pond, swale/meandering creek, mini-wetland, delta pond, amphitheatre, the many detention ponds).
Many conveyance options are presented in form of different channels and swales etc.

Treatment/purification is to a small amount achieved in the open stormwater system (double pond, swales, mini-wetland and the meandering creek).
Some resource solutions are installed: the double pond (let to flood during cloudbusts) and the outlet to the sea. Additional resource solutions, in order to mitigate large amounts of contaminated stormwater to go into the sea during heavy cloudbursts, could however improve the level of sustainability.

Achieved service levels of the urban water in Augustenborg can thus be considered low as the main factor the system achieve is mitigation of flooding and as a bonus some treatment of the stormwater before it reaches the sea or evapotranspirates before it does.

Modularity could potentially be much enhanced onsite if design aims were updated to comply with the IWA-principles. Following the principles for the Regenerative Water Services is presumed to support the rehabilitation of urban waters as well as the mitigation of the carbon footprint the area has (International Water Association, n.d.).

Enable Regenerative Water Services

This principle states the importance of the collaboration between the building and the surrounding landscape to create regenerative water services. This does however have to be disregarded in this thesis, as it is limited to the landscape surface. Nonetheless this cooperation can be stressed playing a big part in achieving sustainable stormwater systems, as supporting/creating regenerative water services which will lead to a range of co-benefits i.e. a reduction of the area's carbon footprint, improvement for biodiveristy and lower housing bills due to the reduction of water and energy needed for the house (International Water Association, n.d.).

Design Urban Spaces to Reduce Flood Risks

Thorough infiltration onsite is not provided, limiting the possibility of the site working according to the ”Sponge concept” - an approach that may be considered the most proficient concept developed today to achieve a natural hydrologic cycle. Mitigation of flooding is nonetheless thoroughly implemented. Many retention areas are installed: within corridors, in playgrounds, the double pond with the flooding area and individual ponds, which combined have the potential of retaining large volumes of water. The Central Drainage Corridor is by Beckmann (2018) described as very large-scale, and has the potential of managing even larger rainfalls than originally dimensioned for, which is up to a 25-year event. Surges that may arise from this kind of heavy storm are hence limited as the system has the potential of managing this volume of water, whilst excess water is diverted into the sea.

Resilience, as described by Walker *et al*. (2010) in section ”*Resilience*” p. 10, could thus be considered fairly good as some areas are built to cope with flooding (double pond, some playgrounds), and stormwater exceeding the retention areas is diverted to the sea, providing more room for water volumes as the neighbourhood does not have to take care of the full volumes by itself. Walker *et al*. does however explain that an area should not only be able to handle a big storm, but also be able to stabilise afterwards as if nothing has happened - absorbing the disturbance. This statement can be connected to this principle's objective of ”Designing for a quick disaster recovery”. As infiltration is limited onsite the recovery of water kept onsite (not diverted to the sea) can only evapotranspirate in order to disappear from site. Hence recovery can be presumed to take more time than on sites where more infiltration is possible, and thus the resilience in the area is not excellent.

Rainwater is in the open stormwater system not used as a resource, which lowers the proficiency of the system. This is concluded considering the water is only meant to be diverted from site through a better solution than the previous sewage system. Had the system included the reuse of stormwater through e.g. irrigation systems or within water features the area could have been considered more sustainable than it is today.

Enhance Liveability with VisibleWater

The aim for regenerative purposes have been carried out onsite. Open green-blue solutions where water can be seen and played with are streched across large parts of the area, which presumably should enhance the attractiveness and recreation. Whereas this have affected residents in and surrounding the site regarding social values, stress, happiness or feeling of safety has not been researched. Neither has the economic development in the neighbourhood. Beckmann (2018) express the importance of carrying out these sort of surveys.

Multi-purpose functions for the environment include: the seeing and presumed recreation of water, initiations for children's play made in certain areas and space provided for teaching methods and learning (Folkesson, 2018), and the presumed increase in local biodiversity.

The lack of multi-purpose systems regarding water services does however disregard the risk of experiencing drought and heat islands. As the area currently has a larger amount of vegetation (mixed with concrete) in comparison to nearby neighbourhoods, the area becoming a heat island is less likely to happen than in nearby areas, but still cannot be considered out of the risk zone. Drought on the other hand has the same potential of happening in Augustenborg as anywhere else since no efforts has been made of saving freshwater.

The connection this principle has to the water cycle is: if the sustainable approach enhance the living standard at a varierty of levels in a neighbourhood, residents are more likely to approve of the design. Hence more similar projects can be carried out to positive reactions. Increased sustainable development aids the hydrologic cycle.

Modify and Adapt Urban materials to minimise environmental impact

Materials onsite have not been selected with considerations of how the material may impact the site or stormwater onsite (Beckmann, 2018; Folkesson, 2018). Concrete is one of the main materials, a material easily produced and to a low cost. It require much energy to be produced but is not toxic (Folkesson, 2018) even though it does include some chemicals (Beckmann, 2018). Also the rubber textile includes some chemicals and is as well as the concrete specifically developed by VASYD (Beckmann, 2018).

Materials used in buildings is not evaluated here.

Using materials with the potential of leaving contaminants in stormwater (e.g. street wear from car tires) can cause pollution in recipients just like oils and gas from a car can, resulting in similar issues.

Plan to Secure Water Resources and Mitigate Drought

Presumably the securing of water resources is not done as Sweden at the time of construction was considered having access to a lot of freshwater. Neither is the mitigation of draught visible onsite. Only the potential water kept in the open stormwater system can be used for transpiration in the area during drier climate, and no water can be used for freshwater. During a draught the neighbourhood can only depend on extracting water from ground- and surface waters. Dramatic extraction from a recipient can cause vast mitigation of the hydrologic processes, resulting in issues for habitats, ecosystems and access to freshwater, as infiltration of precipitation in other sites does not happen overnight.

Protect the Quality of Water Resources

Once again the collaboration between different fields of responsibility is stressed. Everyone using the same water as the regarded neighbourhood does have to take part in the sustainability adaptation for the site to become fully sustainable, including everyone affecting the stormwater prior reaching the regarded site.
This is not carried out in Augustenborg as this would supposedly need to include the full region of Malmö. As stormwater in Augustenborg is not aimed to become freshwater, this has not been regarded in the design development at all.

Prepare for Extreme Events

The system is not fit to survive a 100-year storm event, but is sufficiently dimensioned for a 25-year event along the Central Drainage Corridor respectively 15-20-year event along the Lönngatan Corridor. However, as the Central Drainage Corridor is especially large-scale, it has the potential of coping with more volumes of water than it is dimensioned to do (Beckmann, 2018).

As Augustenborg is located far from the coast the coastal concerns does not affect this neighbourhood.

Would the area be resilient enough to cope with a 100-year event and retrieve most of the water to the hydrologic cycle locally, it would aid the natural water flows.

Empowered Citizens

Residents were welcomed to take part in designing and deciding in the design process (Stahre, 2008). Residents living in Augustenborg at the design stage were involved, could take part in the decisions, and could therefore also decide to what extent they wanted to maintain the designed areas. It is emphasised by Stahre (2008, p. 52) that “a trustful cooperation with the residents is of utmost importance for a successful result”. This is strengthened by the International Water Association (n.d.) who states that empowered and *water-wise* citisens will adapt their behaviour into accepting water wise systems and maintenace of them as they understand the importance of water in their community.

Professionals Aware of Water Co-benefits

This principle supports the idea of needing a close collaboration between all professionals within the subject of water. In Augustenborg collaborators are Malmö Stad (the municipality of Malmö), VASYD (water and sewage-organisation in collaboration with the municipality of Malmö) and MKB Fastighets AB (MKB Real Estate Inc.), along with landscape engineers and architects.

International Water Association (n.d.) present the need of additionally including professionals within water (eg. hydrologists), energy (eg. civil engineering), urban planning transport and waste services in order to make most use of the co-benefits across the urban sectors. This would provide for the best solutions possible.

It seems like professionals are aware of the benefits of working together theoretically, but many issues are presenting themselves practically.

Transdisciplinary Planning Teams

Also this principle stresses the need for collaboration between disciplines. Augustenborg had people from some various professions working together, but not enough to achieve the goals of the International Water Association. All neighbourhoods in the city who has the possibility of affecting each other has to hold water solutions entangled in one another to achieve sustainable urban water. The issue arising when discussing this is according to Beckmann (2018) the problem of the many ownerships of the real estates in the city. Treating Augustenborg as a whole was made easier as MKB owns most of the real estates. When many property owners are engaged in the process the development and design becomes more complicated.

Policy Makers Enabling Water-Wise Action

No proper policies or general principles were followed whilst developing Augustenborg. The compendium “Skyfallshantering i Malmö” (Cloudburst Management in Malmö) has been in development during recent years, following the cloudburst catastrophe in Malmö 2014, and was authorised in early 2017 (VASYD, 2017). This is aimed to provide guidelines for future development to be more sustainable than it has been before.

Leaders that Engage and Engender Trust

This is not achieved.

Concluding remarks

The Augustenborg project has achieved its own aim, as it can handle quite heavy precipitation without flooding, but regarding the hydrological cycle it has to improve to provide for natural flows to happen, and regarding achieving a fully sustainable site much more would have to be done on as well as offsite.

Resilience onsite should somehow be further improved in order for the area to absorb the disturbance, not only be able to manage it. It should be able to absorb almost any cloudburst with few remaining issues to be truly sustainable. The site can however not do this alone, the complete city has to work sustainable in order to achieve this.

Additional resource solutions might reduce sea contamination, but to decrease contamination in another site the resource solution has to function sustainably throughout and be part of a larger concept than Augustenborg.

Learning how to reuse and recycle stormwater water onsite can improve our future access to freshwater, and potentially aid the hydrologic cycle. If e.g. using fallen precipitation onsite instead of rediverting it elsewhere, evapotranspiration and (in other cases) also infiltration is achieved where it falls like in natural conditions with little runoff elsewhere.

Augustenborg does not comply much with the principles in level 3, and less with level 4. The explanation could presumably be a lack of collaboration between professions, as spoken of by Svenskt Vatten (2016) and Malmö Stad & VA SYD (2016) in Sweden, and by international authors (i.e. Barbosa *et al.,* 2012) who refer to the same issue within the field of city planning. Lack of collaboration between fields and professions who affect city planning and structure individually result in split foundations difficult to unite to an entity. This way it is difficult for either of the fields to truly change the urban environment and reach the political level. Not only should the designers and people in direct connection to the site be part in the decision making, but also from other fields of responsibililty i.e. developers in related sites and people who may affect water and stormwater reaching the site from a distance (eg. other neighbourhoods, farmers, park owners etc.) (Barbosa *et al.*, 2012; Svenskt Vatten, 2016).

Collaboration and united sustainable water systems let excessive water travel from a variety of connected open stormwater systems, potentially also from neighbourhood to neighbourhood if needed. This would increase the resilience, as spoken of in the beginning.

Tåsinge Plads (Taasinge Square)

Location: Copenhagen, Denmark
Construction date: Ongoing in 2018
Aim: Part of project St Kjeld's Kvarter which will become the greenest, most climate-resilient inner city neighbourhood in Copenhagen, able to withstand the recently experienced voluminous downpurs and create relief for sewage load (Klimakvarter Østerbro, 2018).

Just like Augustenborg, St Kjelds Kvarter is a demonstration project, or pilot installation, aiming towards inspiring the rest of the city to take action developing cities to be more climate-resilient (Teknik- og Miljøforvaltningen, 2018a).

In St Kjelds Kvarter the water will be used as a resource, rather than an issue. Not only will the new approach be more sustainable economically in comparison to updating the old sewage systems in Copenhagen, but also be easier and provide more greenery (reducing heat islands) as well as make the spaces more recreational. The construction will be a possibility to find new innovative and preferably green stormwater solutions for the city (Teknik- og Miljøforvaltningen, 2018a).

St Kjelds Kvarter is a broad area. Therefore one focus point have been chosen to collect ideas from: Tåsinge Plads (fig. 37).

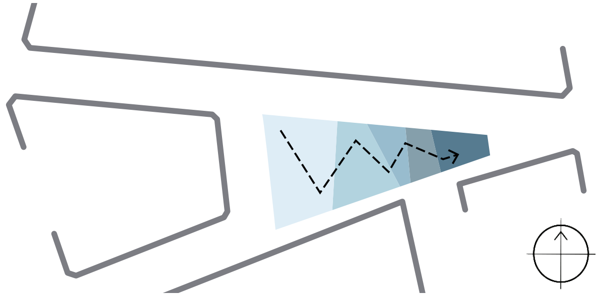


Fig. 35. GHB Landskabsarkitekter *et al.*, 2013, p. 10

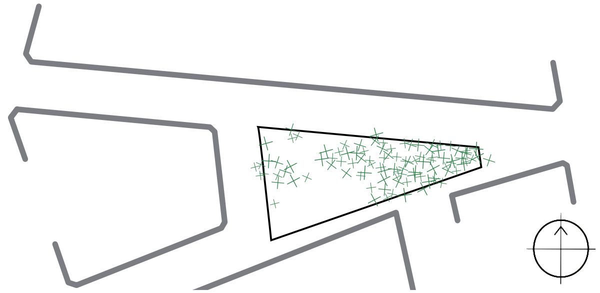


Fig.36. GHB Landskabsarkitekter *et al.*, 2013, p. 12

Topographic solution

Tåsinge Square is designed like a large raingarden. It has an elevated design, leading down from its highest point in the west to its lowest point in the east (fig. 35 and 40) (Teknik- og Miljøforvaltningen, n.d.; GHB Landskabsarkitekter *et al.*, 2013). As water always aims to reach the lowest point through the easiest path, the water flow at Tåsinge Square is directed towards the east of the site where it will stay and infiltrate (GHB Landskabsarkitekter *et al.*, 2013). This way the area is presumed to be resilient up to a 500 year cloudburst event, and will at that time be filled to the brink (fig. 41) (GHB Landskabsarkitekter & Københavns Kommune, n.d.).

Vegetation

The vegetation design follows the topographic structure: keeping plants needing less water at the higher topographic location, and as the toporaphy gets lower the plant species changes and are in need of more water (fig. 36 and 38). As the soil turns humid, more plants will be filling the area. Finally the vegetation constellates into a rainforest-like structure, which due to the amount of vegetation also has a high transpiration factor. The variation in topography, species and potential for water volume is not only made to handle stormwater. The variations create a variety of biotopes providing numerous habitats in order to enhance the biodiversity in the area. The area is also exciting for people to engage in and explore GHB Landskabsarkitekter & Københavns Kommune, n.d.).

Inspirational case studies (1)

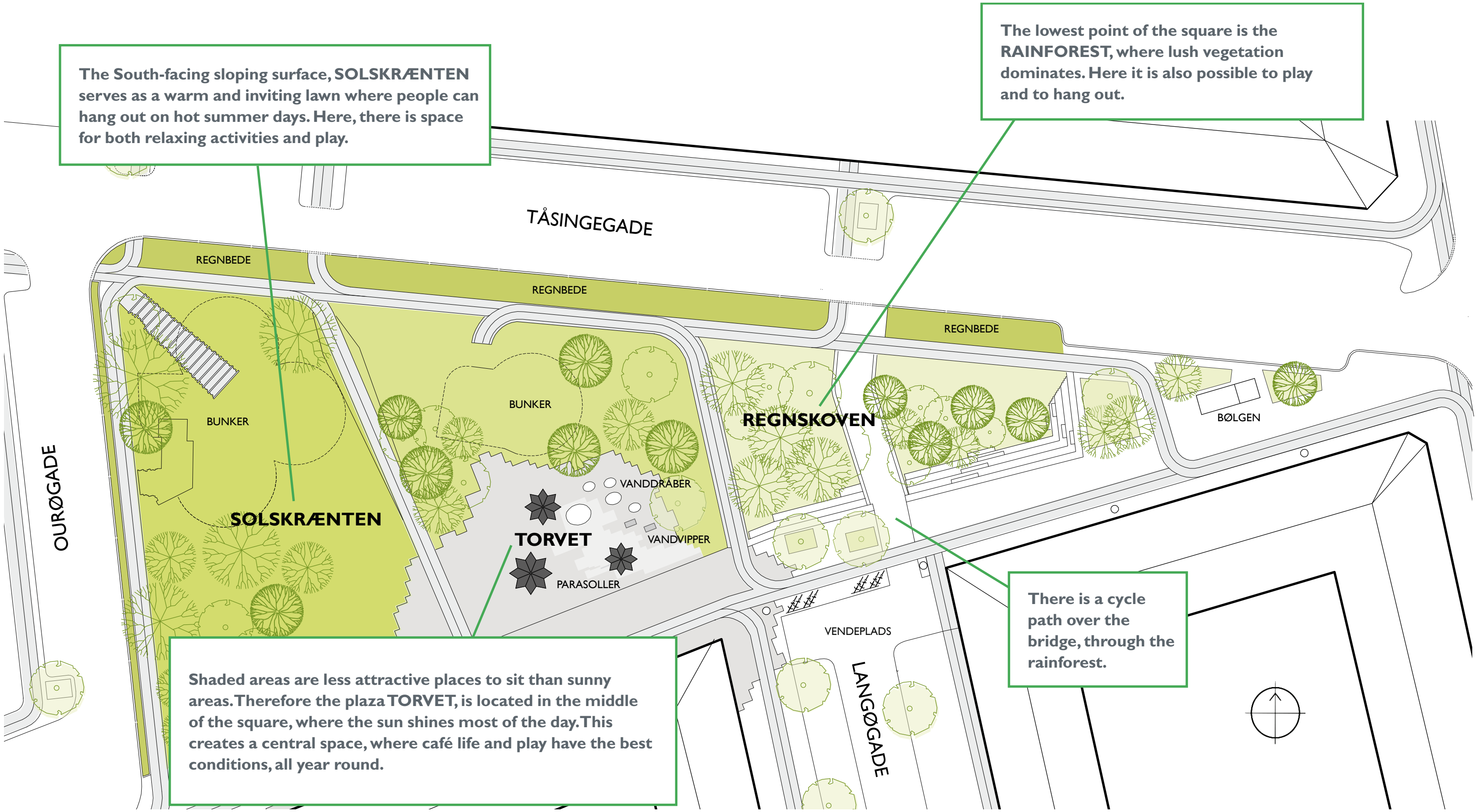


Fig. 37. GHB Landskabsarkitekter & Københavns Kommune, n.d., p. 4

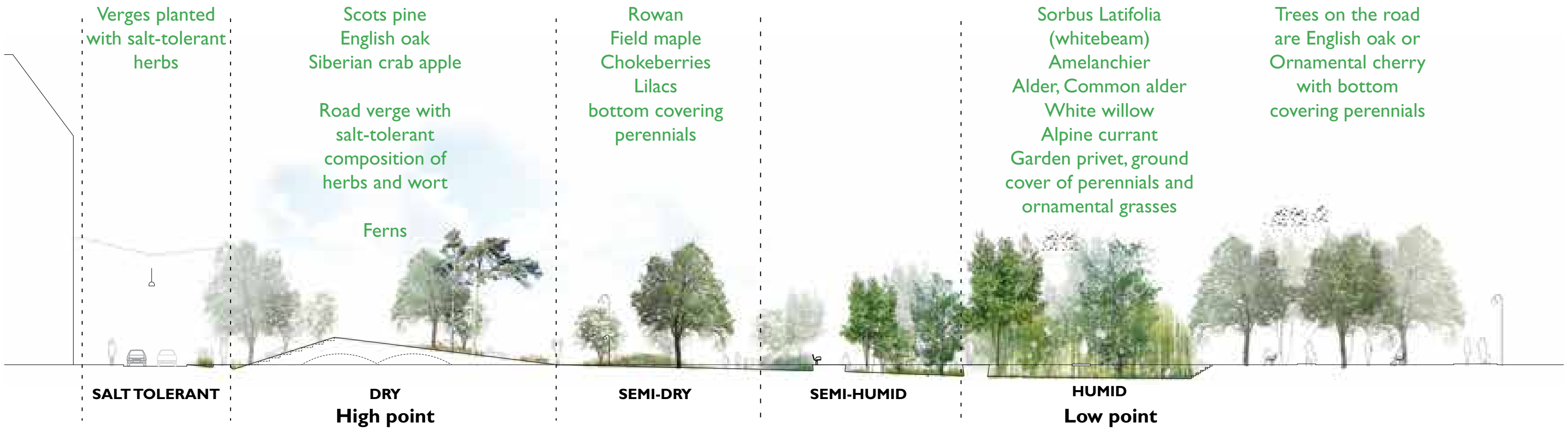


Fig. 38. GHB Landskabsarkitekter & Københavns Kommune, n.d., p. 5

Stormwater system

Water falling on roofs around site is diverted through drain pipes to underground tanks located underneath a water feature located on the site's square. The water is processed multiple times underground, cleansed through systems i.e. UV purification, resulting in the possibility for people to engage with the water without risking falling ill. The water feature is made by reflective metallic water drop constructions, to which the roof water is pumped. Water from the water feature is through topographic design lead towards the raingarden, providing time and space for people to interact with the water whilst it flows towards its infiltration destination in the "rainforest". In times when the underground reservoirs are overfilled with water, it is let to run freely across the square surface and into the rainforest, as it naturally would (fig. 39) (Teknik- og Miljøforvaltningen, n.d.).

Runoff from roads is not let to directly infiltrate. Its high scale of contaminants needs to be reduced, as it otherwise may pollute the groundwater. Pollution reduction is achieved by the use of filter earth in the roadside swales including infiltration trenches to which the road runoff is directed. As the main contamination remaining is salt, the water can from there be transported to the sea (fig. 41) (Teknik- og Miljøforvaltningen, n.d.).

Stormwater parasols located next to the water feature at the square collects water to let it evaporate (fig. 39) (Teknik- og Miljøforvaltningen, n.d.).

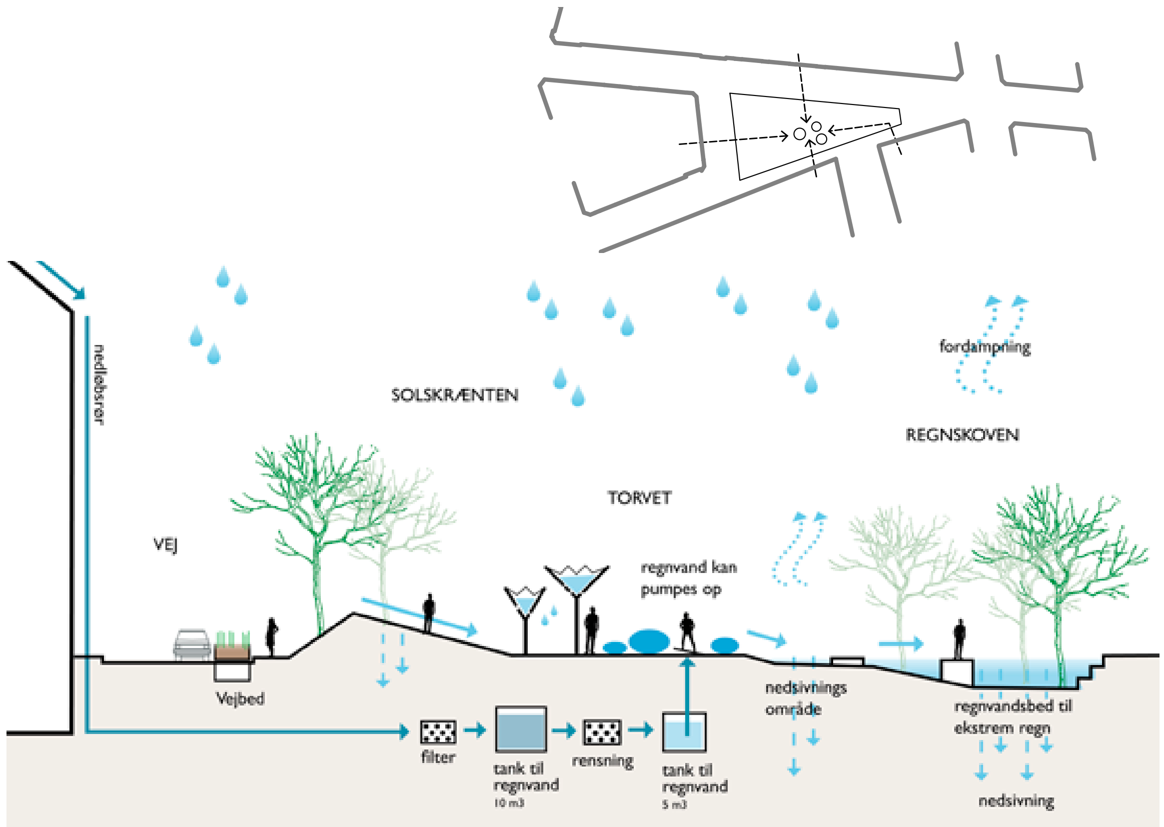


Fig. 39. GHB Landskabsarkitekter & Københavns Kommune, n.d., p. 8

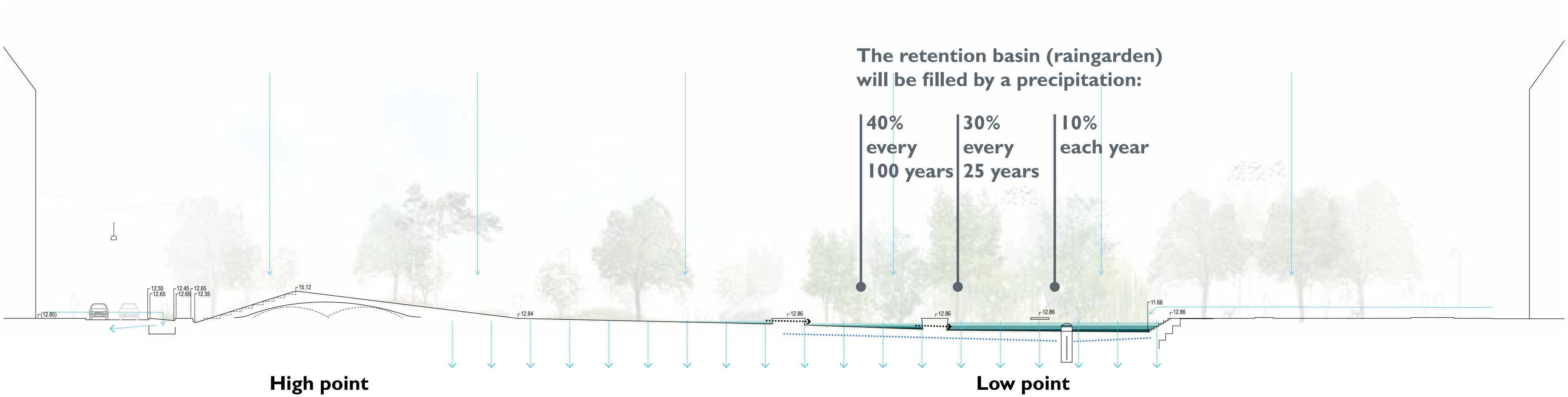


Fig. 40.GHB Landskabsarkitekter & Københavns Kommune, n.d., p. 7

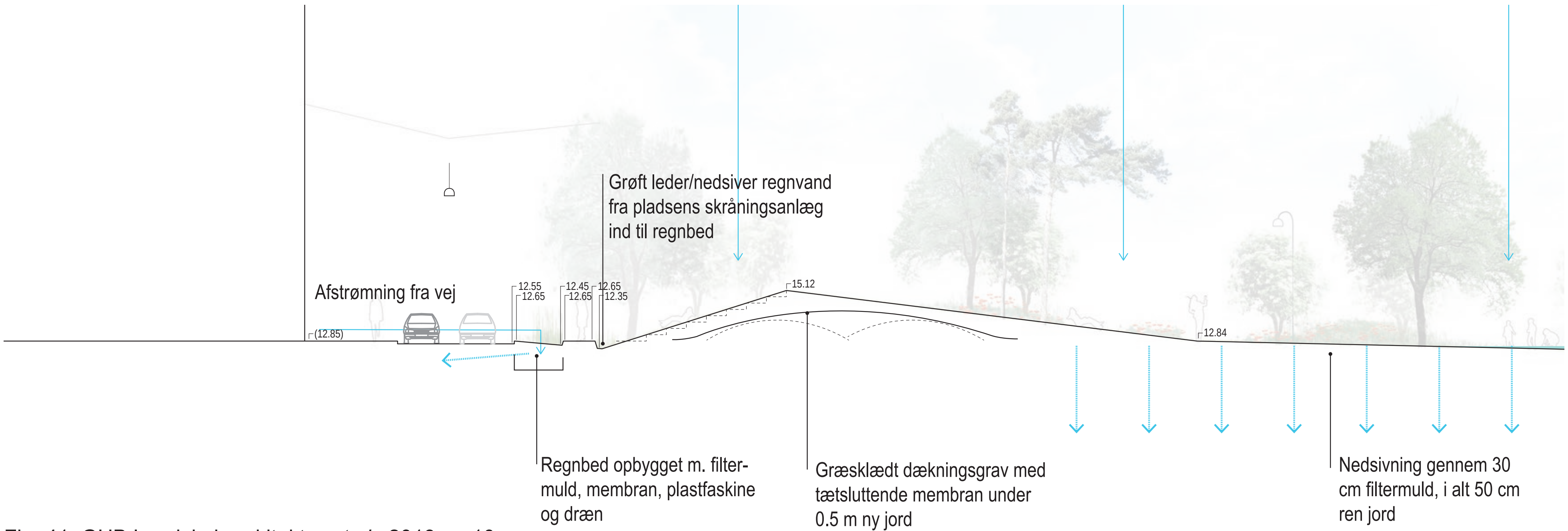


Fig. 41. GHB Landskabsarkitekter *et al.*, 2013, p. 10

The Water Square Concept & Benthemplein Water Square

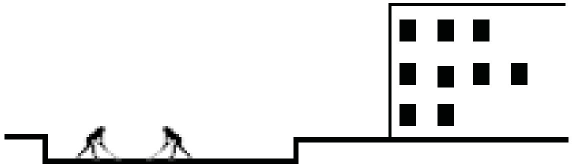
The Water Square Concept

Location: No specific area as the water square is a conceptual plan, and can therefore be located anywhere
Construction date: 2006<
Aim: Mitigate flooding in urban areas

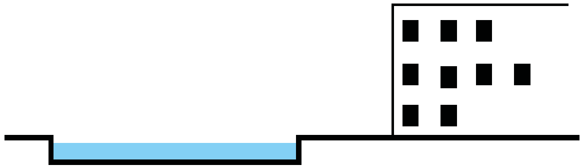
"The Water Square" concept, presented by De Urbanisten, an office devoted to urban research, landscape and design in the Netherlands, is an older solution, having its starting point begun in 2006. It is nevertheless still a contemporary solution. The finishing of the first constructed water square was in 2013. In 2007 the concept became an official policy in the "Rotterdam Waterplan 2" on an urban scale (De Urbanisten, n.d. a; De Urbanisten, n.d. b).

De Urbanisten (n.d. a & b) explains that the concept combines urban life and environment quality with stormwater storage. Money is saved on sewage system management and enlargement, whilst creating environment quality, increased potential for site identity and recreation.

Depending on timely length and volume of precipitation in a cloudburst, the square(s) will be filled accordingly (fig. 42). During dry periods, the squares can be used as e.g. sports area, playground etc., and in winter for ice skating (De Urbanisten, n.d., a).



90% of the year



10% of the year

Fig. 42. Approximately 90% of the year the water square will be empty and can be used for recreational activities or other leisure. The additional 10% of the year the square is expected to be water-filled. During this time it can be used as a water feature, for activites or other solutions.

Netherlands

Water guidance within the Water Square Concept

The rainwater is initially collected in the water squares to later be guided into the divided sewage system pipes allocated stormwater (fig. 43). The water is purified in the process.
The purified rainwater will be emitted into nearest surface water when the city has stabilised after a cloudburst and once again has the capacity to transport the water (De Urbanisten, n.d.).

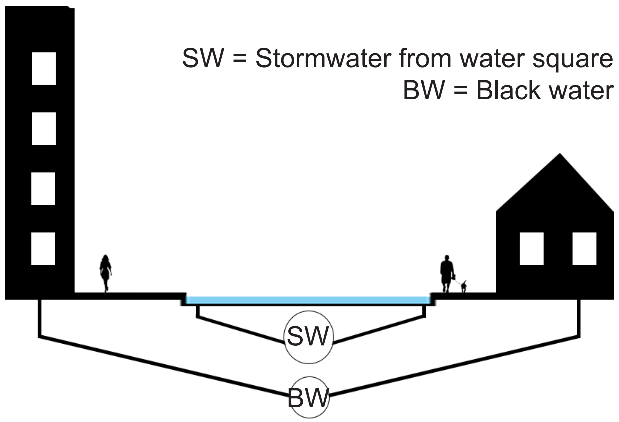


Fig. 43. Water from the water squares is divided from black water from buildings through a divided double sewage system, just as adviced by Svenskt Vatten in Sweden (2016).

Benthemplein Water Square

Location: Rotterdam
Designed: 2011-2012
Completed: 2013

The water at Benthemplein Square (fig. 46) is designed to be visible for human recreation, taking detours and constantly on the move during rainfall to create excitement. During dry time it is a place for young people having a chat and practice sports amongst other things, as this is a major age group roaming the area (fig. 47 and fig. 48). During and after precipitation the squares turn into interactive dams (fig. 49) (De Urbanisten, n.d., b).

Three large basins create the foundation, keeping two shallow (collecting rain from average precipitation) and one deep (coming in use during heavier precipitation) (fig. 44). They collect runoff from the local and nearby area as well as from roofs (fig. 45) through steel gutters, specially made to be functional also for skaters and for aesthetics (fig. 50) (De Urbanisten, n.d., b).

Water from the shallow basins is after treatment lead to an underground infiltration device, promoting refill of groundwater. Only water from the deep basin is drained after approx. 36h (to prevent quantities of contamination) into the city's mixed sewage water system. The complete system ease the burden of the city's sewage system, as some water is taken care of onsite or diverted to groundwater (De Urbanisten, n.d., b).

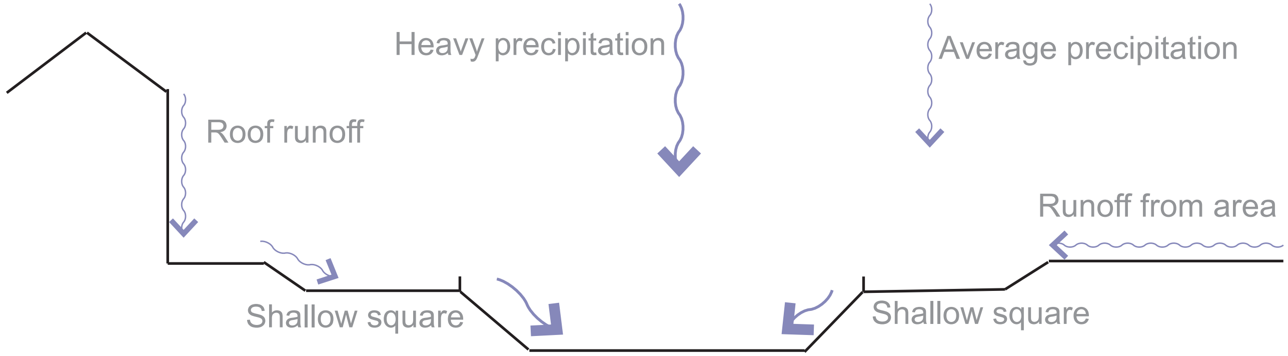


Fig. 44. Simpllified elevation of water square function (not technically correct).

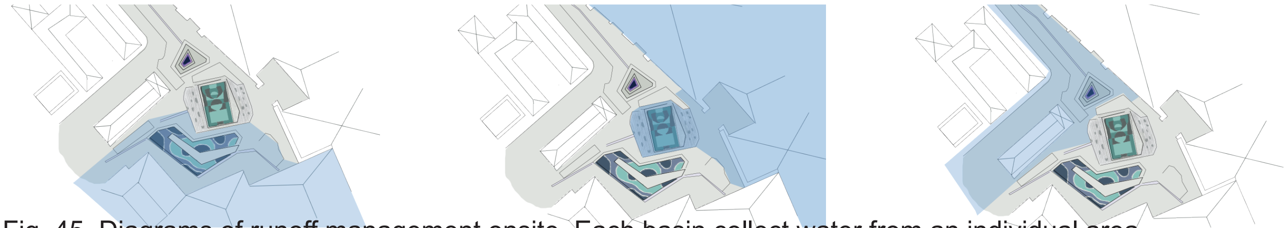


Fig. 45. Diagrams of runoff management onsite. Each basin collect water from an individual area.


Fig. 46. Outline for masterplan of Benthemplein Water Square.

Inspirational case studies (2)


Fig. 47. Bike left behind.


Fig. 48. Children playing hide and seek.


Fig. 49. Water is guided to the three submerged squares, all with the quality of holding amounts of water as can be seen in created hollows.


Fig. 50. Steel gutters for directing water.


Fig. 51. One end station for directed water, led by steel gutter presented in down left corner.

3

Solution discussion
Solutions overview
Project discussion
Conclusion
(Additional: references & appendix)

The final part first and foremost introduces the application site analysis. The knowledge achieved from section 1, and the information provided of the application site and supporting case studies in section 2, will here be combined into an analysis in which the aim is to figure out how a landscape architect can approach the issue of aiding the hydrologic cycle whilst infiltration onsite is difficult to achieve.
Following design overview and discussion add small comments and considerations to the project, and will finally end in a short concluding remark.

Working with the hydrologic cycle

Approaches within the concept of sustainable stormwater management are discussed on many levels today: what are the best approaches and solutions to achieve the agreed goal of overall sustainability presented by the United Nations World Commission of Environment and Development? The complexity of the field of water makes this difficult (Fletcher *et al.*, 2013; Sage et al., 2015). This can be seen in the number of concepts which generally aims to achieve the same goal but tries to solve the issues with different approaches, i.e. SUDS and LOD (Fletcher *et al.*, 2015).
Instead of choosing one of these concepts to work from, for this thesis the approach has been to look at the goals and solutions from a distance. What is the main issue and what can be done to mitigate it?

The factor involved in all terminologies and approaches is the process of the hydrologic cycle – the life of water. Calkins (2012) describes in her book the importance of understanding and adapting our systems to the water cycle, the natural processes of water – how it acts naturally and what effects it may have on our surroundings – in order to be able to mitigate negative impacts of anthropological development (i.e. large areas of impermeale paving) has on the processes. This statement is supported by many authors, amongst those are Fletcher *et al.* (2013), Sophocleous (2002) and Svenskt Vatten (2016). As water is vital to life on Earth, the logic apprehension is that changes in the water cycle have the potential of affecting our surroundings on many levels, since the hydrologic cycle can affect a site and a site can in turn affect the hydrologic cycle. The understanding of the hydrologic cycle therefore has to act as foundation for the development of sustainable stormwater management and systems that go hand in hand with natural water processes on Earth.

Augustenborg analysis

All sites are individual, just like people. They have their own characteristics, qualities and identity, certain water flows running subsurface and supposedly also in the atmosphere, meaning every site is in need of a “personal” approach regarding water management (Fletcher *et al*., 2013; Gwenzi & Nyamadzawo). To be able to develop systems adapted to this flexible approach, further research within the field of water on many levels is required (Ellis, 2000; Fletcher *et al*., 2013; Gwenzi & Nyamadzawo, 2014; Han *et al*., 2017; Katul *et al.* 2012; Keys *et al.*, 2012; Valett & Sheibley, 2009).

Pilot installations and projects such as The Eco City Augustenborg and St. Kjelds Kvarter hence are important to design and develop sustainable sites. These installations are not perfect to begin with, since we still can be considered being in the ”process toward achieving and then maintaining sustainability” as stated by Novotny *et al.* (2010, p. 80) and supported by Fletcher *et al*. (2015). Researching imperfections at sites designed with systems keeping a sustainable approach provide much information of how to improve them and similar projects in the future to achieve a higher level of sustainability than we have today.

Augustenborg and St Kjeld’s Kvarter could be considered each other’s equivalents, although made with a time gap of 20-30 years (depending when the finishing of St Kjelds Kvarter construction will be). Both are a pilot installation of sustainable solutions of its time, made to inspire and provide a “show-how”, as well as provide an area for further research within the field.

The apprehension of what makes a site sustainable today is the same as it was in the 1990’s, which can be seen in the summary from the United Nations World Commission of Environment and Development Bruntland Report, Our Common Future (UNWCED, 1987) made by Calkins (2012, p. 2): “the design, construction, operations and maintenance practices that meet the needs of the present without compromising the ability of future generations to meet their own needs". Today the objectives to achieve sustainable stormwater management are discussed, as mentioned previously. If we are to believe Calkins (2012) promoting evapotranspiration and infiltration is of highest importance. Fletcher *et al.* (2013) on the other hand states the two main objectives to be the mitigation of hydrologic changes and the treatment (purification) of water. Whoever we are to believe, the gists to achieve sustainable stormwater systems can be considered to a major part include (if not completely) the aiding of the water cycle.

The open stormwater system

In the 1990's, when Augustenborg was reconstructed, the general approach to achieve sustainable solutions might have been slightly different than today as the research since then has developed and (hopefully) improved. That is, although the aim in the 90's had the same apprehension and goal as we do today, they approached it differently according to what the beliefs in how to achieve the goal was at that time.

In Sweden it is today promoted to construct double sewage systems connected to a slow open surface system above ground (Svenskt Vatten, 2016), since we cannot completely rely on sustainable stormwater system technology being completely sustainable as of yet. The design in Augustenborg (to be referred to as AB) has followed the advice from Svenskt Vatten (2016) of using open stormwater systems and double sewages. Today it keeps almost solemnly a double sewage system connected to slow open stormwater systems dimensioned to certain resilience. Water that is not taken care of onsite is diverted to the sea.

The focus lies within the concept of mitigating flooding in the area by slowing the flow of rainwater runoff to prevent peak flows and reduce the water volume near buildings. This way the runoff diverted to the sea is additionally mitigated and made sluggish.
Water diverted to the sea is not purified to a high level since purification of water was not an aim within the design project. Instead the limited treatment onsite became an additional positive feature (Beckmann, 2018).

Contamination of the sea

Being critical to this part of the system, contamination of surface waters is risky on many levels. Not only may it disturb ecosystems in the sea, e.g. death of plants and animals, of which ecosystem services we are dependent on (Calkins, 2012). As surface waters often are connected to groundwater, there is a potential of the groundwater becoming contaminated as well, which through the water flows in the groundwater in turn could pollute other surface waters (Valett & Sheibley, 2009). This sort of spreading contamination could therefore affect our sources to freshwater . Of course, the level of pollution in receiving waters and the impact it may have on ecosystems depend on the amount of contaminants in relation to the water volume they end up in, as explained by Barbosa *et al*. (2012). However, would all stormwater systems be constructed with outlets of polluted stormwater in the sea, the outcome for the sea and related ecosystems can presumably be disastrous. Therefore this part of the stormwater system in Augustenborg can be considered unsustainable.

Although polluted water may cause vast disturbances within living organisms on Earth, it does not seem to affect nonliving elements, such as the processes in the hydrologic cycle – at least not immediately. The processes affect living organisms as it can serve as a way of transportation for pollutants. Nonliving processes of water flows seems to only be affected by changes in water volumes, and the hydrologic cycle can through this process be presumed undisturbed. Looking at it in the reverse order it could however be discussed whereas changes in ecosystems, in the same way anthropological changes on e.g. land does, might affect the hydrologic cycle in the long run. This will however not be further discussed in this thesis.

Analysis of the retention-based approach

Reaching back to the stormwater system onsite, the soil type in the area allow for very slow infiltration (table 1) whilst areas where the rubber sheet is located prevents much infiltration to take place. Consequently a certain approach had to be taken to reduce water onsite. The open stormwater system is constituted by multiple retention solutions to slow down the stormwater flow and attenuate outflow to the sea, which simultaneously also provide time for the water to evapotranspirate before its potential entering into the sewage system, as has previously been seen in fig. 15-16.

Retention-based techniques can be lined (Fletcher *et al.*, 2013) as they are in the areas covered by rubber sheet in Augustenborg, where the water is not concentrated on infiltrating to the groundwater. Retention systems can also be drained, with the purpose of collecting large volumes of water to reduce peak flows, but still include the potential of infiltrating the collected water (Fletcher *et al.*, 2013). The downside with retention basins is that they are limited to their size (Fletcher *et al.*, 2013), and are therefore full when they are full. The only way to reduce the water is through infiltration or evapotranspiration, where neither happens fast enough during cloudbursts to mitigate flooding further than their own size.

Soil type	Permeability
Gravel moraine	High
Sandy moraine	Medium
Moraine clay	Low
Fine gravel	High
Coarse sand	High
Medium fine sand	High
Fine sand	Medium
Clay	Low

Table 1. Simplified permability status of soils to show the permeability of moraine clay in relation to other soil types. Information gathered from Sveriges Geologiska Undersökning, 2015.

A retention area or system, lined or drained, can also be harvested as a mean to reduce large water volumes in the basin as well as to collect rainwater to make use of it. Harvest can in theory be used for e.g. freshwater, water effective water features or irrigation. In theory the uses appears sustainable and economically proper, yet technically it does cause some issues.

Depending on water quality after treatment in stormwater systems, harvested water can be used for certain purposes. Freshwater has to be further cleansed in additional systems than only through open stormwater systems, as it otherwise may make people ill. Water in water features has to be clean enough for children to be able to drink small amounts of it whilst playing with the water (Hilarie *et al.*, 2008), otherwise they may fall ill. Water let out in surface water has to be more cleansed than water used for irrigation (Calkins, 2012). Contaminants let out in recipients can, as previously mentioned, result in death of living organisms and ruin of ecosystems. Plants and soil on the other hand absorb contaminants before the water reach the groundwater, and do not (as currently known) suffer from the uptake (Ellis, 2000).

More than presented issues regarding water quality for use of stormwater, the dimensioning of a retention basin whilst applying harvest compose an even larger issue technically. Natural forces such as rainfall are neither regular nor systematic, thus knowing how large the reservoir should be is a pickle (Beckmann, 2018). Due to the unreliability regarding precipitations' regularity, the depending on rain harvest can be difficult, no matter if harvested water is used for irrigation or for flushing toilets.

Would enclosed harvesting basins be used, e.g. in underground reservoirs, the dimensioning would once again cause a problem as the size of the reservoir should not be too large and take too much space, but not too small to risk flooding (issues regarding dimensioning of water basins explained by Beckmann, 2018). The combination of enclosed reservoirs and open stormwater systems could therefore compose a functional solution as the enclosed reservoir (if dimensioned well) may function as backup to the open system above ground during cloudbursts.

On the other hand, using enclosed collections of water e.g. in enclosed reservoirs, may cause issues for hydrologic processes, as discussed by Gwenzi and Nyamadzawo. As each area has its individual local hydrologic cycle, the obstruction of evapotranspiration (at large scales) may prevent the recharge of groundwater in a location that is dependent on evaporation from the regarded site in order to receive precipitation. At small scale, as if only used at Augustenborg, the mitigation of evaporation may not constitute grand concerns. Hydrologic models should nonetheless be created in order to try guessing the outcomes for anthropologic interferences (Gwenzi & Nyamadzawo, 2014).

To make a system sustainable for both nature and humans it ideally has to work as a natural process but simultaneously adapt to human living. This is a difficult task to solve.

The lined retention basins already installed onsite could be considered a safe approach within stormwater systems pollutionwise, as there are no worries regarding the polluting of groundwater, nor of excessively overcharging it. Retention basins also provide for evapotranspiration in the area. The installation can however only be considered sustainable to a limited amount, as recharge of groundwater is very limited. Adding the use of harvesting could potentially have made the area less easy to flood and be considered more sustainable due to the usage of stormwater. The installation of it could however be difficult, due to previously mentioned issues.

Analysis of infiltration possibilities

The lack of groundwater recharge across large areas may become a major default, thus a small discussion regarding the objective of infiltration within stormwater systems will follow.

Infiltration is a slow process in moraine clay as the soil type is relatively non-permeable. Thus it can be suspected that the infiltration in natural conditions in Augustenborg, before the area was urbanised, was not extensively severe. However, some infiltration is bound to take place, and the presumed current decrease of infiltration has the potential of reducing recharge of groundwater on a local level (Fletcher *et al.*, 2013). The effects could cause a domino effect of disturbance.

Water bodies disturbed locally can have an impact on every water flow connected to the water both above and underground, and can therefore have both approximate as well as effects at a large scale (Kent *et al.*, 2016). Other water bodies, water flows and habitats connected to them (Alley, 2009), hydrological ecosystems and ecologic processes (Calkins, 2012) are just a few factors that may experience alterations in function when water processes are altered. As groundwater is well connected to other water bodies and plays a major part in the hydrological cycle (Valett & Sheibley, 2009; Sophocleous, 2002), the local disturbance of mitigated infiltration in Augustenborg could spread widely or shortly. Effects of decrease in groundwater does however have to be further investigated according to Valett and Sheibley (2009).

Producing specific areas for infiltration in order to achieve groundwater recharge can be used on sites where permeability is low (Calkins, 2012; Fletcher et al., 2013). Providing space for infiltration is also the absolute first step in Level 1 of the IWA-model criteria: to Replenish Water Bodies and their Ecosystems (*Appendix* p. 75). Considering the site currently (supposedly) does not have optimal infiltration this type of system could be useful to reduce negative impacts on the hydrologic cycle. Using an infiltration area or trench in Augustenborg would however not mitigate flooding effectively, as infiltration through moraine clay progress slowly.

Since diffuse recharge of groundwater is dependent on environmental factors and site conditions such as climate and vegetation (Alley, 2009), infiltration areas should be located where vegetation is low and dominated by grass (avoiding extensive evapotranspiration) in order to achieve uttermost infiltration. As the potential is high in the area for flooding, large green spaces at a promising distance from buildings are presumably proper locations. As there are few large green areas in the neighbourhood apart from the Augustenborg Park, the park is the most suitable location. However, the size of the park in relation to potential size regulations for a possible infiltration area may pose a problem considering the building's proximity to the park. Also the risk of clogging is high, posing another problem for the system to work sustainably.

To successfully achieve this kind of solution investigations of soil type, its permeability and its potential of clogging (Fletcher *et al.*, 2013) has to be carried out along with calculations of precipitation, depth of water table and the potential of pollution as well as the prevention of it.

Considering there is a potential for contamination of groundwater within artificial infiltration systems, water should be cleansed from heavy pollution before entering the infiltration area. As the water in the drainage corridors is not thoroughly cleansed, other or additional treatment systems should have to be installed in addition to the infiltration area, adapted to quality of the stormwater as well as the treatment qualifications of the soil.

Considering infiltration onsite might not be excessive, economic arguments would presumably speak against the solution.
The conclusion regarding this approach can thus, due to the many obstacles appearing when discussing the possibilities and restrictions onsite in relation to the "needs" of an infiltration area, using infiltration areas in Augustenborg is not an optimal solution.

Solution for infiltration

If technically possible, some water not evapotranspirated in AB can be redirected to another neighbourhood in Malmö. This on the premise that open stormwater systems or artificial infiltration areas (properly constructed and purified not to risk contamination of groundwater) are installed in chosen location(s), in order for the site(s) to be able to take care of the additional water in a way that aids the water cycle. As can be seen in the soil map (fig. 52), the nearest locations partly containing sand soil, a very permable soil, are Almhög (S), Törnrosen (NE) and Eriksfält (SW).

Providing infiltration in nearby permeable areas could aid the natural flow of water, as the moraine clay does not infiltrate large volumes under natural conditions. As sand is permeable, encircled locations in the soil map should constitute the natural infiltration areas in Malmö. Systems diverting the water towards these areas can hence potentially mimic natural flows of water, creating a more natural water system than what is currently in place.

Recharging groundwater in another area than onsite can potentially be as effective, considering groundwater flows and recharge across wide areas. Depending on the direction the groundwater has, the water infiltrating in the presented locations can be presumed to flow through Augustenborg as well. Thus, instead of relying on infiltration in moraine clay, more focus is put on soil with higher and more effective infiltration possibilities.

This solution could mitigate some contamination of the sea as some of the water instead would be diverted into another neighbourhood within the city. Potentially the diversion could also aid the hydrologic cycle through increased groundwater recharge.

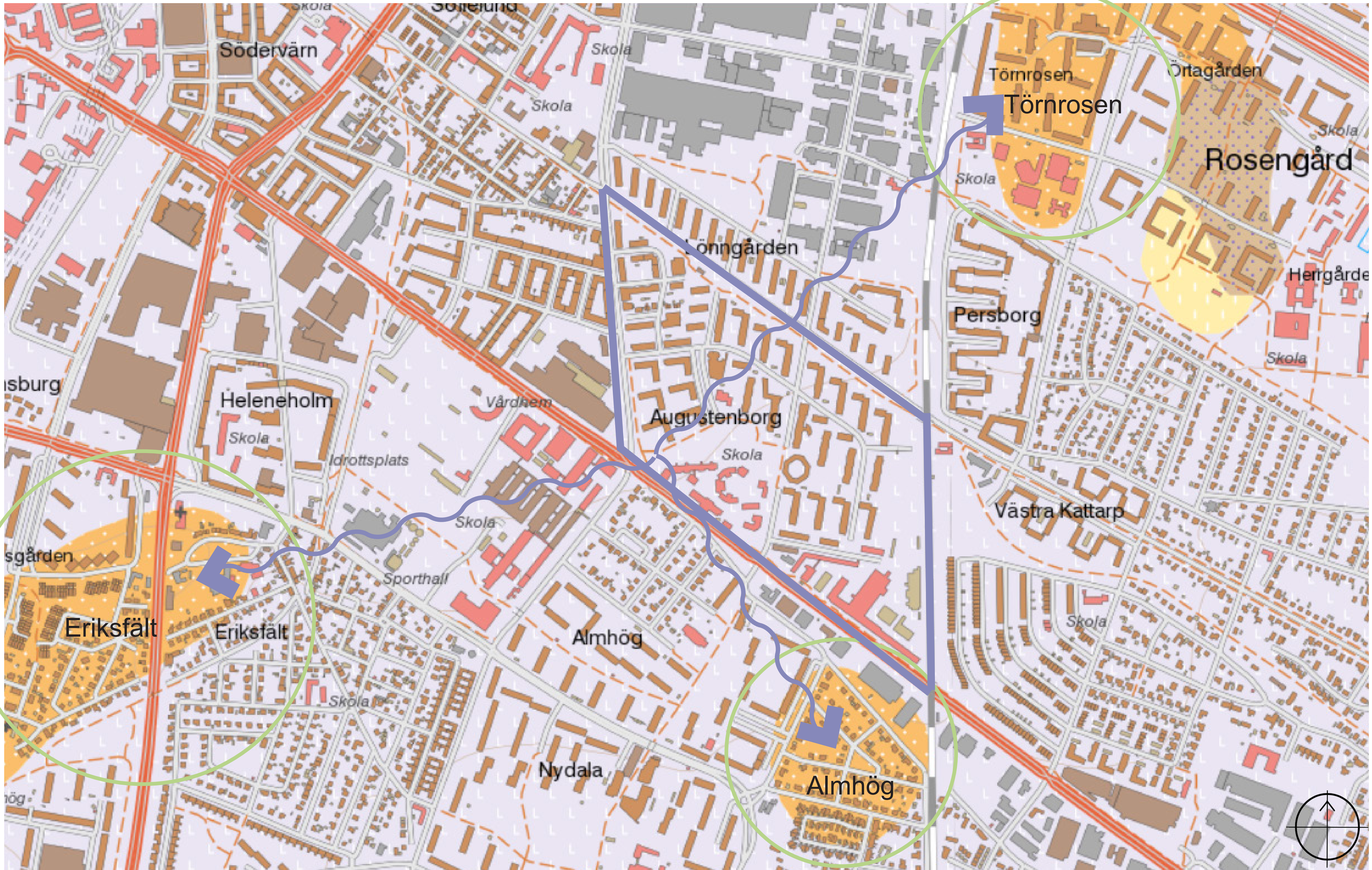


Fig. 52. Water can be redirected to other further permeable areas. Map adapted from SGU, 2017.

Moraine clay | Sand/gravel | Silt | Fen peat

Ideas adapted from Tåsinge Plads

Tåsinge Plads (TP) and Augustenborg (AB) are sites with different qualities, therefore only some solutions practiced in TP can be of use in AB.

Solution 1

Retention areas are implemented both in Augustenborg and at Tåsinge Plads, although the solutions had to be approached differently. TP allow heavy infiltration, which AB does not. Both projects have also worked with gradients: AB has adapted system after topography, whilst TP has adapted topography after system; both areas letting the water flow follow the topography naturally without the need for pumps.

An additional feature in TP's topographical concept is to add plants and adapt them to the topographic location and potential volume of water within the infiltration-based basin (fig. 35, 38 and 40). This combining of retention area and vegetation is one of the solutions in TP that could be useful in AB. A specific vegetation plan or idea has not been found during the research period, therefore erros regarding the vegetation may occur. Hence how the vegetation onsite specifically serves the hydrologic cycle cannot be stated, but rather has to be presumed.

Many areas around the drainage corridors in AB are open grass with some trees and shrubs, which by Beckmann (2018) is presumed to be designed to embrace the site's days of glory in the 50's. Much of the vegetation design hence has to be supposed mainly respond to aesthetic purposes rather than sustainable.

Vegetation located within the stormwater system does have an additional purpose: mitigating water flow.

To further aid the hydrologic cycle onsite, vegetation could be given an even larger task than it may have today, where most (presumed) purposeful vegetation is located in relation to the stormwater system. Using more vegetation to enhance transpiration in the neighbourhood would reduce more stormwater and thus mitigating contaminants reaching the sea. It would provide for hydrologic processes of evapotranspiration as infiltration is not possible, and additionally provide for biodiversity and recreation for humans.

Although implementing more vegetation would contradict the historic concept and therefore perhaps risk losing the current approach for identity of the site, the solution might be worth it in the long run if deemed sustainable enough.

To follow TP's example, heavy vegetation but planted in smaller retention areas rather than one large, allows for them being located in the open park (fig. 54). This would keep parts of the park open, but provide more space for water to gather during cloudbursts (fig. 55). The implementation of this is however dependent on how much space a retention area needs in order to be functional in relation to the volume of water from precipitation. Additionally chosen plants have to survive both drenched and dry as well as in the soil type onsite.

Would the solution work, additional biotopes (like in TP) would be created which in turn enhances biodiversity (which is also one of the aims in the AB-project). Including more trees and shrubs for the vegetation, each adapted to the amount of water that is expected to be collected in each retention space, would increase evapotranspiration in the park. The amount of water that would be reduced using this solution is in this thesis impossible to tell. Thus whereas this solution would be functional enough for economic reasons to implement cannot be stated.

Fig. 53. Location of the open park. Map altered from VA-karta from VA SYD, 2018.

Fig. 54. Current layout of the open park. Image: Google Bilder *et al.*, 2018.

Current design of park

Overview of vegetation in the park. As can be seen a large area of the park is completely open.

Added vegetative retention basins

Adding vegetation along the Central Drainage Corridor may enhance evapotranspiration in the area. Although a lot of vegetation is already planted around site but in other areas, the implementation of a few more retention areas in the open spaces of the park which includes heavy vegetation could potentially provide for enhanced biodiversity as the created biotopes are different from current ones.

Fig. 55. Added vegetation. Image altered from Google Bilder *et al.*, 2018.

Vegetative retention basin

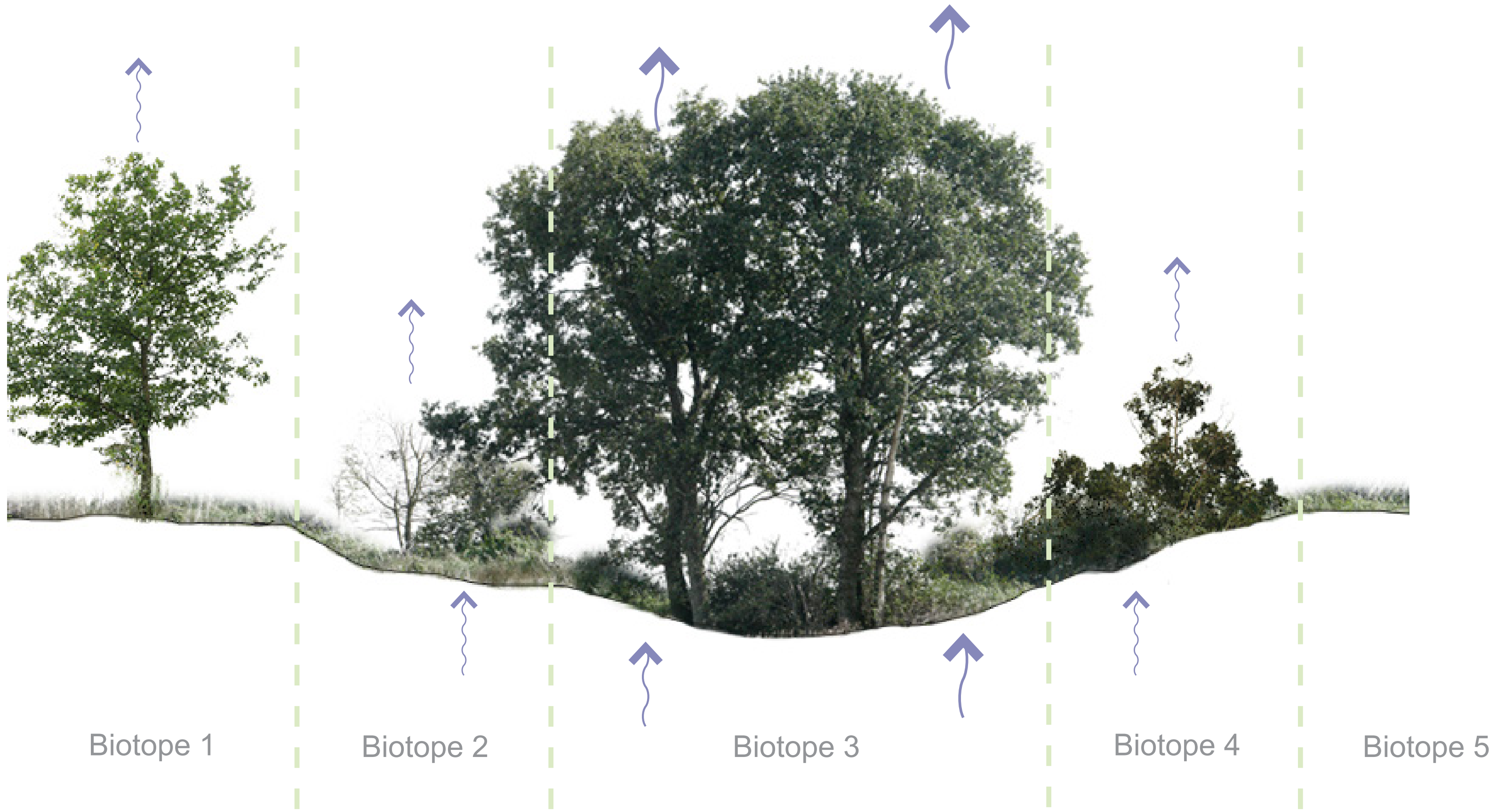


Fig. 56. A range of biotopes comes into place when using vegetated infiltration areas, such as has been done at Tåsinge Plads. Due to the high vegetetation amount evapotranspiration increases and subsurface water is kept in the area by the roots.

Evapotranspiration

Solution 2

AB has not made a difference between stormwater from green areas and from along roadsides, even though the water along the roads is considered to contain a larger portion of contaminants. Differentiating between locations of stormwater provides for the individualities of the site, which can be argued goes hand in hand with aiding the hydrologic cycle as the individual needs onsite are complied with.

As stormwater from AB is, without much purification, let out in the sea issues can arise for habitats near or potentially far from the outlet. Barbosa *et al.* (2012) explains the amount of contamination is relative to the volume of water it enters. Although this is correct, what kind of pollutant also plays part in the effects it has on living forms (Ellis, 2000).

Adapting the solution from TP of diverting stormwater along roadsides to a purification system or similar could potentially reduce contamination of the sea (fig. 57). If negative alterations within ecosystems caused by contamination has the potential of negatively alter water processes, the potential changes in hydrologic processes may be mitigated.

The sustainability of the purification system (the material of the filters + how often they have to be changed) could be further discussed, although not in this thesis. Technicalities onsite could either make this possible or impossible.

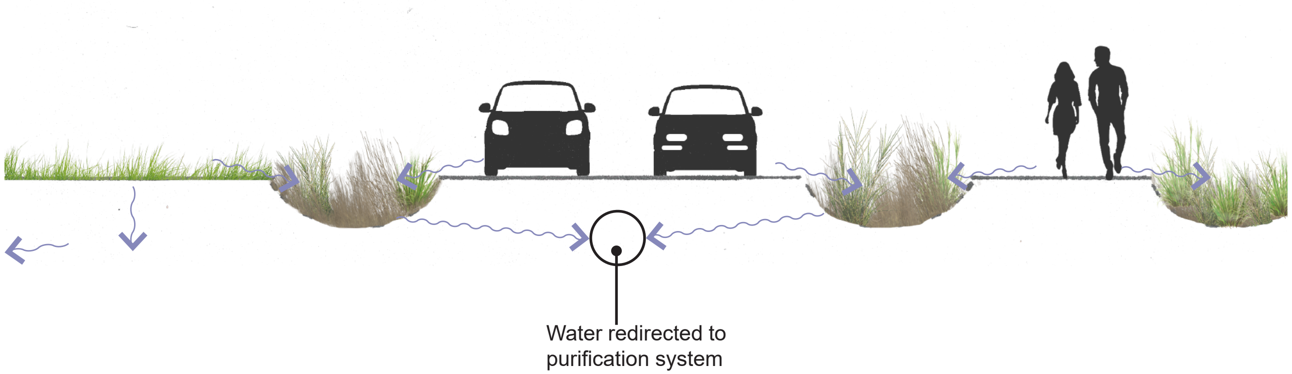


Fig. 57. Polluted water from the car road is directed to an individual water collection system, divided from cleaner water from green areas and partly from pedestrian roads.

Ideas adapted from Benthemplein Square

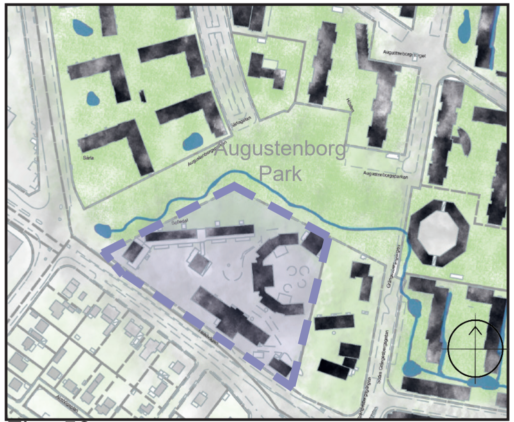


Fig. 58. Area around the Augustenborg Park and School is currently carrying most flooding issues. This can potentially be improved by installing a Water Square-like structure, adapted to site conditions and technichal requirements. Map altered from VA-karta from VA SYD, 2018.

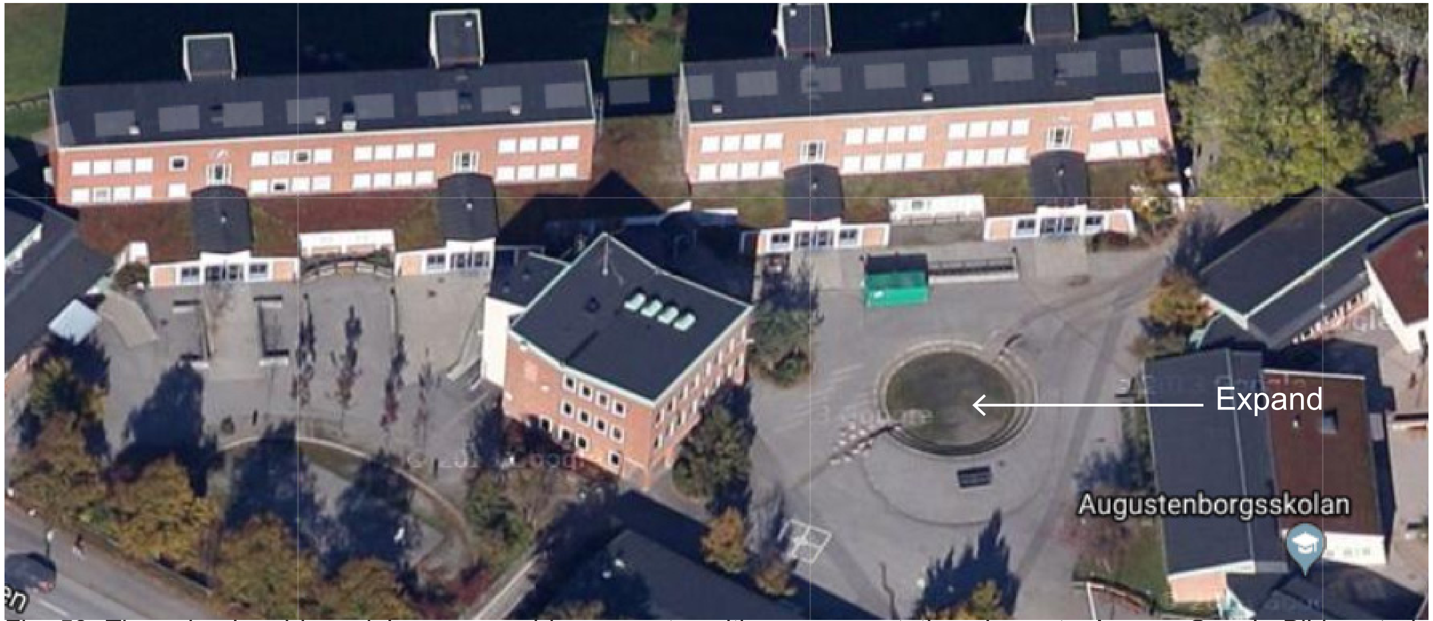


Fig. 59. The schoolyard is mainly compesed by concrete, with some vegetative elements. Image: Google Bilder *et al.*, 2018.

Fig. 60. The schoolyard is mainly compesed by concrete, with some vegetative elements. Image altered from Google Bilder *et al.*, 2018.

The Water Square case study exhibit a retention-based technique situated in a highly urban area. The square does not only collect stormwater through natural gravity, but also fills with water from surrounding rooftops (as seen in both AB and TP) as well as from floor areas at some distance (De Urbanisten, n.d., b). As there are three spacious reservoirs, presumably large volumes of water can be collected from around site.

This kind of installation is useful in an area that for wear-and-tear reasons is covered by concrete. Although infiltration is still made next to non-existent in the focus area, mitigation of flooding and space for evaporation is still achieved.

A variety of stormwater systems should be installed within one site in order to approach all aspects and achieve sustainability on many levels to be considered a sustainable site. Adding this solution to the neighbourhood could supposedly achieve the goal of mitigated flooding around the school and park during cloudbursts.

Evaporation should increase in the area as the square provides a large open area for the water to be exposed to sun whilst being retained, draining less water to the sea. This would in turn aid the hydrologic cycle in form of enhanced "recharge of precipitation" onsite, which in turn may recharge groundwater in other areas that provides for infiltration. Additionally a reduction of pollutants reaching the sea could be achieved as more water evaporates onsite. As it has not been possible reaching the designers during the research period for thesis, consideration has to be taken that the design and construction of this system may be more complicated than as presented. Thus technically the installation could be an economic challenge, considering features i.e. treatment systems, as well as a design challenge, as the system may have to include more technically than presented here.

Fig. 61. Water would, depending on construction of surrounding design, be diverted towards the suitable square. Dimensions in relation to expected water volumes would have to be calculated for the solution to be functionable. Map altered from Google Bilder *et al.*, 2018.

Overview

Installing one or all of these solutions can potentially aid the hydrologic cycle in individual ways. The solution discussion presents how a landscape architect can approach the quest of aiding the water cycle, and this page showcase the summary of found solutions. It does therefore have to be stressed that this is not a design proposal as few considerations apart from the hydrologic cycle are included.

Fig. 62. Map altered from VA-karta from VA SYD, 2018

Additional car road stormwater collection system along all car roads, like in Tåsinge Plads.

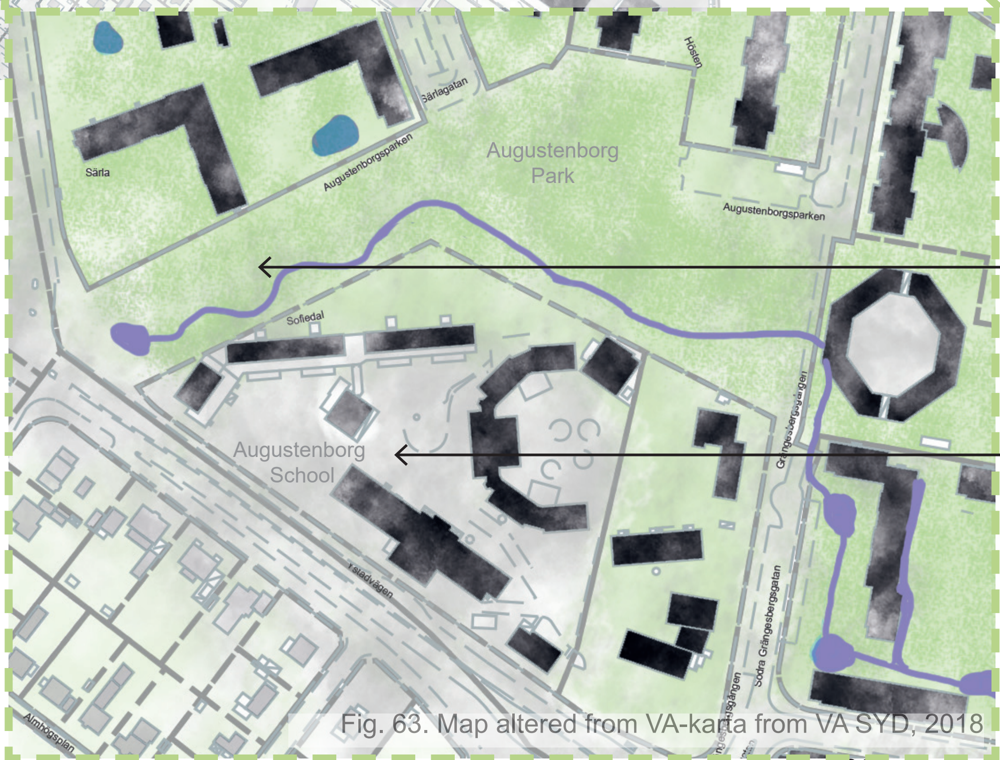
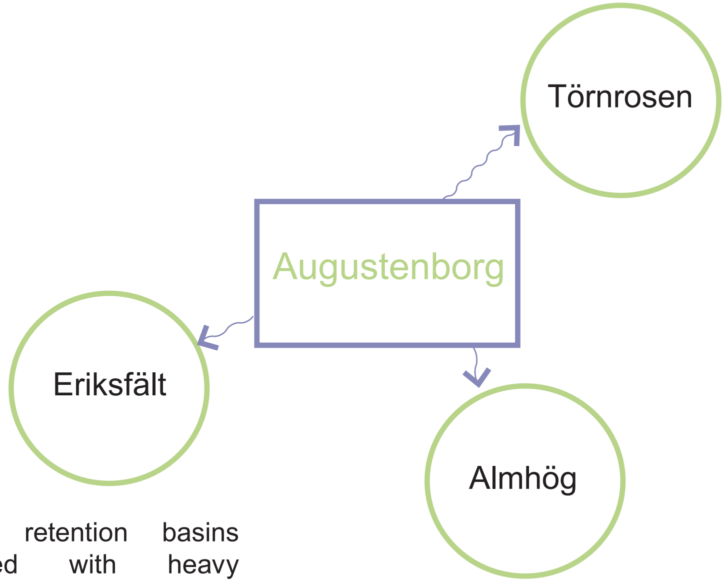


Fig. 63. Map altered from VA-karta from VA SYD, 2018

Addtional retention basins constructed with heavy vegetation, like in Tåsinge Plads.

Concrete retention basins similarly constructed to the Water Square Blenthemplein in Rotterdam.



Redirecting some of the water diverted to the sea to one or several area/-s with higher potential for infiltration.

Augustenborg

The investigation of Augustenborg proved it not to be an easy task to achieve a highly natural flow within an urban area when the natural status of a site is slow infiltration, as infiltration is one of the main objectives within sustainable stormwater management. The mimicking of the complex natural water cycle present difficulties within a lowly permeable urban area as the water at a natural state flows slowly and therefore pose the risk of flooding heavily when adding hardscape to it. Thus the area needs very specific individual design. Some solutions to increase the flow of the stormwater are to redirect it, let stormwater flow along the surface through rich vegetation to allow for extensive evapotranspiration, and/or enhance infiltration where it is possible.

Presumably there are many other solutions to approach this issue with, and the more the field of interest is researched and investigated the better solutions we can obtain.

The IWA principles argue for the importance of considering effects and solutions on all scales whilst designing a site, and construct a checklist of what to consider. A landscape architect has the power of working in line with level 1 and 2 as these relates to the site itself at small-scale. Level 3 and specifically 4 are however issues at large-scale, meaning many more factors take part in the decision making. A strong involvement of many factors between several disciplines can be considered over-dramatic, expensive and non-interesting for some stakeholders if it has to be done for every site in development. Nevertheless, perhaps this is what has to be done to achieve truly sustainable cities.

Augustenborg and the IWA-model

Approaching the IWA-model allows for an investigation of issues not directly related to the site design itself and therefore out of the individual landscape architects' hands. The IWA-model presents a heavy framework of how to achieve a sustainable site. The sustainability approach has to be considered from local to regional level, and across a variety of professions. It can therefore be considered a thourough approach in projects like this.

Some of the principles to consider at a local level (blue principles) has been achieved in AB, as described in part *"Analysis of Augustenborg with the IWA-model",* p. 41-47, whilst the considerations streching outside the site has not. Nor does the scope of this thesis allow for further investigations of how to achieve better prerequisities or qualifications for it (although these considerations may be the most important of all as they allow for change at a large scale). Sustainability-wise the area can therefore be considered obtaining a low sustainability level. The aiding of the hydrologic cycle is merged with sustainability, as a sustainable society (mimicking natural processes to a large extent whilst avoiding causing negative impacts on them) creates a sustainable water cycle. The water cycle on a basic level simply require space for infiltration to keep subsurface flows running to and from recipients; and evapotranspiration to keep atmospheric flows running to provide natural precipitation. In Augustenborg the evapotranspiration facor is well approached whilst infiltration currently needs to improve. Also purification of stormwarter before reaching the sea (the current recipient) should be enhanced and improved.

If achieving this, natural water processes and ecosystems can be kept intact better. Current urbanisation techniques however makes this next to impossible. Thus, in order for humans to keep a society and environment similar to the ones we have today, our systems and technology will have to change, learn from and adapt to natural processes. The complexity of sustainable systems is to keep current "living standards" whilst making them more sustainable without risking the comfortability people in (mainly) developed countries are used to.

The work of a landscape architect

The management of water is generally agreed to be one of our main issues we have to solve to achieve a sustainable development and livelihood. As urban areas pose the highest threat in regard to what landscape architects can approach within this field, this is where most solutions must take place.

To achieve the aim of sustainable stormwater management and systems, landscape architects need to understand the flow of natural water processes to adapt their landscape design to them. However, as landscape architects are far from the only fields working within developing cities and trying to achieve a higher sustainability within them, all fields taking part in this development must work cross-disciplinary. Although this in theory may sound simple, it may be difficult to realise.

The simplest solution that can be argued for here is to apply collaboration between study fields between students at university level, as this is where everyone starts learning their profession. Perhaps the differentiations between the fields can then be realised, making it easier for each field to know where the limits are and where the next field of profession start.

Discussion of method

To further improve the project some alternations could have been made. More time should have been given the design and solutions in order to deepen the solution discussion of Augustenborg as well as to achieve a detailed design proposal. Additionally, the gathering of information material of design briefs, map of vegetation and map of rubber textile sheet of the application would have improved the understanding of the site and thus potentially made it possible to construct a more informed analysis and discussion.

Interviews with Tåsinge Plads designers GHB Landskabsarkitekter and Malmos Landskaber, as well as with the municipality of Rotterdam regarding Benthemplein Water Square, would have provided deeper understanding for the site construction and functionality.

Finally, next to no critique or argumentation between the sources has been provided, which would have made the discussion as well as analysis more informative.

The IWA-model as a tool

The IWA-model presents one version of the foundation the International Water Association believe will help urban developement forward in the chase for uniting human living with natural living. Other principles, created to reach the same aims but through individual solutions and objectives (just like the ideas of SUDS and LOD) can however be found, and may or may not be better suited for the aim than the IWA-principles. The reason however for choosing and presenting the IWA-principles was to use them as a tool to explain the complexity of the field, rather than exposing them as the best option for sustainable development. Applying the principles onto the application area help to form a deeper understanding of how the site works, what has been done to make it sustainable and what could be made better.

Conclusion

The main issue within a hydrologic cycle is the prevention of hydrologic flows from progressing. This occurs mainly due to urbanisation removing and limiting vegetation whilst covering soil with impermeable material. Imbalances in the hydrologic cycle can affect humans negatively directly through the decrease of freshwater access, as well as indirectly through the negative impacts on ecosystems and thus ecosystem services.

Measures to be taken by landscape architects are to gain knowledge within the complex field of the hydrologic cycle, and learn to work across fields. Understanding water processes provide for the improved designing of stormwater systems encouraging infiltration and evapotranspiration as closely to natural flows as possible, which are individual for each site. Aiming towards approaching the large scale of stormwater management sustainability in relation to each site can improve a sustainable development.

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The complete cited IWA-model principles from the International Water Association (n.d.):

LEVEL 1 - REGENERATIVE WATER SERVICES FOR ALL

The main goal is to ensure public health and satisfy all current needs while protecting the quality and quantity of water resources for future generations by efficient production and
use of water, energy and materials. Regenerative water services are underpinned by five principles. Embedding these principles in water and wastewater systems rehabilitation, extension or new development will ensure the resource is protected and not overused. It will create value from energy and resource recovery not only from water but also from other services, and will facilitate financing by generating new revenue whilst delivering broader economic, social and environmental benefits to the city:

1.1 REPLENISH waterbodies and their ecosystems within the basin by taking from or discharging to them only what can be given or absorbed by the natural environment. Reduce water intakes to match quantities that the natural environment is able to renew, and protect the quality of water sources from wastewater and urban run-off so that it is fit for ecosystems and for use with minimal treatment requirements.

1.2 REDUCE the amount of water and energy used. Minimise the amount of water used in accordance with storage capacities. Minimise the energy used in moving and treating urban waters, including rainwater.

1.3 REUSE and use diverse sources of water with treatment that matches the use, applying the “fit for purpose” water quality approach and Integrated Water Resources Management (IWRM5); RECOVER energy from water whether through heat, organic energy or hydraulic energy; RECYCLE and recognise the value of “upcycled” materials, such as nutrients or organic matter;

1.4 Use a SYSTEMIC APPROACH integrated with other urban services. Consider the different parts of a water system and other services such as waste or energy as a whole, to enable solutions that reduce and reuse while improving services costs efficiently.

1.5 INCREASE THE MODULARITY and ensure there are multiple resource, treatment, storage and conveyance options available throughout the system for ensuring service levels and resilience of urban water systems in the face of either gradual or sudden changes. By applying the principles for regenerative services when adapting to population growth, or to the impacts of climate change, water services contribute to reducing the carbon footprint of cities and to rehabilitating their basins.

LEVEL 2 - WATER SENSITIVE URBAN DESIGN

seeks the integration of urban planning with the management, protection and conservation of the total urban water cycle to produce urban environments that are ‘sensitive’ to water sustainability, resilience and liveability co-benefits. This second level of action includes four principles:

2.1 PLAN AND IMPLEMENT URBAN DESIGN ENABLING REGENERATIVE WATER SERVICES. Design domestic
and industrial precincts and buildings in ways that enables regenerative water services. This reduces the water, energy and carbon footprint of housing, contributing to its affordability through lower monthly bills. It also leads to cleaner waterways, benefiting ecosystems and people, while also improving social and urban amenities. It includes building green infrastructure to capture and treat stormwater for a range of co-benefits.

2.2 DESIGN URBAN SPACES TO REDUCE FLOOD RISKS. Increase resilience to flood risks by developing urban drainage solutions, integrated with urban infrastructure design so that safe flooding spaces are provided and the city acts as a “sponge”, limiting surges and releasing rainwater as a resource. Plan vital infrastructure to enable quick disaster recovery.

2.3 ENHANCE LIVEABILITY WITH VISIBLE WATER from roadside green infrastructure to major blue-green corridors as opportunities for recreation, inclusive public space, economic development and transportation, creating multi-purpose spaces and infrastructure. Urban water services are essential for ensuring sustainable irrigation of parks and gardens, providing shade and mitigation of heat islands.

2.4 MODIFY AND ADAPT URBAN MATERIALS TO MINIMISE THEIR IMPACT ON WATER POLLUTION: The urban materials of roofs, walls, surfaces, roads, and urban furniture ought to be carefully selected to prevent the release of pollutants when exposed to sun and rain.

LEVEL 3 - BASIN CONNECTED CITIES

The city is intrinsically connected and dependent on the basin it is part of, and which interacts with neighbouring basins. By proactively taking part in basin management, the city secures water, food and energy resources, reduces flood risk and enhances activities contributing to its economic health. This third level of action includes three principles:

3.1 SECURE THE WATER RESOURCE and plan for drought mitigation strategies by sharing the water resource with other users in the basin, namely agriculture, industry and energy sectors, and other cities who all contribute to the basin’s and city’s economy.

3.2 PROTECT THE QUALITY of the water resource together with the other basin stakeholders, to ensure high quality drinking water achieved with minimal treatment and energy requirements, and ecosystems services (e.g. forest catchment areas, wetlands).

3.3 PREPARE FOR EXTREME EVENTS, such as storms and heavy rains, by managing flow regimes in rivers, by maintaining adequate vegetation in the basin to minimise flash floods. Invest in coastal storm risks mitigation and flood warning systems.

LEVEL 4 - WATER-WISE COMMUNITIES

The implementation of the previous three sets of Principles requires a holistic approach and strong partnerships. This fourth level of action is about people building on their existing capacities to govern and plan; professionals becoming more “water-wise” in their area of expertise, so that they can integrate water across sectors, highlighting the co-benefits of integrated solutions to unlock investments. It is also about

people becoming “water-wise” in their behaviours as citizens. This level of action is where the transition starts; it is where each stakeholder realises the role they have to play to make a difference. It’s about inspired people instigating five key actors of change into this “water-wise” transition:

4.1. CITIZENS involved in the sustainable urban water vision. Water-wise citizens can drive urban planning and design

with their understanding of the risks (flooding, scarcity) and opportunities (resource recovery, reducing dependency on uncertain future resources, increased well-being). Water-wise citizens will also adapt their behaviour. They will develop their acceptance to solutions, enabling regenerative water services, and their willingness to pay for such services while mandating their officials to ensure affordability.

Appendix

4.2. PROFESSIONALS WITH VARIOUS EXPERTISE (FINANCE, TECHNICAL, SOCIAL) who understand the co-benefits across urban sectors so that they may plan and implement the best solutions for urban dwellers and businesses. Synergies and dependencies exist between water and urban planning, architecture, landscaping, and energy, waste and transport services: water services require energy but conversely urban water can be used to produce energy locally; green urban space requires water that can be provided by collecting rainwater or reusing water from treated effluent to recycle nutrients in vegetated areas. Professionals, realising the market and non-market value of the co-benefits associated to an integrated urban agenda, will enable innovative sustainable solutions.

4.3. TRANSDISCIPLINARY PLANNING AND OPERATION TEAMS integrating water in city planning. All waters (freshwater supply, rain, rivers, seas and wastewater) are interconnected with each other and other urban systems (parks, roads, energy and waste) so that efficiencies and synergies arise from a coordinated approach. A city planning organisation recognising these inter-relations and bridging over existing individual departments is needed to enable urban professionals to implement sustainable urban water.

4.4. POLICY MAKERS enable the implementation of the Principles for regenerative water services, water sensitive urban design, and basin-connected cities. Water-wise policy makers establish policies and financing mechanisms (tariffs, partnerships, that are responsive and adaptive to future changes) to drive and enable sustainable urban water through incentivising and rewarding innovative solutions. They phase out the existing subsidies and tax advantages that are environmentally harmful. They monitor, evaluate and adjust the policies based on future needs as they change over time.

4.5. LEADERS provide the progressive vision and a governance structure to coordinate work at 4 scales (catchment, metro, neighbourhood and building) and across disciplines. The people governing at the national and local levels can enable sustainable urban water through coordination and integration, leveraging “effective and efficient governance enhancing trust and engagement”.

Water-wise communities will use the building blocks to put the Principles into action. The progressive implementation of the Principles at three levels: 1/ regenerative water services for all, 2/ water sensitive cities, and 3/ basin connected cities, will strengthen each of the 5 key actors of change of the city’s water-wise communities.