WATER-WAYS TO CLIMATE ADAPTATION

A LANDSCAPE-BASED DESIGN APPROACH FOR SUSTAINABLE URBAN WATER SYSTEMS

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Thesis Report
Master of Landscape Architecture

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WAGENINGEN UR
For quality of life

PREFACE

This thesis report is the result of one year of research and design on 'Waterways to Climate Adaptation'. In the past year we have researched the differences in impact of climate change on the Dutch landscapes. Consequently we searched for possible adaptation measures, especially in the urban context. For Enschede and Gouda, two cities in different landscapes, we worked towards site-specific, resilient, spatially qualitative, and climate adaptative measures. A landscape-based design approach to climate adaptation has resulted in a methodology which forms an interesting basis for climate adaptation in Dutch urban landscapes.

We would like thank in particular our tutors Ingrid Duchhart and Sven Stremke from the Wageningen University, and Pieter Veen from 'Vista Landschapsarchitectuur en Stedenbouw'. From the beginning until the end they have invested time and energy in guiding the process of our major thesis. Their enthusiasm, criticism, and professional knowledge has inspired and motivated us. Especially the combination between more practice based tutoring by Pieter Veen, and the more theoretically based tuition by Ingrid Duchhart and Sven Stremke has proven to be fruitful and finally resulted in a more balanced research and design exercise.

Furthermore, we would like to thank Johan Kolk from the Water board of Rijnland, Hendrik-Jan Teekens from the department 'Water management' of the municipality of Enschede, and Ad Vermeulen from the Water board Hollandse Delta for clarifying the complexity of the water systems of the urban landscapes of Gouda, Enschede, and Dordrecht.

Last but not least, we would like to thank our colleague students, friends, and family for their positive support, interesting discussions, and critical listening.

SUMMARY

The Dutch have a water rich history which brought both prosperity and misfortune. The richness of the delta resulted in the Netherlands being one of the most densely populated countries in the world; where the former dynamic natural water system in which man adapted themselves to the forces of nature was transformed into a static technocratic water system in which man attempts to control nature with dikes, pumps, and storm surge barriers. In this manmade landscape more and more climate related problems emerge, proven by recent droughts and flooding. These problems are likely to increase when the expected climate change is taken into account; sea-level is rising, precipitation peaks increase, while at the same time periods of extreme drought may occur more often. This results in peak discharges and water shortages, putting high pressure on the Dutch water systems.

chapter 1

There is thus a challenge in adapting Dutch water systems to the current and future climate, especially in cities where; the permeability of the soil-surface is minimised, the surface geometry is modified, and population density is (very) high. The main problems emerging in urban landscapes are sewage overflows, stormwater runoff, flooding, water shortage and the urban heat island effect. The question is how the urban water systems should be adapted to the changing climate. Are the contemporary technocratic approaches appropriate to deal with the expected problems? Or should we work towards a more natural and dynamic approach?

chapter 2

From our perspective as landscape architects educated at Wageningen University, we plea for a landscape-based design approach to work towards more sustainable landscapes. A landscape-based design approach acknowledges the importance of landscape in the process of climate adaptation. The differences in climate change impacts are closely related to landscape, while possible solutions are often embedded within the landscape as well. Furthermore, the landscape-based design approach sees city as landscape, thereby recognising the importance of the underlying and surrounding landscape in the process of climate adaptation. The landscape-based design approach is a crucial basis in order to work towards resilient, qualitative, and site-specific 'urban' water systems. This approach forms the theoretical and intellectual basis of this thesis.

Fortunately, various research programmes on impacts of climate change are initiated and many reports are written, thereby increasing the knowledge body. However, most contemporary climate adaptive measurements resulting from the research programmes are small scaled and the link with the landscape is missing, while it is this link that offers great potential in adapting urban water systems to climate change. There is a huge potential in finding site-specific and landscape-based solutions for adaptation to climate change.

chapter 3

The effects of climate change differ per landscape type based upon differences in relief, soil, and hydrology. Based upon these characteristics three major landscape types in the Netherlands can be distinguished; the higher sandy soils in the East, the lower peat and clay soils in the West, and the river landscape in between the two. A desk study revealed the potential impact of climate change for the largest cities in these landscapes. To test how a landscape-based design approach can be a mean in the process of adapting urban water systems to climate change two cities (Enschede and Gouda) in different landscapes, with both a high potential impact of climate change, are further researched.

Enschede is located in Eastern Netherlands and situated on an East-West sloping moraine around 60 metres above sea level with sandy soils and boulder clay lenses in the subsoil. Originally this area was the source of many brooks within the region, but these are canalised or have disappeared in (especially) the industrial period, resulting in a high dependability on the sewage system and quick discharges. Nowadays this area is the source of many problems within the region, of which the most important problems are stormwater runoff, sewage overflows, and flooding in wet periods while in dry periods drought and the urban heat island effect are problematic.

chapter 4

To increase the buffering capacity of the urban landscape and to reduce the climate related problems of the region, a renewed brook system is proposed. Rainwater is collected in catchment areas on the slope of the moraine and is then transported towards the new brook and further discharged through the city towards the surrounding landscape. For the catchment area within which the city centre is located, a plan is made with more detailed designs for different parts of the brook. Calculations are made to test whether the proposed design solutions can meet future water assignments, and by means of the designs the spatial quality is increased and the climate dynamics are made visible.

The strategies developed in the detailed designs are integrated into a spatial plan for the whole urban landscape of Enschede. In the case of Enschede, the landscape-based design approach results in a renewed brook system, which interconnects solutions into a healthy, and integrally functioning system.

The second case study focuses on Gouda, which is situated several metres below NAP in the peaty soils of Western Netherlands. The most important problems that occur in Gouda are flooding during periods of high precipitation and soil subsidence in dry periods due to peat oxidation. Furthermore, brackish seepage and brackish water inlet leads to problems for the tree nurseries in the region. The location below sea-level makes Gouda highly dependent on continuous inlet and discharge of water.

chapter 5

Interesting in this region are the deep land reclamations surrounding the city of Gouda. Two of these polders, the Middelburg- and Tempelpolder, are incorporated as retention areas within a renewed, interconnected, cyclic water network. In this renewed water system water surplus is not discharged, but flows freely from the higher polders in the city towards the deeper Middelburg- and Tempelpolder where it is stored, purified, and re-used in periods of drought. To improve the water flows and to prevent stasis in the renewed water network, bottlenecks are removed and the network is intensified. Furthermore, innovative peak retention basins are designed to reduce pressure on the system during extreme precipitation events.

To research how the network can be densified, how peak storage basins can be implemented, and how Middelburg- and Tempelpolder are transformed into a retention area, detailed designs are made. Calculations are made to test whether the proposed design solutions meet the future water assignments, while visualisations show how this renewed network might look like.

The strategies developed in the detailed designs are integrated into a spatial plan for the whole urban landscape of Gouda. A landscape-based design approach for Gouda results in a interconnected, cyclic water network in which innovative solutions are connected, resulting in a site-specific, resilient, and integrally functioning system, while enhancing the spatial quality within the urban landscape.

chapter 6

From our viewpoint as landscape architects, it has become clear that not only problems differ per landscape, but that the landscape also offers site-specific solutions. Research and design showed that acknowledging the importance of landscape in the process of climate adaptation is a valuable mean in the process of adapting urban landscape to climate change

Based on the two case studies interesting comparisons between the two designs can be made. For the cities in the peat landscape such as Gouda, with little potential for water storage within the city, an active relation with the surrounding landscape is essential. For cities in the sand landscape, where there is potential for storage and infiltration within the urban tissue, the relation with the surrounding landscape is reactive and pressure on the surrounding landscape should be decreased.

Apart from the site-specific solutions, generalised strategies can be distinguished. Collecting, storing, and discharging water are the steps that ought to be applied each time a landscape is adapted to climate change. How this strategy should be applied depends on the site-specific landscape properties, characteristics, opportunities and restrictions

In short, we can say that applying a landscape-based desing approach to the malfunctioning Dutch urban watersystems offers sustainalbe solutions for adaptation to climate change. Hopefully, this thesis forms a start for further research on landscape-based climate adaptation in Dutch cities.

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[1]

CLIMATE CHANGE IN AN URBANISED WATERLAND

This thesis started with a fascination for the Dutch watersystem and the potential impact of climate change. To understand the effects of climate change on this system, we first need to learn more about how the Dutch managed their water and land. Furthermore there is a need to come to grips with the potential effects of climate change on these Dutch water systems. As especially the urban context seems to be interesting, the process of urbanisation in the Netherlands and the effects of this process on the water systems need to be explored. The intriguing combination of the Dutch and their water, climate change, and urbanisation forms the context of this thesis and will be described in this chapter.

1.1 THE DUTCH AND THEIR WATER

Worldwide, the Dutch are famous for their way of dealing with water, Dutch dredging companies are among the biggest in the world, Dutch engineers are called in to improve safety in New Orleans after hurricane Katrina and the Dutch polders and windmills are a worldwide-known tourist attraction. Where does this fame come from?

Contemporary Dutch landscapes show numerous signs of a long-lasting history with water. These signs are a result of the interplay of factors that determine the landscape. "Landscape is the visible part of the earth that is determined by the interrelations and mutual relations of the factors soil, topography, water, climate, flora and fauna, and anthropogenic influences" (Vroom, 2005, p. 196).

The contemporary landscapes we see everywhere around us tell the history of the making of these unique landscapes, which were "originally instigated by the use of muscular strength and wind and water power, in the later Middle Ages progressed by technical achievements, the wind-watermill, and from 1800 to 2000 accelerated and scaled up by steam power and electricity" (Nienhuis, 2008, p.539).

1.1.1 NATURAL DYNAMICS SHAPING THE NETHERLANDS

Rhine Meuse delta

The Netherlands is part of the delta of North-Western Europe formed by the rivers Rhine and Meuse, which brought in sediments from the Alps for thousands of years. The first inhabitants of what is now called the Netherlands had to deal with the wet conditions in these low lands and the regular flooding from both the sea and the rivers. People adapted to these difficult and often dangerous living conditions with technical inventions. Around 3000-4000 B.C. dwelling mounds were created in the northern parts of the Netherlands (Barends et al., 2005). After a series of floods around 1000-1100 the first dikes were created in the Southern parts of the Netherlands and as these dikes got connected the first polders emerged (Rooijendijk, 2009).

Until 1500, more and more dikes and polders emerged and the once meandering riverbeds of the large rivers (Ijssel, Waal, Merwede, Rhine, Lek and Meuse) gradually became constricted between the man-made dikes. Furthermore, vast moorlands and peat bogs were colonised, drained, and exploited during that time (Nienhuis, 2008). These developments brought economic prosperity to the country as more land became available for agriculture and the excavated peat was sold as fuel. However, new problems arose as well. Water levels in the rivers got higher because of the creation of dikes and the reclamation of floodplains, and seepage emerged in the polder.

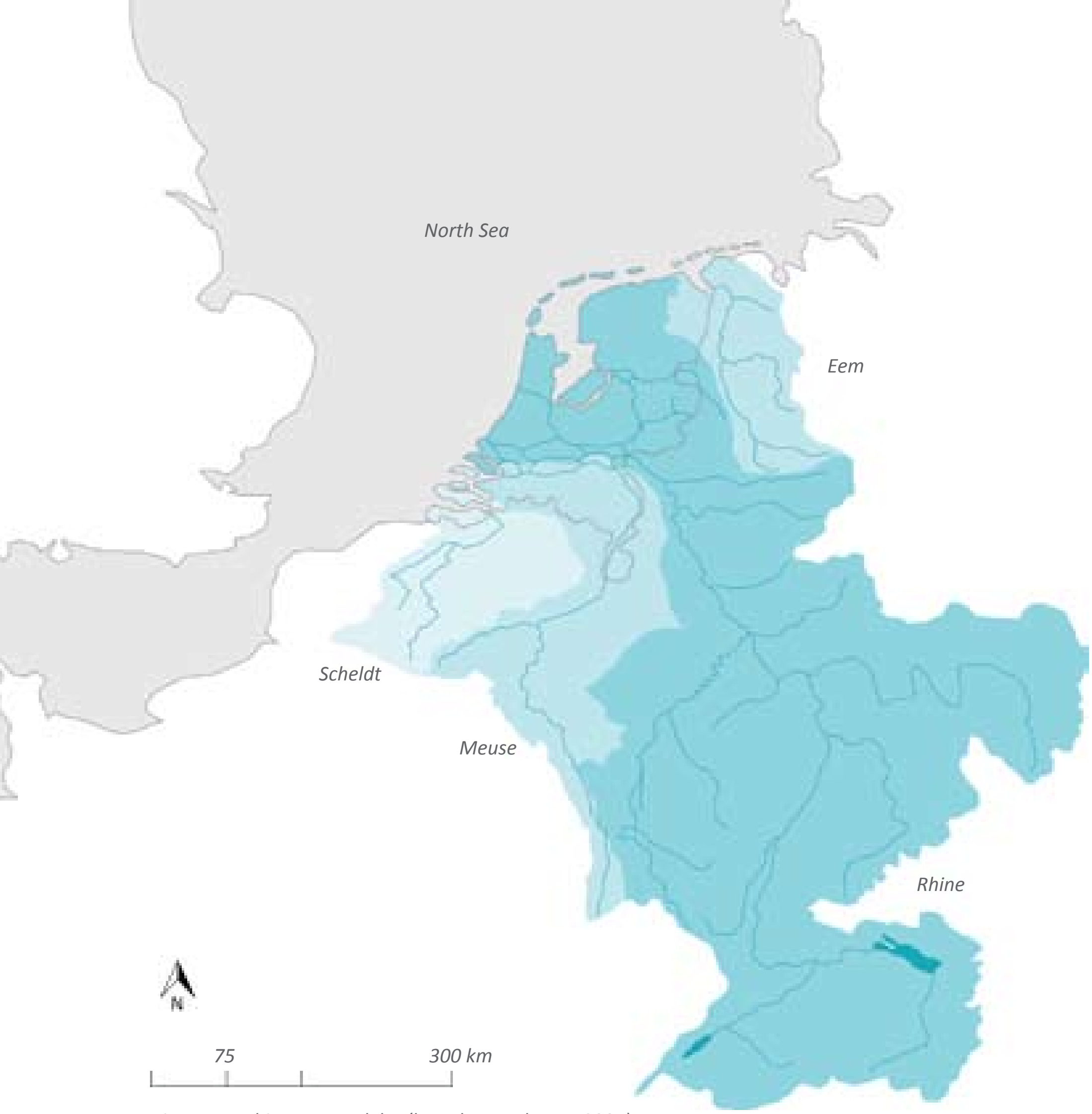

Figure 1.1 Rhine Meuse delta (based on: Deltares, 2007)

These first dikes were rather primitive and often collapsed under the pressure of high water levels in the rivers, which caused flooding in the polders. “Large areas of land were lost owing to the massive dredging of peat. Wind and wave attack on the foreshores accelerated the process of land loss, and hence the creation of peat lakes” (Nienhuis, 2008, p.534).

1.1.2 INCREASED ANTHROPOGENIC INFLUENCE ON THE LANDSCAPE

The invention of the wind-watermill marks a new era in the battle the Dutch fought against the water. The wind-watermill made it possible to drain polders, “it became technically feasible to reclaim large areas of peat land, and to turn peat lakes into fertile land” (Nienhuis, 2008, p.109). The first drainage project started in 1533 with the Achtermeer and large scale land reclamations started during the prosperous 17th and 18th century (Barends et al., 2005). During this period, people found more and more ingenious ways to cultivate the land. This combined with the strategic location at the sea and along the rivers enabled trade with other countries and resulted in economic prosperity. The Netherlands was the richest and most powerful country in the world during a great part of the 17th century.

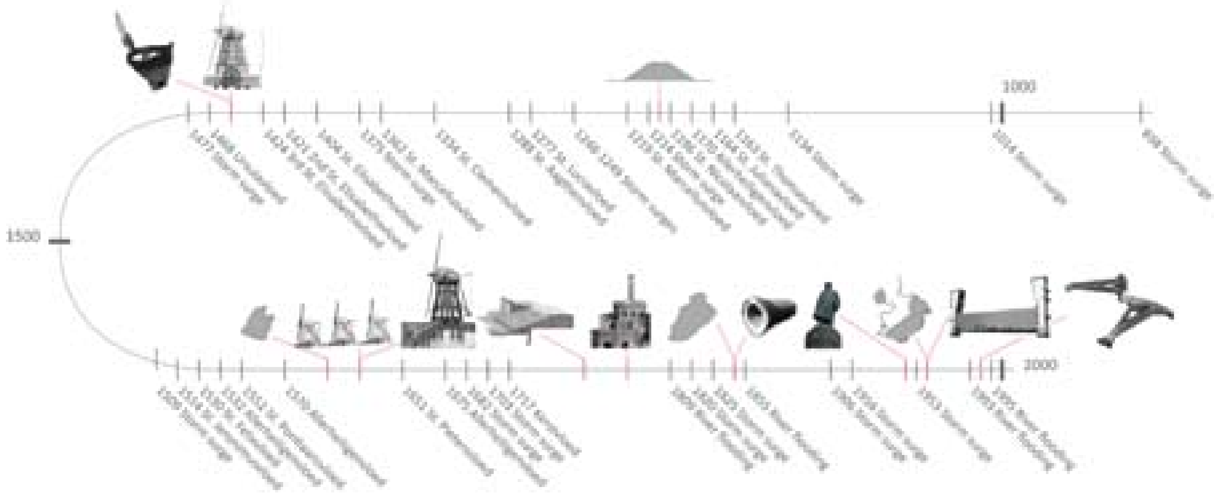

Figure 1.2 Paradox of Dutch water management, alternation of technological improvements and disasters (image by authors)

paradox

During this wealthy period in Dutch history “the paradox of water management became emergent: draining and dredging of peat lands, and harnessing rivers between higher and stronger dikes, unbridled natural forces not foreseen and never experienced before: land subsidence, expansion of (the remaining) peat lakes by wind and water forces, and increasing risks of river floods” (Nienhuis, 2008, p.544). For a long time in history the people lived with the water with a mixture of respect, love, and fear. Sea and rivers were the most important transportation systems, and provided the people with fish, brought fertile sediments to the Dutch delta, and water was used for irrigation and drinking. At the same time, flooding and storm surges inflicted a lot of damage to the people and the country.

After the invention of the wind-watermill, the industrial revolution marked another new era in the battle between the Dutch and the water. Rivers became more and more regulated through the technological improvements in river management, and the invention of the steam pumping station technology made it possible to drain large lakes such as the Haarlemmermeer. The main goal of the reclamation of the Haarlemmermeer was not so much the gaining of land, but flood protection. As water was pumped out it could no longer damage the surrounding land during storms.

1.1.3 TECHNOCRATIC, STATIC WATER DEFENCE OF THE 20TH CENTURY

changing relation

The protection of the Netherlands continued and intensified in the 20th century, the flooding in 1916 gave rise to the building of the ‘Afsluitdijk’, the flooding of Zeeland in 1953 initiated the creation of the ‘Deltawerken’, and the river flooding in 1995 called for the plan ‘Ruimte voor de rivier’. The protection practices continue until the present day situation, but over the centuries, the relation between the Dutch and the water has changed: “The main characteristics of the delta landscape in the past were the dynamic changes in water tables, the erratic and uncontrolled flooding and seepage and the vast, inaccessible stretches of low-lying land during winter inundations… This image has completely changed. Nowadays land is land, and water is water… Erratic changes in water tables are not allowed anymore” (Nienhuis, 2008, p.550). During the last decades of the 20th century, the Dutch felt safe behind their 'Deltawerken', dikes, and dunes, but this feeling of safety might have been misleading. The Dutch lost their feeling for water problems. The threats of the water and possible extremes in weather conditions are much less part of our daily life than they used to be. The awareness of the devastating power of the water is reduced (Hajer and Loeber, 2007). This loss of awareness combined with the feeling of power and safety is illustrated by the location of cities and urban expansions. Where people used to build on safe and higher places, nowadays the deepest polders are being urbanised, increasing the potential damage done. Furthermore, urbanisation is in many cases the base of problems as well. In paragraph 1.3.3 this subject will be discussed.

loss of awareness

1.1.4 LOSS OF NATURAL DYNAMICS

Land reclamations, canalisation of rivers and other impacts of man on the Dutch landscape have reduced the natural dynamics of the sea and rivers. Sedimentation processes of the sea and rivers, which naturally heighten the land along with a sea level rise, do not occur any more. Additionally, areas have been dug out metres deep for the extraction of peat as fuel, and lakes were pumped dry. The lowering of groundwater levels led to soil subsidence due to peat oxidation and the settlement of clayey soils. To keep the land dry, water levels had to be lowered again, resulting in the subsidence of the soil and so on. These processes have led to the subsidence of the soils in Western Netherlands with several metres since the middle ages, and the soil is still subsiding (Pötz and Bleuzé, 2010).

The paradox of losing control on nature by attempting to control it, has not disappeared, but has only become more apparent. Nature has been controlled more and more, natural dynamics disappeared, and natural resources are being depleted.

loss of natural dynamics

If sea levels would rise, and if rivers would discharge more water, or if extreme weather events would become more common, what will the future then look like for the Netherlands? It is very likely that these changes will occur as a result of climate change. The evidence that the climate is changing is more and more abound, both national and international research predict sea level rise, increased river discharges, extreme precipitation, and summer droughts. Thus, the 21st century will add a next interesting chapter to the rich history of the Dutch with the water. The call for new and innovative solutions has to be answered.

1.2 CLIMATE CHANGE

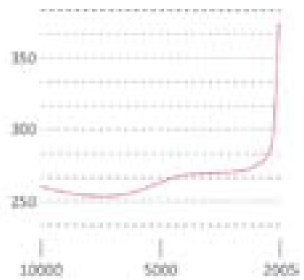

Figure 1.3 Concentration CO_2 (ppm/yr) (in: IPCC, 2007b)

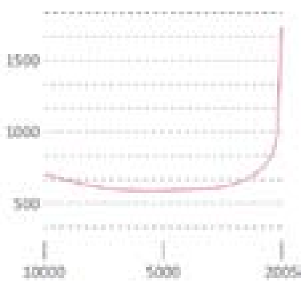

Figure 1.4 Concentration CH_4 (ppb/yr) (in: IPCC, 2007b)

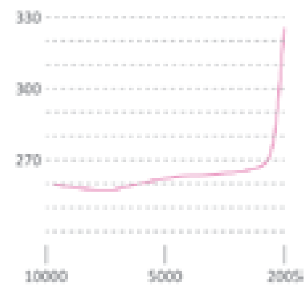

Figure 1.5 Concentration N_2O (ppb/yr) (in: IPCC, 2007b)

It is generally accepted that climate is changing and that this has consequences for people and their environments, however what this change exactly compels and what the consequences are is however not so distinct. This chapter will explain what climate change is, and describe the causes and consequences on global scale, based on data from the Intergovernmental Panel on Climate Change (IPCC). Subsequently, the causes and consequences of climate change will be described in the Dutch context. This is mainly based on studies of the Koninklijke Nederlandse Meteorologisch Instituut (KNMI). This broad impression on climate change gives an insight in the causes and consequences of climate change and forms the base for further research in this thesis.

“Climate is an average of the weather conditions in a certain area over a longer period of time. Often this is a period of 30 years, in which measurements describe average and extreme weather conditions during different seasons” (KNMI, 2009, p.11).

The climate on earth has always been changing, it is dynamic as all processes and phenomena on earth are. Climate change can be seen as a natural event influenced by differences in solar radiation activity, meteor crashes, volcanic eruptions etc. These processes influence the atmospheric concentrations of greenhouse gases and the land surface properties, which alter the energy balance of the climate system. However, the global atmospheric concentrations of the greenhouse gases carbon dioxide, methane and nitrous oxide have increased significantly as an effect of human activities since 1850 and now far surpass pre-industrial values (Solomon et al., 2008). This increase in greenhouse gases during the industrial period has resulted in an increase in the average global temperature. Thus, it is likely that the recent abrupt change in climate can be attributed partly to anthropogenic influences (Alley et al., 2003). Since the industrial period fossil fuels are being extracted and used to meet our continuously growing energy demands. Furthermore, natural carbon dioxide and methane sinks such as marshes, swamps and forests are being destroyed by humans. Consequently less greenhouse gases can be stored and therefore these are released into the atmosphere where it causes the greenhouse-effect (Reay and Hewitt, 2007).

1.2.1 GLOBAL CONTEXT

Climate change is a global issue with diverse consequences throughout the world. What are these consequences and what are the most vulnerable systems? In this chapter will discuss insights in climate change on global scale.

IPCC-scenarios

uncertainty

How the future will look like in relation to climate change is uncertain and depends on many factors such as inadequate knowledge of the climatic system, limited technological possibilities for calculating different models, and the non-linear climatic developments. However, when planning future developments, climate change should be taken into account. Climate scenarios help explore possible and plausible future events with relation to the developments of the climate (Klein Tank and Lenderink, 2009).

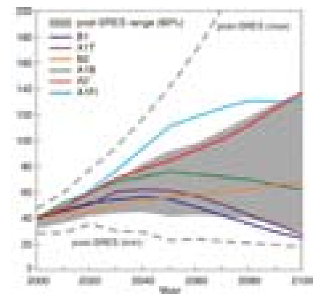

Figure 1.6 GHG emission scenario's (Gt CO_2-eq / yr) (in: IPCC, 2007b)

The IPCC has developed greenhouse gas emission scenarios which form the base for climate scenarios. Variations on a wide range of economic, demographic and technological driving forces have formed the base for the IPCC greenhouse gas emission scenarios. And despite the high level of uncertainty in such models, there is high agreement and much evidence that with current policies on climate change mitigation and associated sustainable development, greenhouse gas emissions will continue to grow over the next few decades (IPCC, 2007b).

Depending on the various greenhouse gases emission scenarios, the increase in temperature in the year 2100 compared to temperatures from the period 1980-1999 will be 1.8 – 4.0°C (Parry et al., 2008; IPCC, 2007b). An increased average global temperature results in thermal expansion of water. Additional, higher temperatures cause rapid dynamical changes in ice flow. The melting of glaciers and ice-caps cause the volume of water in the oceans to increase even further, which can lead to a sea-level rise of approximately 1m in 2100 and 6-7m in the next millennia. However, if the melting icecaps are not taken into consideration, the expected average sea-level rise at the end of this century is 18 – 59cm (Parry et al., 2008).

Weather extremes

impacts of weather extremes

Research on changes in climatic extremes during the second half of the twentieth century by Frich et al. (2002) indicates that during the second half of the 20th century the world has become both warmer and wetter. Heavy precipitation occurs more frequently and cold temperature extremes became less frequent (Frich et al., 2002). Between 1951 and 2003, more than 70% of the global land area showed a significant increase in the occurrence of warm nights while the occurrence of cold nights showed a similar decrease. Furthermore, warming is apparent in all seasons, however March to May generally show the largest temperature increase and September to November the smallest (Alexander et al., 2006).

Weather events that can have large impacts, such as heat waves, storms and droughts, are likely to become more frequent and widespread. Furthermore, these events will in some cases not only become more frequent, but also more intense. According to the IPCC it is realistic to expect events such as Hurricane Katrina, which hit New Orleans in 2005, to occur more often in the future (Parry et al., 2008).

1.2.2 THE MOST VULNERABLE SYSTEMS AND REGIONS

Climate change affects the whole world, however, not all systems and regions are equally affected by this change. Some places have to deal with more negative and severe effects of climate change than others. Warming, for example, is expected to be greatest on land at northern latitudes, and least over the Southern Ocean and the North Atlantic. Consequently, the melt depth of permafrost is expected to increase and melting of sea ice and glaciers is predicted, all influencing ecosystems and the sea level. Precipitation amounts are likely to increase in high-latitude regions, while subtropical regions will have to deal with about 20% reduction in precipitation, contributing to the process of desertification. Furthermore, future tropical cyclones will become more intense due to heavy precipitation (IPCC, 2007).

low-lying coasts

According to the IPCC, low-lying coasts are among the most vulnerable systems. These areas will be exposed to increasing risks, such as coastal erosion and flooding, due to the threat of sea-level rise, and increased extremes in drought and precipitation. By the end of the 21st century millions of people in the densely populated and highly urbanised coastal regions will experience regular flooding as a result of the sea level rise (Parry et al., 2008).

1.2.3 DUTCH CONTEXT

The Netherlands is an example of a low-lying, densely populated, and highly urbanised coastal region vulnerable to the effects of climate change. As discussed previously, the Dutch always had to struggle with the threats from sea and rivers and due to urbanisation the risks (potential damage) in this region has only increased, while the capacity to adapt to change has decreased. Problems are already abundant, however, it is most likely that climate change will only amplify these contemporary problems and that new challenges will arise.

KNMI scenarios

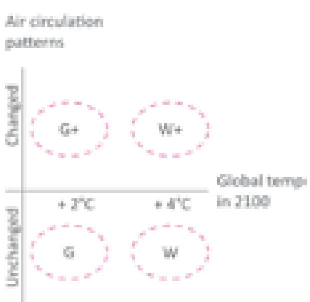

Figure 1.7 KNMI climate scenario's (in: Klein Tank et al., 2009)

To answer the question how the future climate in the Netherlands will look like, the KNMI developed four climate scenarios up to the year 2100 based on the IPCC climate-models. Global climate models, regional climate models for Europe, and historic measurements of the climate in the Netherlands have been combined to get possible and plausible climate scenarios for the Netherlands. The scenarios are determined by the temperature change and by the change in air flow patterns in Western Europe.

base of probability

As is the case with the IPCC scenarios, the KNMI scenarios have to deal with a high rate of uncertainty. By taking the differences in temperature change and air flow patterns into account the four scenarios developed by the KNMI form a base of probability, which deals with the uncertainty in predicting climate change.

Table 1.1 KNMI climate change scenarios. Based on differences in global temperature rise and changes in air circulation patterns the KNMI developed 4 climate change scenario's. The G scenario is the most modereate with a predicted global temperature rise of 1°C and no air circulation changes. The most intense scenario, W+, is based on a predicted global temperature rise of 2°C with changes in air circulation patterns. The table gives an overview of the predicted climatic changes per scenario per season (in: Klein Tank et al., 2009).

		G	G+	W	W+
Winter	Average temperature	+1.8°C	+2.3°C	+3.6°C	+4.6°C
	Coldest day/season/year	+2.1°C	+2.9°C	+4.2°C	+5.8°C
	Hottest day/season/year	+1.6°C	+1.8°C	+3.2°C	+3.4°C
	Average precipitation	+8%	+14%	+14%	+28%
	Wet days (≥ 0.1mm)	0%	+2%	+16%	+24%
	Exceeding precipitation amounts once per 10 years over 10 days	+8%	+12%	+16%	+24%
	Highest average daily wind velocity per year	-1%	+4%	-2%	+8%
Spring	Average temperature	+1.8°C	+2.4°C	+3.6°C	+5.2°C
	Coldest day/season/year	+2.0°C	+2.8°C	+4.0°C	+5.6°C
	Hottest day/season/year	+2.0°C	+3.0°C	+4.0°C	+5.8°C
	Average precipitation	+6%	+2%	+12%	+6%
	Wet days (≥ 0.1mm)	-2%	-6%	-4%	-10%
	Exceeding the daily precipitation amounts once per 10 years	+18%	+10%	+36%	+36%
	Exceeding precipitation amounts once per 10 years over 10 days	+12%	+6%	+24%	+14%
Summer	Average temperature	+1.7°C	+2.8°C	+3.4°C	+5.6°C
	Coldest day/season/year	+1.8°C	+2.2°C	+3.4°C	+4.6°C
	Hottest day/season/year	+2.1°C	+3.8°C	+4.2°C	+7.6°C
	Average precipitation	+6%	-19%	+6%	-38%
	Wet days (≥ 0.1mm)	27%	10%	54%	20%
	Evaporation	+7%	+15%	+14%	+30%
Autumn	Average temperature	+1.8°C	+2.6°C	+3.6°C	+5.4°C
	Coldest day/season/year	+2.0°C	+2.6°C	+4.0°C	+5.2°C
	Hottest day/season/year	+2.0°C	+3.6°C	+4.0°C	+7.2°C
	Average precipitation	+6%	-6%	+12%	-12%
	Wet days (≥ 0.1mm)	-2%	-10%	-2%	-22%
	Exceeding precipitation amounts once per 10 years over 10 days	+6%	+16%	+14%	+30%
	Absolute sea-level rise	35-60cm	35-60cm	40-85cm	40-85cm

communalities

The KNMI climate scenarios describe different possible futures, but all have at least five communalities (Van den Hurk et al., 2006):

- Temperatures in the Netherlands will continue to rise, and milder winters and hotter summers will become more common.
- On average winters will become wetter and extreme precipitation amounts will increase.
- In summer extreme rainfall will increase, however the total of rainy days in the summer will decrease, overall making summers dryer.
- Changes in the wind climate are relatively small, compared to the natural inconstancy of the wind.
- Sea level will continue to rise.

The W^+ predictions wil be used for further calculations within this thesis.

Precipitation

seasonal differences

On average the amount of precipitation will increase during the next century as a result of climate change. However, there are seasonal differences. During winter periods for example, the amount of precipitation will increase with 4-14% while in summer periods the amount of precipitation might decrease up to 19%.

The increase in winter precipitation might increase the risk of flooding while the decrease in summer precipitation might lead to a shortage of water as the decrease in precipitation is coupled with an increase in evaporation due to the rising temperatures. Moreover, not only the amounts but also the intensity of precipitation is changing. While precipitation in summer periods is predicted to decrease, the intensity of summer rain showers is predicted to increase.

Sea-level rise

absolute sea level rise

relative sea level rise

A very threatening effect of the changing climate in the Netherlands will be the rising sea level. Global atmospheric concentrations of the greenhouse gases have increased distinctly as an effect of human activities since the industrial period (Solomon et al., 2008). This increase has a linear correlation with the increase in the average global temperatures. The temperature rise causes thermal expansion of water in oceans and seas. Furthermore, glaciers and ice-caps melt, resulting in an increase in volume of water in oceans and seas. Consequently, the sea level rises. This has consequences for coastal regions and cities. A rise in sea-level can have dramatic consequences for the Netherlands, according to the KNMI scenarios the absolute sea-level rise in 2100 will be 35 – 85cm. Additionally, the western part of the Netherlands is slowly, but certainly lowering with 15cm – 135cm by the end of this century. Combined with the rising sea level this will result in a relative sea-level rise of 50 – 220cm in 2100, depending on the process of soil subsidence and the different KNMI climate scenarios. Possible melting of ice-caps is not taken into consideration. If this would be included, one metre should be added to these numbers (KNMI, 2009; IPCC, 2007a).

As discussed previously, the Dutch have a rich history in defending themselves against the threats from sea. This has led to the built of hard sea-defence constructions and stringent laws and dune management. These measurements have provided safety to the country, but have also proven to have downsides. Measurements of the Rijkswaterstaat show that there has been a loss of sediments along the Dutch coast during the past decades. The consequences of this loss of sand for the coastal region is unclear, however there is a concern that the coast will become more vulnerable when exposed to extreme storm events and sea-level rise (Klein et al., 1999).

River discharge

Another effect of the changing climate that will be noticeable in the Netherlands is the changing discharge pattern of the rivers. According to Engel (1997), the average annual precipitation over the Rhine area has, since 1890, shown an increase of ca. 80mm. Furthermore, between 1890 and 1990 the winter precipitation of this same area has increased with 20%. In the Alps there will be more rain rather than snow, which increases the Rhine discharge during the winter period even more (Van den Hurk et al., 2006). The expected maximum water discharge of the Dutch delta for 2100 measured at Lobith is 17.500m³/s compared to the current maximum discharge of 16.000m³/s. However, this increased rate of flow is based on potential flooding in Germany. If the dikes in Germany will be strengthened and the surface area of floodplains will be reduced, the maximum rate of flow at Lobith will be 22.000m³/s (Vellinga et al., 2008). The main problem of an increased river discharge is the related flooding risk. Downstream the influence of the sea-level rise is becoming more apparent. High sea-levels stow water-levels in the rivers. Especially the combination of storm surges and extreme precipitation can cause high water-levels. This problem also occurs in the IJssel river, at the IJsselmeer during northwestern storms (Rense, 2009).

beyond boundaries

Additional to the increase of river discharge in winter, the river discharges are expected to decrease during the summer period, due to less melting water from the Alps and because of more evapotranspiration. Moreover, the Rhine, currently fed by both melt- and rainwater, is expected to transform in a more rainwater fed river, which means higher discharges in winter and lower discharges in summer (Rense, 2009).

Soil subsidence

A special characteristic of the Dutch delta that should be taken into account regarding climate change is the subsiding soil. Large parts of Western Netherlands already are below sea level as a result of the draining practices to make the land suitable for agriculture, industry and housing. And, as this draining is still happening these days, the land continues to subside with a maximum of 4mm/year due the settlement of the clay soils, and approximately 8 – 12mm/year due to oxidation of the peaty soils (Berendsen, 2005; Geofoon, 2010). Additionally, the Western part of the country is lowering with 1.5mm/year due to tectonic subsidence (Van Loon, 1999). This means that the subsidence of the land in the year 2100 can be up to 1.35m for parts of Western Netherlands compared to the year 2000.

settlement / oxidation

tectonic subsidence

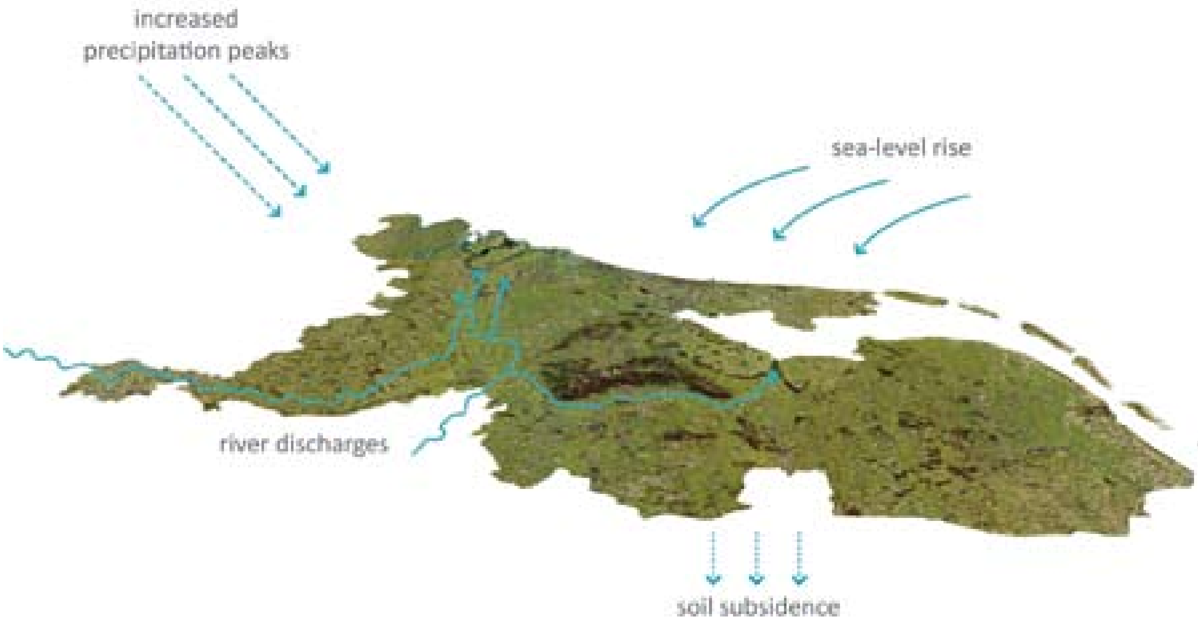

figure 1.8 potential accumilation of the climate change effects

Accumulation of problems

The Dutch, with their sophisticated water system, are facing a 4 sided risk. First of all, the Netherlands are sinking due to tectonic subsidence and oxidation of the peat soils. Secondly, increased river discharges put high pressure on the dikes and discharge mechanisms. Thirdly, both extreme high and low precipitation peaks result in increased water shortages and surplusses and finally the sea level rise threaths the Dutch coastal region.

Especially when some of these risks occur simultaniously, problems are bound to happen. As described previously, there is a call for solutions for the Dutch water problems of the 21st century. However, at the same time the question emerges how this call should be answered? Are contemporary solutions sufficient, or is there a need for another approach?

1.3 TECNOCRACY VERSUS DYNAMICS

To protect the Netherlands against flooding, technocratic solutions were found and trusted upon and the dynamics of the rivers and sea were tamed. Land was reclaimed, dikes were built, rivers were canalised, and in the second half of the 20th century mega storm barriers were constructed. Nonetheless, the natural forces never could be restrained and controlled completely, proven by the many flooding events in the course of time. However, without these technical interventions the Dutch culture would not be what it is, the polder landscapes the country is famous for would not exist, and large parts of the country would be uninhabitable. On the other hand, this technocracy has led to a static system that can hardly adapt adequately to change, while change is inevitable, just as Heraclitus (ca. 544-483BC) once stated: "All things are flowing", "Nothing endures but change", "Nothing stays still", and: "Nothing ever is, everything is becoming" (Müller-Merbach, 2006, p.170-171).

emerging conflicts

Higher water levels due to extreme precipitation, river discharges and sea-level rise will influence water management and the water systems. The dynamics of the changing climate will conflict with the static water management and water system. The functioning of contemporary water systems in the Netherlands highly depends on water pumping stations, storm surge barriers, the sewage system, dikes, and other technocratic structures. The functioning of these structures will change in the future in the perspective of climate change. For instance, storm surge barriers will close more frequently when the sea level rises. Consequently, discharging river water at high tides will become difficult, resulting in water surpluses upstream and increased pressure on the dikes, which then increases the risk of a dike breakthrough or overflow. In the report 'Samen werken met water' the Delta commission states that large parts of the dike system already do not reach the safety norms and that, when climate change is taken into account, the potential flooding risk is high (Deltacommissie, 2008).

figure 1.9 Change from a natural dynamic, into a technocratic static water system over time

Furthermore, periods of extreme drought, which are likely to occur more frequently, lead to water shortages. The reduction of the buffering capacity of the land, as a result of fixed water levels, unnatural water levels for agriculture (higher groundwater levels in summer than in winter) and the quick discharge of water, makes the water system vulnerable. Water shortages are more common for the Netherlands than perhaps would be assumed, while the danger of flooding always remains (Klein Tank and Lenderink, 2009).

problematic transformation of the water system

The transformation from a natural dynamic water system in which mankind adapted to the forces of nature into a technocratic static system in which the forces of nature are attempted to be controlled, turns out to be problematic. Particularly in the urban context, where this transformation is most apparent, problems are bound to happen when weather events become more extreme due to climate change.

1.4 URBANISATION

Additional to climate change in the Netherlands, the process of urbanisation nowadays is one of the most important forces shaping the landscape. More and more people migrate to urban regions, expanding cities to mega metropolitan regions. New urban landscapes emerge, "which are characterised by a functional homogeneity" (Antrop, 2004, p.9). The process of urbanisation inevitably influences the functioning of the natural forces of landscape and ecology. Therefore, this global process is included as one of the three important foci of this thesis. In this chapter the facts, causes, and consequences of urbanisation will be discussed briefly.

"Urbanisation is a process of population concentration… Just as long as cities grow in size or multiply in number, urbanisation is taking place… Urbanisation is a process of becoming. It implies a movement… from a state of less concentration to a state of more concentration" (Tisdale, 1942, p. 311).

1.4.1 FACTS

Currently half of the world's population lives in urban centres, compared to less than 15% in 1900 (Satterthwaite et al., 2007). 74% of the total population in the European Union lives in cities and towns with more than 5000 inhabitants, which means only a quarter of the European inhabitants live in a rural environment (Eurostat, 2009). Delta regions are among the highest urbanised areas in the world. These regions always have been magnets for economic activities, attracting many people who seek to benefit from this wealth (UNEP, 2002).

urbanised deltas

The Netherlands, as a part of the Rhine and Meuse delta, is an example of such a highly urbanised delta. 81% of the population lives in urbanised areas, of which 58% lives in highly urbanised areas (CBS, 2009a). The Randstad metropolitan region with 6.7 million inhabitants is even among the most densely populated regions of Western Europe and the population is still growing (TNO, 2007; Schnabel, 2009).

In total, over ten million of the Dutch urban inhabitants live in the low elevation coastal zone, of which a great part lies below sea-level (McGranahan et al., 2007). Flooding of sea and/or rivers poses a serious threat and has occurred more than once, even in the recent past. There is no guarantee that this will not happen again. Furthermore, the many people living and working in the urbanised areas make these economically very important. Urbanised areas are clustered risk zones where the potential damage is huge.

clustered risk zones

figure 1.10 Highly urbanised delta's (based on: NASA, 2004 & Heller, 2001)

1.4.2 URBANISATION IN HISTORIC PERSPECTIVE

In the previous section an outline of the current situation regarding urbanisation has been sketched, however, how this situation arose was not yet discussed. This section will briefly discuss the process of urbanisation in an historic perspective. Another question that will be answered is how urbanisation affected the environment in different periods of time.

"Until the middle of the twentieth century, urbanisation levels were too low and the number of large cities was too small for there to be anything other than local climatic and hydrologic impacts" (Berry, 2008, p.103). Nevertheless cities did have an indirect environmental impact and still do through consumption of external (outside the city) products. To meet the urban demands minerals, forests and farmlands around cities were exploited.

related to natural resources

Initially, urban developments were closely related with the natural resources located on the settlement site. The towns or villages were a direct result of the successful agriculture, which created a food surplus. This in turn reduced the time required for gathering food, which enabled the development of new activities. Economies based on specialisation and trade emerged and triggered other activities which caused further population growth (Antrop, 2004).

waterways

In time, transportation and mobility became increasingly important and were significant factors in economic and urban development and growth. Up to the early 17th century barge boats navigated to harbours over sea and facilitated the hinterland via canals and rivers. Waterways initiated important landscape changes and played a major role in the process of urbanisation. Along the network of waterways cities and industries could emerge and grow (Antrop, 2004). Rivers and sea connected countries and continents, enabling trade over a longer distance which was highly profitable. The economic growth attracted many people to these connected centres. Nevertheless, the world remained largely agrarian until the 17th-18th century and less than 10%

of the population lived in urban areas. Moreover, only five cities had more than 500.000 inhabitants and only 34 exceeded 100.000 inhabitants. Unsurprisingly, the environmental impact of urbanisation was minimal, although a clear pattern became visible around the cities: the further away from the city, the less the clearance of forests for ships' timbers, fuel wood, and farming (Berry, 2008).

The rapid development of industry and commerce in and around cities resulted in further urbanisation. "Urbanisation is closely related to industrialisation and economic growth and spread with the innovations caused by the Industrial revolution" (Antrop, 2004, p.14). Crucial for the industrial revolution was the invention of the steam machine, which enabled mass production. This innovative technique also led to the invention of steam trains and railroads, which covered most of Europe by 1875 and disclosed many villages which then could grow in size and population (Antrop, 2004).

industrial revolution

The process of urbanisation really accelerated during the 20th century when generalised car use increased mass mobility, and rapid population growth lead to urban sprawl in many places in Europe and the U.S.A (Berry, 2008; Antrop, 2004). Furthermore, the Second and Third World countries are increasingly urbanising, some 70% of the world's urban population lives in Africa, Asia or Latin America. Where there were only 43 cities with more than 500.000 inhabitants worldwide round 1900, today almost 400 cities exceed 1.000.000 inhabitants (Berry, 2008; UNEP, 2002).

mass mobility

1.4.3 ENVIRONMENTAL IMPACT OF URBANISATION

"Current urban development and urban living are nowadays regarded by many as ultimately unsustainable because of the destructive burden they place on the cities' regional and global environments" (Frey, 1999, p.20). This burden cities place on the environment can be seen as the physical effects cities directly have on their surroundings, modifying climate and hydrology. Cities as well have an indirect destructive effect on the environment through lifestyles of the cities' inhabitants that puts great pressure on the both regional as the global environment. The ecological footprint of a city surpasses by far the surface area of the city. This is one of the causes of climate change, as discussed in the previous chapter. However, in the context of this thesis, with the focus on climate adaptation, the direct environmental impact of urbanisation is most relevant.

destructive burden

The process of designing, building, and maintaining cities has more often harmed and excluded ecological processes instead of utilising these, resulting in ill cities in which soil, water, flora and fauna are often destructed or poisoned. Ecology "deals with the relations of organisms to one another and to their physical surroundings" (Oxford University Press, 2010).

Urbanisation has resulted in a larger area built up land and increased sealed (paved/asphalted) surface and a decrease in green and blue surface area. This influences the infiltration capacity of the soil, the surface albedo, available moisture in the urban atmosphere, and the airstream patterns. Thus, the microclimate of urbanised areas is modified, with temperatures in cities generally higher than in their surroundings and ventilation being minimal (Arnfield, 2003; Corburn, 2009; Voogt, 2002). Furthermore, cities often serve as trap for atmospheric pollutants (Berry, 2008).

modified environment

Due to the sealed soil surfaces, storm water cannot infiltrate in the soil and artificial drainage systems cannot cope with extreme rainfall. Stormwater runoff and sewer overflows pollute soil and water in and around cities (Bronstert et al., 2002).

Thus, urban areas are extra vulnerable to certain extreme weather events, such as extreme precipitation or extreme drought and high temperatures, which in the future will become more common.

1.4.4 URBANISATION IN THE NETHERLANDS

industrialisation

The industrialisation late 19th century marks an important era in Dutch urbanisation. Dropping mortality rates resulted in population growth and an increase in productivity initiated a migration of people from the countryside towards the urban areas where they hoped to find a job in one of the many emerging factories. The growing population resulted in large-scale construction of new housing projects.

As these houses were too expensive for most factory workers slums emerged and living conditions were poor. In order to improve the living conditions, the government initiated the 'woningwet' thereby stimulating the building of rental houses and improvement of building quality. Furthermore the 'woningwet' resulted in urban development planning on both national and municipal scale.

renewed urbanisation

After the Second World War a period of renewed urbanisation started. National Government initiated large-scale restoration of infrastructure and housing to overcome the housing shortage. Where most housing projects before the war can be characterized as small-scaled extensions connected to and within the existing urban tissue, the building projects from the 50's and 60's are characterised as large scaled, high-rise at the edge of towns and cities. The availability of houses nearly doubled between 1945 and 1970 from 2.1 million to 3.8. At the same time as the housing projects moved further and further into the rural areas, the city centres were renovated; houses were removed and replaced by offices, shops and infrastructure.

growing cores

Individualisation of society during the 60's and 70's resulted in a shift in thinking about urbanisation and a migration from the old cities to cities like Almere, Zoetermeer and Nieuwegein which were declared as so-called growing cores by the National Government. Within the cities a start was made to renew the old residential areas the so-called urban renewal whereby the old urban structures were taken into account.

compact city

VINEX

An economic crisis marks the 80's and this crisis had its impact in the cities. Problem areas emerge as a result of the migration of the middle and higher incomes and a clustering of the lower incomes. In an attempt to overcome these problems, vacant areas in the inner cities were redeveloped. An initiative called the compact city. When the economic crisis ended in the 90's the National Government initiated the VINEX areas, new residential areas close to the city centres that should accommodate the high and middle incomes. Furthermore, the redevelopment of problem areas continued, poor living areas were restructured to improve living quality and diversify the social milieu (Raatgever, 2010).

figure 1.11 Urbanisation 1900
(based on: Alterra, 2004)

figure 1.12 Urbanisation 2000
(based on: WUR GIS data, 2000)

This continuous process of urbanisation resulted in the Netherlands being one of the most densely populated countries in the world (TNO, 2007). We have seen a population growth from 5.1 million inhabitants round 1900 to 8.8 million in 1940 and to 16.5 million nowadays (CBS, 2009b).

When we look at the technological development in the Dutch delta and the process of urbanisation one can see that there is a strong correlation between the two. Ever since technology improved, often as a reaction to a flooding event, more land became habitable and living conditions improved. Especially during the industrial period, with the invention of the steam engine, this resulted in strong population growth and a migration towards the city ending up with the Netherlands as it is nowadays; A densily urbanised country with high economical value which is protected by a rigid water defence system.

However, bearing the changing climate in mind, the questions emerge; what the impacts of climate change are in the urban context and whether the Dutch can continue protecting themselves against the threats in the contemporary ways, or is a different approach asked for?

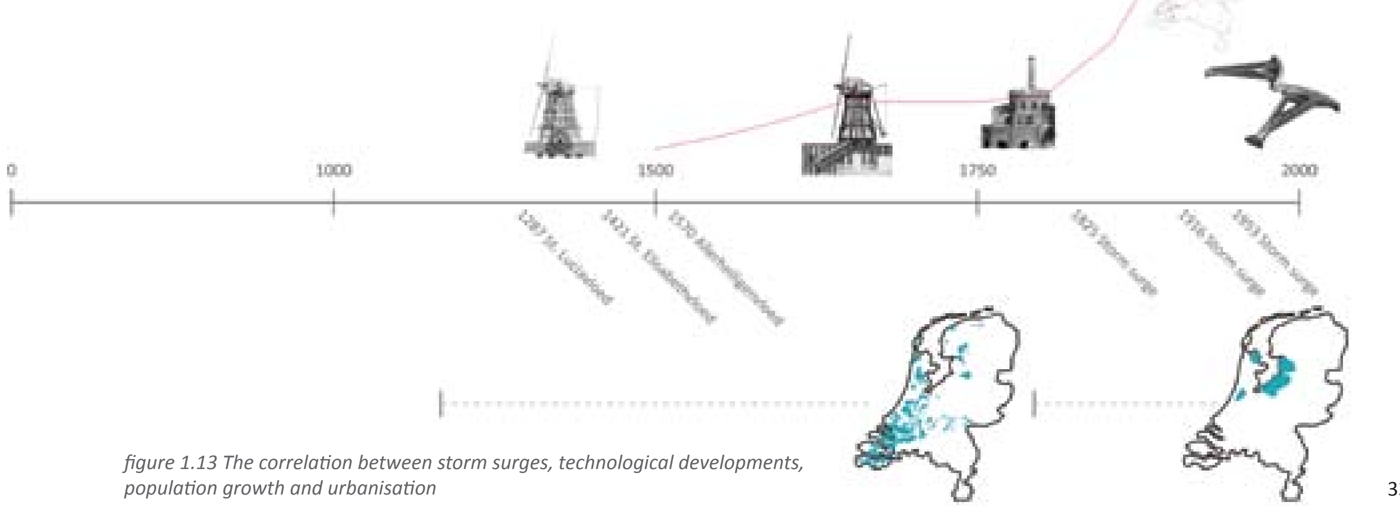

figure 1.13 The correlation between storm surges, technological developments, population growth and urbanisation

1.5 CLIMATE CHANGE IN THE URBAN CONTEXT

"There is growing consensus that the populations, infrastructure and ecology of cities are at risk from the impacts of climate change" (Wilby, 2007, p.31). Additional to the sea-level rise, soil subsidence and the increasing volumes of water in the rivers that affect the whole Netherlands, there are weather related problems where especially urban landscapes have to deal with.

weather related problems

Weather related risks, such as heat waves, urban heating, pollution, and flooding negatively influence the built environment, while built-up areas have impact on their local environment and climate (Wilby, 2007). The contemporary environmental effects of urbanisation have been discussed in the first chapter, climate change will amplify these problems; the KNMI expects more precipitation in winters, while the summers are expected to be dryer with occasionally extreme rain showers (KNMI, 2009a). Health, comfort, and safety of urban populations are at risk due to urbanisation and climate change. The following paragraphs will discuss the consequences of drought and heat and the effects of precipitation in the urban context will be discussed in the next section.

1.5.1 DROUGHT AND HEAT

urban heat island

Extreme drought and high temperatures in the urban context can lead to the Urban Heat Island (UHI) effect. The UHI-effect is a phenomenon that occurs independently from climate change. However, climate change does amplify the effects of UHI, since heat events are likely to occur more frequent in the future.

The Urban heat island (UHI) refers to the characteristic excess warmth of urban areas compared to their non-urbanised surroundings. The metaphor 'island' for urban heating can be explained by the island pattern that becomes visible through the isotherms of an urbanised area (Voogt, 2002).

According to Kim (1992) the soil surface albedo and availability of moisture are important aspects that influence the micro-climate of an area. Kim shows a correlation between the albedo of the soil surface, available moisture and the difference in temperature for grass, bare surface, river, city blocks and forest. City blocks at night time can be 10 – 12°C warmer than surrounding woodlands (Voogt, 2002, Kim, 1992). According to Corburn (2009) the suspected warming in urban areas is 3.5 – 4.5°C more than in the surrounding rural areas and will increase with 1°C every decade. In the summer UHI is undesirable because it has negative consequences for human

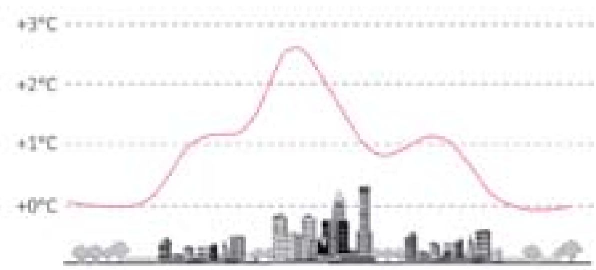

figure 1.14 The UHI-effect (based on: KNMI, 2009b)

comfort and health, urban air pollution, and energy management. In the summer of 2003 a dangerous heat event occurred across Europe, with average temperatures of 3.5°C higher than normal, leading to 22.000 – 45.000 heat related deaths among the vulnerable (elderly and ill) people. Furthermore, hospital admissions due to illnesses related to heat events (such as heat stroke, heat exhaustion, cardiovascular and respiratory problems) are a serious public health concern (Patz et al., 2005, Corburn, 2009).

causes UHI-effect

The main causes of the UHI-effect are modifications in the surface geometry (built environment traps more solar radiation), surface thermal properties (urban building materials have larger surface thermal admittance), surface conditions (less vegetation and water leads to less evaporative cooling), anthropogenic heat (released heat by vehicles and other human energy use), and the urban greenhouse effect (the polluted and warmer urban atmosphere causes extra greenhouse-effect). The built environment absorbs sunlight, re-radiates heat and emits heat. This in combination with less water and vegetative cover to provide shade and to hold (cooling) moisture contributes to urbanised areas being warmer (Corburn, 2009, Voogt, 2002).

1.5.2 INCREASED EXTREME PRECIPITATION

An overall increase in precipitation and extreme rainfall patterns in combination with a highly urbanised landscape can cause drainage problems and storm water runoff in cities leading to sewerage overflows and flooding. Climate change and changes in land-use and soil-surface conditions are important causes of these problems. The permeability of the soil-surface, saturation of the soil, and the quantity of precipitation determines whether rain can infiltrate (Bronstert et al., 2002).

decreased permeability

The permeability of the soil-surface in urbanised areas is relatively low because open and vegetated areas have been replaced by buildings, roads, parking lots and other built-up structures. Rainwater that does not infiltrate into the soil due to impervious land surfaces flows off towards open water or into the sewerage, carrying pollutants (such as dust, sediments, heavy metals, chlorides, oil, and grease) from urban areas into waterways. According to Pratt (1996) urban stormwater runoff is the second largest source of pollution of lakes and estuaries in the U.S.A. and the third largest source of impairment of rivers in Europe. Furthermore, sewage overflows during extreme rain events, further pollute the open water (Wilby, 2007). Nowadays most Dutch municipalities have a sewer system that cannot process extreme rainstorms,

failing sewage systems

while these rainstorms will occur more frequently in the future (Rombaut, 2008, Kwadijk et al., 2006). As a result of these sources of pollution, the ecology of a city and the surroundings are negatively influenced, declining the liveability for man and nature. Reduced permeable soil-surfaces due to urbanisation, in combination with increased extreme precipitation due to climate change, can even lead to urban flooding.

As becomes clear, all Dutch cities will be confronted with the consequences of the changing climate to a greater or lesser extend depending on their geographical location. To keep the cities and the country habitable, adaptation measures need to be taken. It are these adaptation measurers that this thesis will focus on. In the following chapter the problem defenition and landscape architectural view we have on this problem will more elaborately be described.

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[2]

MALFUNCTIONING URBAN WATER-SYSTEMS

In the first chapter the water related history of the Netherlands, the processes of urbanisation, and the changing climate have been described. These three topics have played, play, or will play, an important role in the formation of the Netherlands, the Dutch landscape, and the Dutch culture. The Netherlands being the delta of North-Western Europe connects rivers with the sea. This dynamic transition zone has always been subject to change. Climate change however, with a rising sea level, increased river discharges and weather extremes, poses new challenges for the Netherlands, where water systems, cities, and coastal defences in time evolved into static technocratic systems. Urbanised areas in particular became static and the environmental modification of cities in relation with climate change leads to great challenges, this chapter will describe these challenges and the resulting hypothesis and research questions.

2.1 PROBLEM STATEMENT

The basis of the problem definition of this thesis consists of the water related issues, urbanisation, and climate change in the Netherlands. The interactions of these topics results in the scope of this thesis, which in short is, 'waterways to climate adaptation in Dutch urban landscapes'. Next paragraphs will at first briefly mention the most important issues of each topic, followed by an examination of the overlapping area of these three topics, which results in the problem definition for this thesis.

The Dutch always have had to deal with water, as the Netherlands forms the delta of North-Western Europe. The water- and land management has been defensive, offensive, or manipulative, which eventually resulted in a static technocratic water system. High and broad dikes protect against river floods, storm surge barriers keep out the sea, and water is continuously let in and pumped out of polders. However, this system can hardly adapt to change, is highly inflexible, and asks for new and innovative solutions for adaptation to climate change.

Climate change in the Netherlands will most likely result in sea-level rise, extremer peaks in river discharges, periods of extreme drought, and occasionally extreme precipitation. Large parts of the Netherlands already lie below sea-level and are still subsiding, increasing the flooding risk. Furthermore, the extremes in weather will lead to water shortages, and water surpluses. The water related problems and safety issues that are already abundant in the Netherlands will be amplified due to climate change.

figure 2.1 Running out of time (available at: http://ferdi-rizkiyanto.blogspot.com/)

The ongoing process of urbanisation has resulted in the Netherlands being one of the most densely populated countries in the world. Furthermore, it leads to more build up land and increased sealed surface area, which affects the climate and hydrology in and around cities resulting in ailing urban water systems. Consequently, cities became extra vulnerable to extreme weather events, such as extreme heat or precipitation.

These three topics combined results in many problems. Summarised this means; modifications of the soil-surface properties and the surface geometry due to urbanisation combined with the static, technocratic water systems in and around urban landscapes, make cities extra vulnerable to extreme weather events. Furthermore, the adaptive capacity of the urban landscapes is minimised as well. Bearing in mind the predictions of climate change, it is most likely that contemporary climate related problems in urban landscapes will become worse, new problems will arise, and that adaptation to climate change will be necessary.

As all urban climate related problems are in a greater or lesser extent related to the water systems, there is a challenge in healing the Dutch urban water systems in order to adapt the urban landscapes to the changing climate. And as more and more climate related problems are emerging there is an urgency to start with healing theurban water systems. New concepts and techniques are required to overcome problems resulting from the static, technocratic circumstances in contemporary urban water systems.

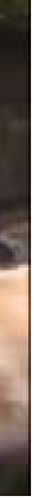
healing urban water systems


figures 2.2 - 2.10 contemporary climate related problems in the urban context varying from fish mortality and river flooding to droughts, rainwater flooding and soil subsidence









2.2 LANDSCAPE ARCHITECTURAL LENS

In the previous chapter the question arose whether the contemporary static technocratic approach to deal with climate related issues in the Dutch urban context is desirable for the future. One could say that this technocratic approach is the result of contemporary society where, according to Frey (1999), the old symbiotic relationship between city and the country no longer seems to exist and city and country became mutually exclusive. Odum (1993, p.263) goes even further stating that cities are parasites on the environment and that "anything that grows rapidly and haphazardly (without plan or control) and without regard to life support will outstrip the infrastructure necessary to maintain its growth, thereby bringing on boom-and-bust cycles". Especially in the context of climate change one could speak of an imbalance between city and landscape, people and place, and man and nature.
In this section we will describe our viewpoint, from our perspective as landscape architects educated at Wageningen University, on the imbalanced situation.

meaning of landscape

First of all it is important to discuss what is meant by 'landscape' and 'landscape architecture'. It is however difficult to give one single definition of these terms which covers the whole range of meanings that can be addressed to them. According to Vroom (2005, p.196) "definitions often reflect ideals, interests, and goals. What is, is mixed up with what should be". Thus, landscape and landscape architecture can be perceived in countless ways leading to dozens of definitions, everyone can have his or her own perspective on landscape.

Therefore, we will not give a definition that covers all possible views, because this is simply impossible. Instead, we will discuss the definitions that fit within the perspectives of the authors of this thesis.

Kerkstra and Vrijlandt (in Duchhart, 2007, p.16) define landscape as "the visible result on the surface of the earth of the interactions between man and nature". Thus, the interrelations and mutual influences between both natural and cultural processes, which are embedded in soil, relief, hydrology, climate, flora, and fauna, as well as human interference, define landscape (Vroom, 2005, p. 196).

According to Vroom (in Duchhart, 2007, p.15) "landscape architects perceive the landscape as physical space. His/her activities are thus primarily of a spatial character. Architecture is the ordering and shaping of processes". Duchhart (2007, p.16) states that in the field of landscape architecture "design for space plays an important role. In the design, spatial form and ecological processes are two major ingredients (…) Furthermore, the response of human beings to the physical environment (…) was thought to be related to needs such as the need for identity, structure, and meaning".

Thus, landscape architecture addresses both form and process in space and time, in which “the result should be a dynamic, coherent whole that can continue to evolve to meet changing needs and desires and that also connects the present with the past” (Spirn in Duchhart, 2007, p.17).

2.2.1 RESTORING IMBALANCED RELATIONSHIPS

human - nature relationship

As already introduced in the beginning of this chapter, human-nature relationships have become imbalanced. For landscape architects and environmental/spatial planners it is therefore important to consider what the human-nature relationship is and what the consequences might be of such an imbalanced situation. “We are a product of nature, yet the concept of nature is a social creation. The forces of nature are real phenomena.

So, we continue to refine & redefine our relationships with our surroundings, which, in turn, continue to exert influences on how we live” (Steiner, 2002, p.173). Where we used to protect ourselves against the influences of our environments, it is now time to protect our environments against negative human impact. We have to realise that the landscape contains us and sustains us, and we have to be aware of the impacts of our actions. Landscape architects can play an important role in designing and planning sustainable environments and in increasing public awareness which is of great importance. As Hester (1995, p.9) states “designers must offer choice… educate people about the ramifications of these choices and help people choose sustainability”.

lost relationships

An important aspect contributing to the imbalanced human-nature relationships is the loss of diversity (in all forms), while “diversity is our hope, diverse systems have the capacity to respond to infection more quickly and effectively than homogeneous ones” (Steiner, 2002, p.157). In the context of this thesis, this infection can be seen as the malfunctioning of cities and their watersystems in the perspective of climate change. Cities have become technocratic and static, and the city-landscape and people-place relationships are lost. Landscape properties such as soil, hydrology, relief etc. can help to restore the imbalanced human-nature relationships in cities. Landscape offers the opportunity to deal with the loss of diversity in cities, “as it can be seen as a means to resist the homogenisation of the environment “ (Corner,1999, p.13).

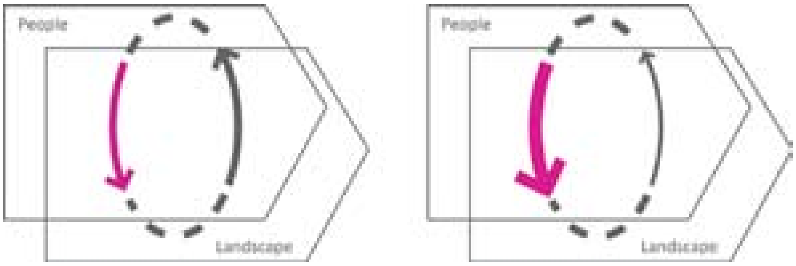


figure 2.11 Changed people place relationships, from a dynimac balance to human domination of nature (in: Vrijlandt, 2006)

2.2.2 CITY = LANDSCAPE

As macro-climatic processes take place on a large scale, beyond urban boundaries, successful climate adaptation requires seeing cities as part of the surrounding landscape instead of seeing them as separate entities. It requires a search for a renewed symbiosis of the landscape and the city to regain the balance between the natural carrying capacity and the human land use (Duchhart, 2000). In the search for a dynamic balance in which changes and development can take place, it requires man to overcome the dualism between the urban and the rural, the city and the landscape.

renewed symbiosis

The city should be seen inclusive of landscape and vice versa. The term 'cityscape' is first coined by Victor Gruen in 1955. At that time it referred to the built environment of buildings, paved surfaces, and infrastructures and was positioned opposite to landscape. According to Gruen (in Waldheim, 2006), 'landscape' refers to the environment in which nature is predominant. According to Koolhaas (in Waldheim, 2006) however, city as scape is a condition in which architecture, infrastructure, and landscape are undifferentiated and subject to the same forces.

cityscape

The total dissolution of the dualism of landscape and urbanism has led to Landscape Urbanism. "Landscape Urbanism describes a disciplinary realignment currently underway in which landscape replaces architecture as the basic building block of contemporary urbanism" (Waldheim, 2006, p.11). The most important aspect of this idea is the recognition of landscape as "a medium uniquely capable of responding to temporal change, transformation, adaptation and succession. These qualities recommend landscape as an analog to contemporary processes of urbanization and as a medium uniquely suited to the open-endedness, indeterminacy, and change demanded by contemporary urban conditions" (Corner in Waldheim, 2006, p.39).

landscape urbanism

Landscape acts as a "functioning matrix of connective tissue that organizes not only objects and spaces but also the dynamic processes and events that move through them" (Wall in Waldheim, 2006, p.77). Thus, "a landscape approach to the city recognizes the city spatially and functionally as integrated with (and part of) the landscape. This implies the reversal of the city-over-land relationship" (Koh, 2009, p.18). In other words, city is landscape.

reversed city-over-land relationship

This landscape architectural view, in which the city is recognised as part of the landscape can be the crux in adapting cities to the changing climate

2.3 HYPOTHESIS

As became clear previously, most Dutch urban water systems are malfunctioning as a result of the transformation from a natural dynamic system into a technocratic static system. Furthermore, the static and technocratic urban water systems will increasingly have to deal with the effects of climate change. Therefore, it is important to find ways to heal the urban water systems, to make them more flexible and thereby adapt the urban landscapes to the consequences of the long-term and short-term climate change. As landscape architects, we plea for an integral, landscape-based design approach to urban issues. Applying such an approach to solve the problems described in the beginning of this chapter, leads to the following hypothesis:

landscape-based design approach

'A landscape-based design approach offers sustainable solutions for adaptating Dutch urban water systems to climate change.'

A generally accepted definition for sustainable development is "paths of progress which meet the needs and aspirations the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987, p.4).

sustainable solutions

According to the authors, sustainable solutions for adaptation to climate change are resilient, site-specific, and improve spatial quality. Thus, the solutions should not only be functional, but should also enrich the environment for man and nature in both process and form.

2.4 RESEARCH QUESTIONS

To explore the hypothesis, the most important question to answer is:

How can a landscape-based design approach offer sustainable and climate adaptive design solutions to the present and future demands on Dutch urban water systems?

To be able to answer this question we need to find out:

- What is already being done on climate adaptation in the urban context?
- Why is a landscape-based design approach necessary?
- What is a landscape-based design approach in the context of this thesis?
- What are the spatial differences regarding climate change in the Netherlands?
- Do these spatial, landscape-based differences offer opportunities for site specific solutions?
- What did we learn from the site specific, landscape-based design solutions to the ailing Dutch urban water systems in both form and function?

2.5 METHODS

To answer the research questions a methodology is laid out. First of all, an analysis is made of what is already done on climate adaptation in the Netherlands by means of a desk study on the many reports written. This desk study gives more insights in the state of climate research in the Netherlands. Furthermore it helps to find the potential contribution we can make as landscape architects by using a landscape-based design apporach in the process of adapting Dutch cities to climate change

desk study

Secondly, the proposed landscape-based design approach is described and explained. How does a landscape-based approach differ from the contemporary approaches and what is the added value of such an approach are questions we will try to answer.

spatial differences

We will continue with a search for spatial differences in climate change impact based on the previously mentioned desk study. And, based on these spatial differences, we search for two interesting case cities to test the landscape-based design approach. To select the case cities an analysis will be made of the Dutch urban context based on adress densities and city clusters.

landscape based design

For the selected case cities a working method is proposed which serves as a guideline for working through the cases, a search is made for landscape-based and site specific problems. To overcome these specific problems, a design process will be carried out which results in landscape-based concepts for adaptation to climate change. Calculations will be made to test whether the proposed concepts are capable to deal with the predicted climate dynamics.

Furthermore the possibilites for combining the landscape-based concepts for adapting cities to climate change with the contemporary climate adaptation measures is researched. Finally we zoom out to the national scale to see whether the proposed landscape-based design apporach is applicable to other cities within similar landscape types and whether the whole method can be a valuable mean in adapting the Dutch urban water systems to the changing climate.

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[3]

HEALING URBAN WATER-SYSTEMS

Recent years, the larger public was made aware of the changing climate and, as the topic was placed high on the political agenda, people and governments began to realise what the implications of their lifestyles are and will be, with as one of the most important consequences the changing climate. Various research programmes were initiated and many reports were written on the impact of this changing climate. In this chapter we will focus on the results of these reports, especially in relation to the urban context. Missed opportunities are described and new conclusions are drawn from the reports resulting in a methodology for a landscape based design approach in the context of this thesis

3.1 SPATIAL IMPACT OF CLIMATE CHANGE

Where the IPCC and KNMI mainly focused on climate change as a phenomenon, research programs and commissions like ‘Future cities’, ‘Knowledge for climate’, the ‘Climate changes spatial planning programme’, the ‘Delta commission’ and numerous others focused on the spatial impact and consequences of climate change, resulting in many reports on this topic. With the increase of knowledge available on climate change, the more it became apparent that there are spatial impacts related to climate change and adaptation which calls for spatial adjustments.

anticipatory strategies

Especially interesting in regard of the research focus described in the previous chapter seemed to be (the parts of) the programmes that focus on the spatial impact of climate adaptation in cities as in ‘Future cities’, ‘Climate proof cities’ (part of the Knowledge for climate programme), and some projects within the ‘Climate changes spatial planning programme’. These programmes focus on creating “anticipatory strategies which are needed for adapting the urban structures in a way that the impacts of a changing climate will not endanger the urban living environment” (Future Cities, 2010), and they aim at creating “a quantitative knowledge base on urban climate, the vulnerability of cities to climate change, and expected impacts of possible future changes in climate” (Albers, 2010).

figure 3.1 Reports on spatial impacts of climate change in the Netherlands (period from 2007 - 2010)

3.2 HOTSPOTS AND PILOT PROJECTS

Within the different research programmes there are different pilot projects or hotspots where is being worked on. Hotspots in the Netherlands are cities like Rotterdam, Arnhem, Nijmegen, Amsterdam/Schiphol airport, Tilburg, and Tiel. The following paragraphs will give a brief overview of what is already done on climate adaptation and climate research in the pilot/hotspot cities.

3.2.1 SMALL SCALED PROJECTS

Aim of the hotspot and pilot projects is to adapt cities to the predicted impacts of climate change. The main focus is adaptation to both the UHI effect and wetter winters. In adaptation strategies green structures, water systems, and energy efficiency are said to be included. However, when looking at what is actually achieved within the different projects, it seems that city structures, green networks, and water systems are generally not integrally researched and that the focus lies more in small-scaled projects and initiatives such as;

Green roofs

Depending on the type of vegetation, green roofs can catch 60 to 100 percent of incoming precipitation, which decreases the peak discharge from roof surface and the pressure on the sewage system and increases surface water quality (Van Woert et al., 2005; Mentens et al.,2006). The collected water can evaporate and return back into the natural hydrological cycle. The cooling effect resulting from this evaporation supports a better microclimate. Furthermore, green roofs are good for isolation, decreasing the energy needs for heating and cooling, and the vegetation protects the roof surface against extreme weather conditions like heat, cold, snow, storm and hail, thereby increasing the durability. An additional benefit is that green roofs filter pollutants from the air (Niachou et al., 2001).

60 - 100 % effectiveness

Vertical green

Vertical green acts as a buffer against heating in both the building itself as for the exterior of the building by shading walls from the sun. The temperature fluctuation in buildings can be reduced with 50%, which makes buildings effectively insulated against high summer temperatures (Dunnett and Kingsbury, 2004; Alexandri and Jones, 2008).

temperature fluctuations reduced by 50 %

Runoff water from the roof surface can be stored in vertical green elements, having a similar effect as green roofs. Furthermore, air is filtered which reduces the concentration of fine dust in the air, increasing the liveability of the city (Werthmann, 2007). Both green roofs and vertical green have potential to increase biodiversity in cities.

Swales

A swale is a u-shaped green ditch with a drainage element underneath. Water from surrounding roofs, gardens and streets is transported to the swales via gutter along the streets, in this way the water remains visible. Within the swales, water is allowed to seep into the ground. The purpose of water catchment in swales is to decrease the pressure on the sewage system, decrease peak discharges in creek systems and prevent desiccation.

up to 99 % infiltration

Monitoring of the first swales in the municipality of Enschede showed that up to 99 percent of the rainwater infiltrated into the soil instead of being discharged into the sewage system or surface water (Beenen, 2006).

Rainwater collection in gardens

This might be one of the easiest ways of adapting cities to the changing climate although public awareness and participation are essential. Rainwater collection and infiltration in gardens decreases the pressure on the sewage system as also the rainwater from the roofs might be discharged to the gardens instead of into the sewage system.

rain barrels, infiltration zones, and ponds

There are, generally spoken, three ways of collecting rainwater in gardens; rain barrels, green infiltration zones, and ponds. Many municipalities subsidise the purchase of rain barrels (Walthie et al., 2007). Rain barrels are very cheap, easy to install and the collected water can be used for watering the garden in dryer periods. Green infiltration zones allow the rainwater to infiltrate into the soil instead of being discharged to the sewage system. Depending on the depth, quite large amounts of water can be stored in ponds, again decreasing the pressure on the sewage system.

Water squares

Water squares are places in urbanised areas where rainwater can be temporarily stored during extreme precipitation instead of funnelling it into the sewage system. The storage spaces will be dry for most of the year, but during storm events, water will be collected from the surrounding neighbourhood. In dry periods, the collected rainwater can recede into nearby bodies of water or seep into the soil.

water visibly incorporated

Thus instead of discharging water into the sewage system, the urban hydrology is visibly incorporated into the surface fabric of the city. Programmed with different possible recreational opportunities it provides public space for the surrounding area (PRUNED, 2009). In 2012, the first two water squares will be realised in the city of Rotterdam.

figures 3.2 - 3.10 Contemporary initiatives on urban climate adaptation; green roofs, swales, green walls, rain barrels, sedum vegetation on roofs, water squares, ponds and retention ponds (left - right, top - bottom).

no integral strategy

The previously mentioned initiatives are only five out of many. Research in climate adaptation continues and more innovative solutions will emerge. However, in general it can be said that most of these initiatives are small scaled local solutions, and that an overall integral strategy is lacking, as will be discussed in the following paragraphs.

3.2.2 MISSED OPPORTUNITIES

small scaled, stand-alone, unorganised

The contemporary approaches do give a contribution to climate adaptation in urban landscapes and the research carried out and the projects realised contribute to the knowledge base of climate adaptation in urban landscapes and increases public awareness. However, as said, the approaches are small-scaled, they stand-alone and are unorganised. In this manner, local problems can be solved, but when we look at the scale of urban landscapes the small-scaled solutions are not sufficient for sustainable climate adaptation. According to the authors, the previously described research done on the spatial impacts of climate change has much more to offer.

missing connection

The dualism between landscape and city as described in chapter two, also becomes apparent when reading through the many reports written on the spatial impact of climate change. There is a separation between the analyses and research on the rural, landscape-based, differences of climate change impact and the implementable initiatives on the scale of urban adaptation to climate change. The connection between the urban and rural landscape is missing while it is exactly this link that is necessary for sustainable climate adaptation in urban landscapes.

What is missing is a methodology for a landscape-based design approach for climate adaptation in the urban landscapes; an approach that searches for a renewed connection with the landscape and seeks for the site-specific challenges and opportunities the landscape offers.

3.3 THE LANDSCAPE-BASED DESIGN APPROACH

The disconnection of city and landscape resulted in an imbalanced and unsustainable situation; cities became technocratic, static, and homogenised. As a result, urban systems are hardly capable to adapt or respond naturally to infection or change. Such a static system is unsustainable, as change is inevitable and natural dynamics always influence the built environment.

3.3.1 INCORPORATING CHANGE AND DYNAMICS

In the perspective of the city-landscape relationship, it became clear that landscape and city should not be seen as separate entities, but as one (city = landscape). This gives new insights in increasing the adaptive capacities of urban landscapes. Change and dynamics should be accepted and incorporated, thus designers and planners should "make use of the dynamic and self-correcting natural processes", and as a result "the designed urban infrastructures will perform as 'artificial ecologies'. They contain a higher degree of ecological resilience, require less intervention and technical control than conventional systems and, at the same time, offer attractive landscape experiences" (Stokman in Shannon, 2008, p.47).

increasing adaptive capacities

The inclusion and acceptance of change and dynamics within cityscapes corresponds with the Wageningen landscape design approach. "It is an integrative, dynamic, evolutionary approach that seeks field immersion for its understanding, experience and design of landscape… it is not only about process design but also about experience design, definitely not about form alone, but about form in landscape" (Koh, 2009b, p.6). The Landscape design approach, according to Koh (2009a), "combines objective material understanding of processes with subjective experiential imaging of phenomena, and integrates spatial thinking with process understanding. In a complementary way it balances continuity with change, permanence and transience, and individuality with community".

Wageningen approach

The Wageningen Landscape Design Approach focuses on design for space in which spatial form and ecological processes are the major ingredients, with as main goals the "creation of landscapes that provide safer and healthier human habitats, that are more resilient to deteriorating forces and in harmony with natural processes than in an unplanned world" (Duchhart, 2007, p.21).

The landscape design approach with the inclusive unity, the creative balance and complementary as its fundamental principles is a holistic approach to landscape design

holistic approach

and can be the key theory to incorporate sustainability and aesthetics in climate adaptation (Koh, 2004). In the following paragraph, useful methods and techniques from the Wageningen landscape planning and design approach will be discussed.

3.3.2 METHODS

the sociophysical-organisation model

In the sociophysical-organisation model, the physical system can be seen as a coherent whole of abiotic and biotic components, which forms the physical base for life of humans as well as flora and fauna. On the other side of the framework is the social system which is made up of three components; the economic subsystem, the political subsystem and the cultural subsystem (Hidding and van den Brink, 2002). The sociophysical-organisation model shows the interaction between the physical and the social system. In other words, "it shows an abstract notion of the functioning and co-coordinating of human activities required for living a meaningful life" (Duchhart, 2007, p.18).

Duchhart modified the sociophysical-organisation model by combining it with the triplex-model promoted by the founders of the Wageningen Approach; Kerkstra and Vrijlandt. "Both the triplex-landscape model and the sociophysical-organisation model take the interactions between the natural system and the society as a starting point in their explanation of the physical environment. However, while Kleefmann focuses mainly on exploring the driving forces behind the factors that form the landscape, Kerkstra and Vrijlandt are more concerned with defining the landscape in visible and tangible terms" (Duchhart, 2007, p.193).

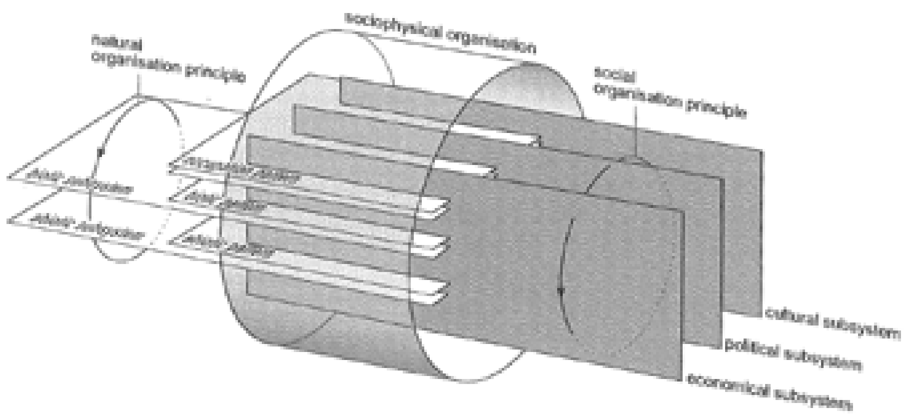

figure 3.11 The sociophysical organisation model intertwined with the triplex model (in: Duchhart, 2007)

the triplex model

The triplex model shows the vertical relations in the landscape. Kerkstra and Vrijlandt divided the landscape in three layers; abiotic, biotic and anthropological. The triplex model is a powerful analytical tool for the understanding of landscapes, revealing relationships between human and natural occupation and geomorphologic conditions. Some useful and essential additions to the triplex model come from the layer cake model used in landscape planning which is another model that shows the vertical relations in the landscape.

the layer-cake model

Where the triplex model focuses on landscape genesis, the layer cake model used in spatial planning focuses more on landscape form, based on a soil, network and object layer. The network layer can be a valuable addition to the triplex model, as landscape and society are strongly related to the both visible and invisible networks.

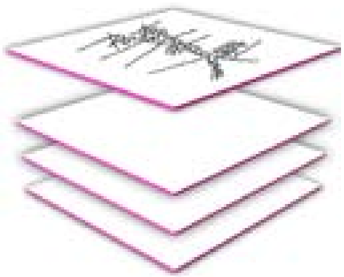

figure 3.12 Triplex model (in: Vrijlandt, 2006)

According to Duchhart (2007), the combination of the sociophysical-organisation model and the triplex model gives opportunities to make detailed and alert observations of the actual physical environment and can provide a wide range of clarifications from both physical as well as social perspectives. Questions the model could help answer could be: “What are the landscape-forming principles in both the natural and the social environment?” and “Do these principles converge or diverge?” (Duchhart, 2007, p.19)

Besides the spatial dimensions that are discussed, another important notion is the dimension of time that plays a role in landscape processes. Processes in different layers take place over different time scales.

process of change

According to Vrijlandt (2006) the landscape can be seen as the spatial expression of a force field, which is formed by the interaction between landscape forming factors, thus the interaction between the different layers of the sociophysical-organisaton model. This landscape is not static, as the landscape forming factors change in time. Some changes happen quickly and often, other processes change so slowly that they seem not to change at all. However, from a wider time perspectiv, the whole landscape forming force field is continuously changing. What we see is a snapshot in a continuous process of change.

the casco model

Regarding the different paces of change, the casco model (by Kerkstra and Vrijlandt) is interesting. The casco model focuses on “a segregation in space between intensive use requiring a flexible layout and the more extensive types of use requiring stability,” (Kerkstra and Vrijlandt, 1990, p.279) Thus, a separation between high dynamic (agricultural production, urban development) and low dynamic (nature management, forestry, recreation and water control) processes. This results in a framework for low-dynamic processes within which high dynamic processes can take place. “The location of major interconnected elements of the framework could be based on – or adapted to - existing major physiographic elements, this in combination with actual land-use” (Kerkstra and Vrijlandt, 1990, p.280).

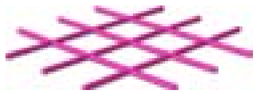

figure 3.13 Casco model (based on: Vrijlandt, 2006)

The landscape design approach with several methods which are incorporated within this approach forms the theoretic and intellectual base of this thesis. In the next paragraph we explain how the landscape based design approach can be used as a mean to adapt cities to the changing climate.

3.4 THE LANDSCAPE-BASED DESIGN APPROACH IN THE CONTEXT OF THE THESIS

A landscape-based design approach (as described in the previous section) to the malfunctioning urban water systems is an approach based on the regional differences in climate change impact. These regional differences result in site-specific climate challenges, but at the same time, they offer opportunities for adaptation to these challenges.

The landscape-based design approach seeks for a renewed connection with the surrounding and underlying landscape and uses the potential of the landscape to overcome site-specific climate challenges. Not only does this result in site-specific solutions, but such an approach to the ailing urban water systems also makes these systems more resilient, improves the spatial quality and eventually is a mean to strategically and spatially organise the small-scaled solutions mentioned before.

3.4.1 WHY A LANDSCAPE-BASED APPROACH?

When speaking about a landscape-based design approach to the urban water systems, the question emerges why such an approach is necessary. Can the problems not be solved in the contemporary technocratic static manner? Or can we not return to the natural dynamic system mentioned in chapter one?

undesirable technocratic static approach

According to the authors, the landscape-based design approach is a better alternative to both the contemporary technocratic static approach and turning back to the natural dynamics. The contemporary technocratic static way in which urban water systems are managed turned out to be problematic and resulted in the ailing urban water systems. However, the rate of new and innovative developments is high and it is likely that the urban landscapes can be adapted to the changing climate by technocratic static means; sewers can be scaled up, pumping capacities can be increased and it is probably even possible to develop machines for cooling the city. Nonetheless, such developments are undesirable as they are unsustainable, mono-functional, increase the dependency on technical systems, and hide climate dynamics thereby decreasing public awareness.

natural dynamics impossible

Returning to the natural dynamic water system is not an option as well; the Netherlands is inhabited by 16.7 million inhabitants (CBS, 2010) resulting in a high percentage of built up surface, hidden networks, and a dense infrastructural network of more than 136.000 km (CBS, 2008) of roads covering the country. Furthermore, the Netherlands is highly dependable on the regulated water systems and the technocratic water defence systems. This all makes returning to a natural dynamic system simply not an option. But we can work towards a more dynamic system, as will be described in the next section.

3.4.2 MEDIATING BETWEEN TECHNOCRATIC-STATIC APPROACHES AND NATURAL-DYNAMICS

A landscape-based design approach offers an alternative that mediates between the natural dynamics and the technocratic statics. Dynamic natural processes are incorporated in the contemporary static urban setting to achieve balanced and sustainable design solutions for climate adaptation. In this manner climate processes in relation with site-specific landscape properties are revealed, which can increase public awareness on climate and landscape. The landscape-based design approach focuses on a different working method. Where in most contemporary approaches form and function alter the landscape, the landscape-based design approach sees landscape as a basis for form and function. The approach thereby is a mean to find a balance between previously described contemporary technocratic static adaptation to climate change and the former natural dynamics.

revealing site-specific climate processes

landscape as basis

Thus, in the context of this thesis, a landscape-based design approach works towards more natural and dynamic site-specific design solutions for ailing urban water systems which not only solve the problems, but increase the spatial quality as well.

figure 3.14 Renewed balance

3.5 REGIONAL DIFFERENCES IN CLIMATE AND LANDSCAPE

As stated in the first chapter of this thesis, climate change will result in sea-level rise, changes in river discharges, and changes in weather patterns (droughts and increased precipitation), and in the third chapter climate change is related to the urban context. The impacts of these changes differ spatially throughout the country. This differentiation of impacts is mainly based on the differences in landscape properties soil, relief and hydrology, the same characteristics on which the main Dutch landscape types can be characterised.

3.5.1 LANDSCAPE TYPES

figure 3.15 Landscape types; high Netherlands indicated in white, lower Netherlands indicated in light grey, the river landscape indicated in dark grey

climate change related to landscape

Based on differences in topography, soil, relief, and hydrology, the Netherlands can be divided in 3 main landscape types; high Netherlands, low Netherlands and the river landscape which cuts its way through both the high and low parts of the Netherlands.

High Netherlands consists of sandy soils and is situated above sea level. Within these sandy soils, boulder clay areas can be found. The lower Netherlands consists of peat and clay soils and lies, for a large part, below sea level. Within the lower Netherlands some clearly distinctive areas can be recognised; the land reclamation areas, the dunes and the South-Western delta which is the estuary of the rivers Waal, Meuse and Scheldt. The river landscape consists of sandy to clayey soils and flows through both the higher and lower Netherlands.

Substrate and climate together form two important conditional factors in the landscape, and create the outlines for groundwater, soil, flora and fauna (Berendsen, 2005). Differences in climate change impacts are also related to differences in height, soil and water system. One can thus say that climate change differences can be related to differences in landscape. For instance, the infiltration capacity of sandy soils is higher than clay soils, and flooding risks are higher in low-lying areas than on higher grounds.

3.5.2 REPORTS ON THE IMPACTS OF CLIMATE CHANGE

As described in the first paragraph of this chapter, a great deal of research has been done to come to grips with the spatial impacts and consequences of climate change. Especially in the urban context this research appeared to be small scaled and relations with the underlying and surrounding landscape were not included, while the crux in successful climate adaptation lies within the spatial differences in landscape and the problems and opportunities this offers for adaptation to climate change. Nevertheless, other research carried out by institutions such as Future cities, the Knowledge for climate programme, the Climate changes spatial planning programme, the Delta commission and numerous others do focus on the spatial differences of the consequences of climate change, each on different scale levels [national, provincial, regional and municipal], which resulted in countless amounts of reports.

To come to grips with the spatial consequences and differences of the changing climate on a national scale a desk study is done with the best available knowledge, which are the following reports:

desk study

Together working with water (Deltacommissie, 2008)
National water plan (Directoraat-Generaal Water, 2008)
Netherlands in sight (Directoraat-Generaal Water, 2009)
Climate sketchbook of the Netherlands (KNMI, 2009)
Roads to a climate proof Netherlands (Planbureau voor de Leefomgeving, 2009)
Make space for climate (Nationaal Programma Adaptatie Ruimte en Klimaat, 2007)

As described previously, most climatic problems are related to water, as water is a very important component in the Dutch landscape and in climatic effects. The sea level rise calls for extra measures in river deltas and low-lying areas, and increased extreme peak discharge in rivers can cause problems both upstream as well as downstream. Furthermore, extreme precipitation calls for better storage and discharge capacities on land, while extreme drought is related to the shortages of water (Hajer and Loeber, 2007).

The following part of this section summarises the consequences of climate change based on the previously mentioned reports. Knowledge from the reports is bundled and the problems are reorganised in flooding and drought related problems. Goal of this desk study is to get an overview of the long-term spatial consequences and challenges of the changing climate.

3.5.3 FLOODING RISKS

Flooding risks in the Netherlands are caused by several aspects, such as; weak links along the coast, weak dikes along rivers, or extreme precipitation. In the following paragraphs the factors that form a flooding risk in the Netherlands will be discussed.

Sea level rise

Possible problems of sea-level rise will be mainly noticeable in the lower Netherlands. After the flooding of 1953 in the province of Zeeland there was widely spread attention for the Dutch water system, however after the realisation of the Delta Works this attention diminished. People nowadays feel safe behind their dikes, dunes, and Delta Works and there is little attention for flood resilient planning of the space behind the dikes, as the chance of a dike burst is thought to be out of question due to the high safety standards (Pols et al., 2007). However, there are several weak links along the coast and there are a lot of dikes that do not reach the safety norms.

weak links

The cities in the lower Netherlands, which are below sea level and behind the weak dunes and dikes, face the risk of flooding during extreme storm surges or when problems with the safety mechanisms occur. This risk will only increase with the changing climate and the related sea level rise. Along the Dutch coast there are eight so called weak links, areas that cannot resist a storm that occurs every 1/4000 year. Cities like Scheveningen, The Hague, Noordwijk and Katwijk lie directly behind these weak links and face a high risk of flooding (Ministerie van Verkeer en Waterstaat, 2005).

stability dunes

Furthermore there are worries about the stability of the dunes as the sea is continuously eroding sand from the coast. Yearly sand supplementation is a necessary mean to keep the coast safe (Deltacommissie, 2008).

River discharges

stability dikes

Where the five big rivers (Rhine, Meuse, Scheldt, Waal and IJssel) used to meander through the landscape they are nowadays captured between dikes. The dikes brought us safety but as the near flooding in 1995 and 2011 showed, this safety is only relative. With the changing climate and the predicted increase in river discharge the chance of flooding increases, especially as the strength of stretches of dikes cannot be guaranteed (Deltacommissie, 2008).

Increased extreme precipitation

problems on transition areas

Based on the reports, it can be stated that problems related to extreme precipitation are more troublesome in some situations that in others. On the transition area of higher and lower lands for example extreme precipitation causes serious problems. The quick discharge of precipitation water from the higher areas can cause flooding in the lower lying areas. The same accounts for brooks where downstream urban landscapes face the risk of flooding when large amounts of water have to be discharged.

stagnating water on boulder clay

Furthermore, on boulder clay lenses in the subsoil rainwater can stagnate, causing undesirable high groundwater levels (Directoraat-Generaal Water, 2009). These high groundwater levels might also occur when precipitation increases.

3.5.4 DROUGHT RELATED PROBLEMS

soil subsidence

Another effect of climate change affecting the landscape is extreme drought. Already, large parts of the Netherlands are subsiding due to peat oxidation and clay settlement and this will become worse during periods of extreme droughts, due to water shortages and high temperatures (higher rate of peat oxidation) (Antheunisse et al, 2008).

dropping ground water levels

In the high sandy landscapes, drought has negative consequences as well. Groundwater levels can drop during droughts, leading to heat stress and water shortages for agriculture and vegetation in cities (Directoraat-Generaal Water, 2009; Planbureau voor de Leefomgeving, 2009).

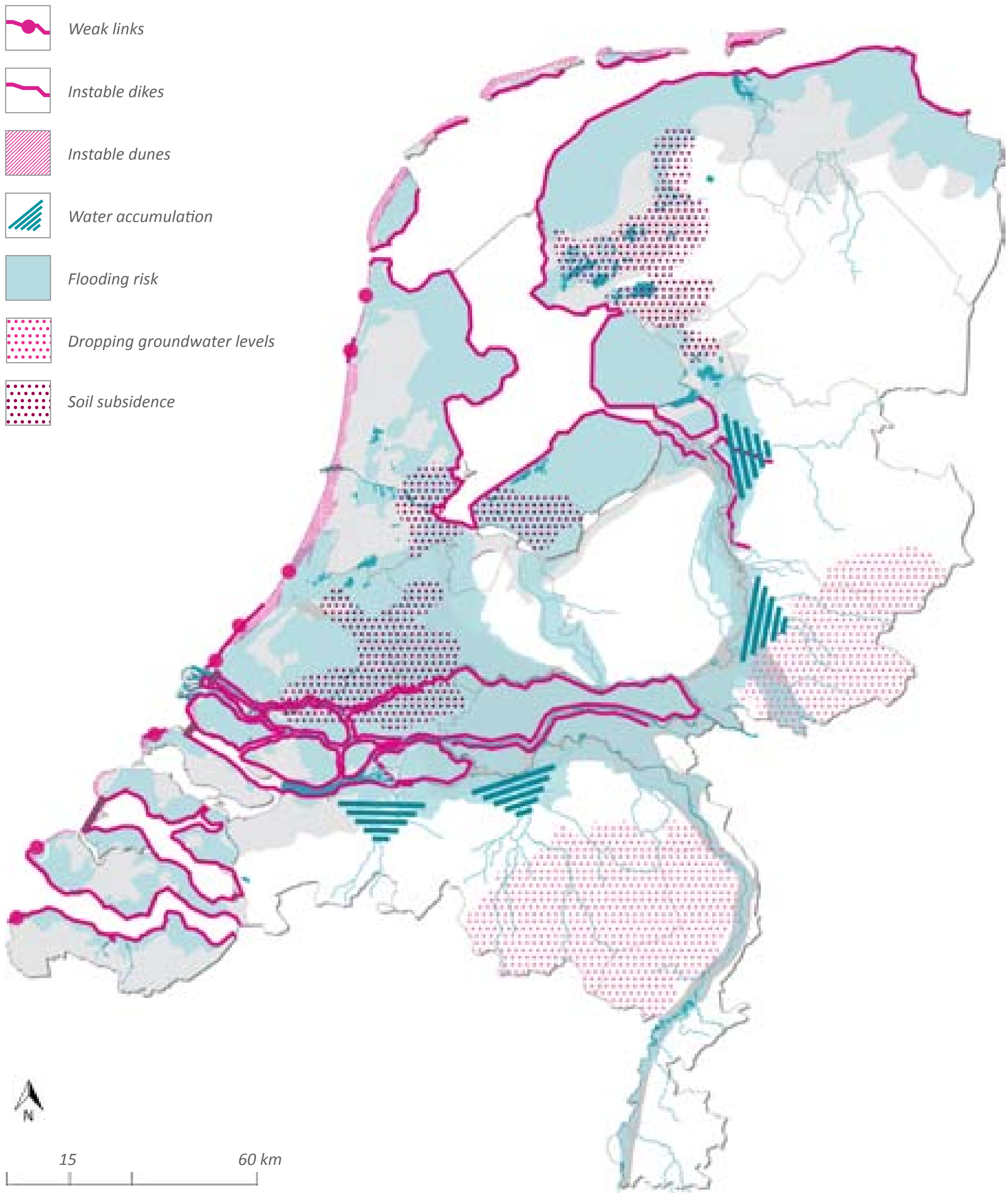

figure 3.16 Spatial differentiation of climate related problems in the Netherlands, based on the reports used for the desk study as described in paragraph 3.5.2

3.6 CLIMATE CHANGE IN URBAN LANDSCAPES

Previous paragraphs described the regionally different impacts of the changing climate in the Dutch landscapes. As the landscape-based design approach to climate adaptation focuses on the urban landscapes a selection of cities in these landscapes is needed. For this selection, two criteria are used; the city size and the intensity of the problems the city is facing.

3.6.1 INITIAL CHOICE CITIES

As discussed in chapter one, the Netherlands is densely populated and the level of urbanisation is very high. But how is urbanisation defined, what is a city, and which cities should be taken into account? Historically seen, places could receive city rights but these have no value regarding urbanisation. To give an example, The Hague, being the 3rd largest city of the country, has no city rights while a small place like Sint Anna ter Muiden with only 50 inhabitants does have city rights.

adress density

A better alternative might be the 'Centraal Bureau voor de Statistiek' (CBS) definition regarding urbanisation. The CBS publishes national official statistics on various topics such as finances, culture, demography, agriculture and much more. They define the level of urbanisation by looking at the number of addresses per square kilometre. Five categories are distinguished; very highly urbanised (>2500 addresses/km²), highly urbanised (>1500 addresses/km²), moderately urbanised (>1000 addresses/km²), lowly urbanised (>500 addresses/km²), and not urbanised (<500 addresses/km²) (CBS et al., 2001). A problem with this definition however is that data is based on municipal borders instead of city borders which in some cases might be misleading. However, being the best available information, the CBS definition and data is used for further research in this thesis.

highly and very highly urbanised municipalities

As this thesis focuses on climate adaptation in the urban context, as selection of the highly and very highly urbanised municipalities was made. This is especially interesting when one considers that a areas with a high adress density are likely to have a high percentage of impermeable surfaces as the houses need roads, parking lots and so on. Areas with a high adress density are thus areas where the transformation from a natural dynamic watersystem into a technocratic static watersystem is most apparent. This resulted in a list of 72 municipalities, which was then further reduced to 48 as some municipalities are clustered together into larger agglomerations. A well know example of such an agglomeration might be Amsterdam which consist of the municipalities Amsterdam, Amstelveen, Ouder-Amstel, Diemen, Weesp, Zaanstad and Haarlemmermeer.

3.6.2 TWO CASE CITIES

The selected municipalities and agglomerations were then organised per landscape type and rated according to the risk of facing the previously described impacts of climate change; sea level rise, river discharge, drought and extreme precipitation as is shown in figure 3.17.

Furthermore the analysis of the reports on climate change also pointed out specific problems in some Dutch cities. Dordrecht for example is situated on the transition area between the influence of the sea and the rivers. Gouda lies in an area which suffers from quick and deep flooding when the 'dijkring 14' collapses (Deltacommissie, 2008). Roermond, Maastricht and Venlo are already facing the nuisances of extreme precipitation. Furthermore, Maastricht is situated in a valley where heat is captured (DHV, 2008). These specific risks are also taken into account.

climate change matrix

This desk study of climate impacts in the Netherlands resulted in a matrix (table 3.1), which ranks the cities according to their chance of facing problems with the changing climate. High scores indicate that there is a higher chance to face serious challenges and these cities are interesting as case studies for further research in this thesis. The most interesting cities are Enschede, Arnhem, Gouda, Dordrecht, 's Gravenhage and Almere. In the ideal situation all six urban landscapes should be analysed thoroughly, and a complete plan would be made for all of these to be able to present the differences of climatologic problems and the specific solutions for climate adaptation per urban landscape. However, within the time span of this thesis we could only do further research and design on two interesting and spatially very different cities; Gouda and Enschede. In the next paragraphs and chapters we will more thoroughly describe and discuss the working method and climate challenges and chances for both Enschede and Gouda.

six urban landscapes

two case cities

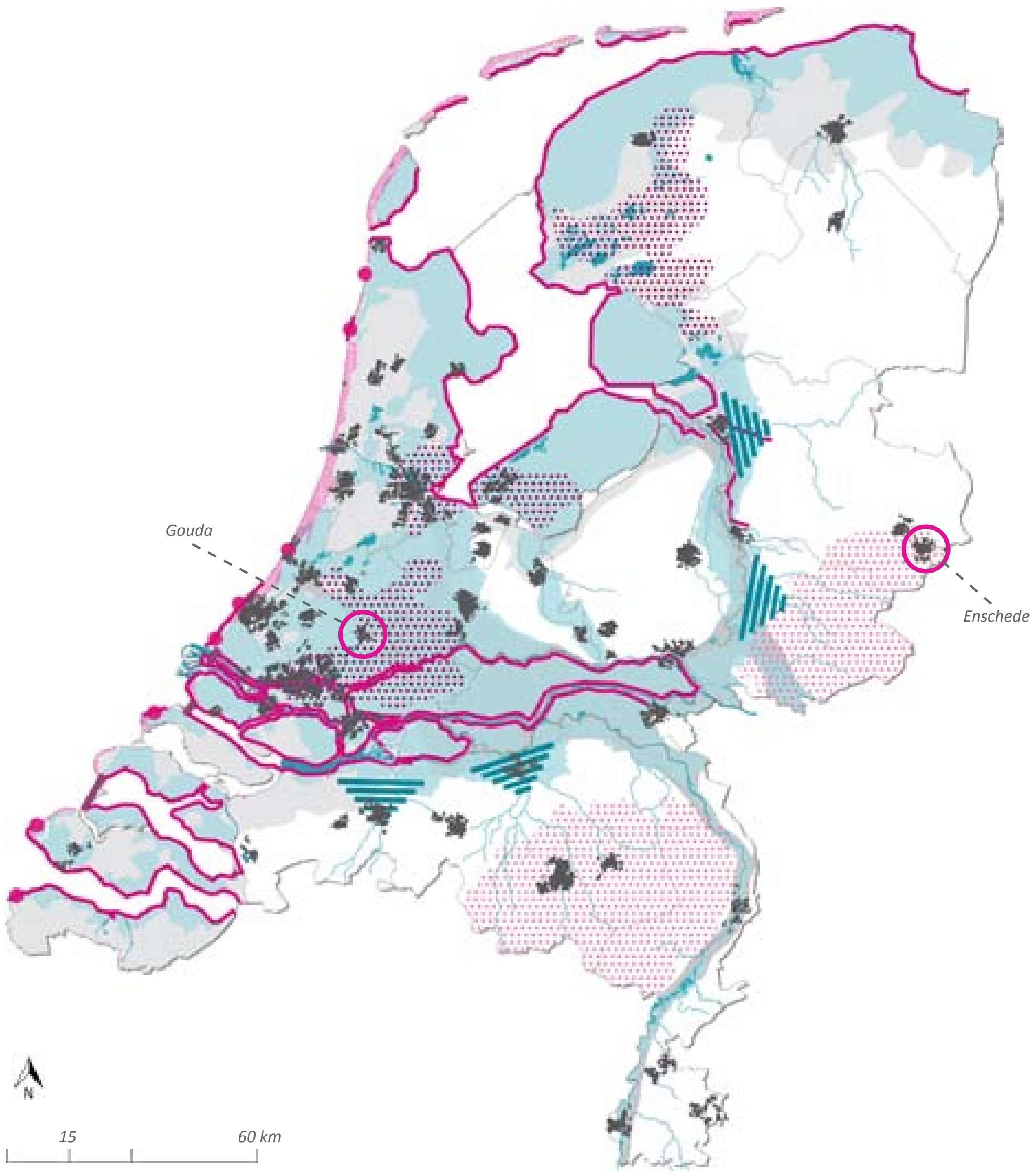

figure 3.17 The largest Dutch cities and agglomerations juxtaposed on the spatial differentiation of climate related problems in the Netherlands

		SEA-LEVEL RISE	RIVER-DISCHARGE	HEAT	PRECIPITATION	TOTAL
HIGH LAND	**SAND**					
	Agl. Eindhoven	0	0	0	0	0
	Agl. Heerlen-Kerkrade	0	0	0	1	1
	Amersfoort	0	1	0	0	1
	Apeldoorn	0	0	0	1	1
	Bergen op Zoom	0	0	0	0	0
	Breda	0	0	0	1	1
	Ede	0	0	0	1	1
	Etten-Leur	0	0	0	0	0
	Helmond	0	0	0	0	0
	Hilversum	0	0	0	0	0
	Sitard-Geleen	0	0	0	1	1
	Tilburg	0	0	0	1	1
	Veenendaal	0	1	0	1	2
	Wageningen	0	0	0	1	1
	BOULDER CLAY					
	Assen	0	0	0	0	0
	Enschede	0	0	1	2	3
	Hengelo	0	0	1	0	1
RIVER	Venlo	0	1	0	0	1
	Agl. Utrecht	0	1	0	0	1
	Arnhem	0	2	0	1	3
	Deventer	0	2	0	1	3
	Maastricht	0	1	1	0	2
	Nijmegen	0	2	0	0	2
	's Hertogenbosch	0	1	0	2	3
	Venlo	0	1	0	0	1
	Zwolle	0	2	0	1	3

table 3.1 Climate change matrix. The larges cities and agglomerations are ordered per landscape type. For each city or agglomeration the potential risk of sea-level rise, increased river discharge, drought or extreme precipitation is assigned. Indicated in pink are cities and agglomerations that have a high risk of facing the consequences of climate change.

		SEA-LEVEL RISE	RIVER-DISCHARGE	HEAT	PRECIPITATION	TOTAL
LOW LAND	**PEAT**					
	Agl. Amsterdam	0	2	0	0	2
	Agl. Beverwijk	1	0	0	0	1
	Agl. Leiden	2	0	0	0	2
	Alkmaar	1	0	0	0	1
	Alphen aan den Rijn	1	0	1	0	2
	Bussum	0	0	0	0	0
	Delft	1	0	0	1	2
	Gouda	1	1	1	1	4
	Haarlem	1	0	0	0	1
	Heemstede	1	0	0	0	1
	Heerhugowaard	0	0	0	0	0
	Weesp	0	2	0	0	2
	Zaanstad	0	0	1	0	1
	CLAY					
	Agl. Rotterdam	3	2	1	0	6
	Agl. Dordrecht	3	2	0	0	5
	Hellevoetsluis	3	0	0	0	3
	Vlissingen-Middelburg	3	0	0	0	3
	Den Helder	3	0	0	0	3
	Hoorn	2	0	0	0	2
	Groningen	0	0	0	1	1
	Leeuwarden	0	0	0	0	0
	Huizen	0	0	0	0	0
	DUNE					
	s Gravenhage	3	0	0	0	3
	RECLAMATION					
	Almere	2	0	1	1	4
	Purmerend	1	0	0	1	2
	Zoetermeer	2	0	0	1	3

3.7 WATER-WAYS TO CLIMATE ADAPTATION

In this section we will briefly describe our working method for the two case cities. A step-by-step explanation shows the preliminary process of analysing and researching the urban landscapes, searching for the site-specific problems before working towards site-specific climate adaptive design solutions. This step-by-step methodology can be seen as an example for research that can be applied to other urban landscapes as well, in both the same as in different landscape types.

3.7.1 LANDSCAPE AS BASIS

As is described in previous sections of this chapter, regional differences in landscape are important related to adaptation to climate change. Differences in soil, relief and hydrology result in site-specific challenges and offer site-specific solutions for climate adaptation at the same time. For urban landscapes, the altered surface geometry (built-up areas, pavement, etc) and the hidden and infrastructural networks form important layers that should be added to the previously described ones.

renewed relationships

Where soil, relief, and hydrology form the a-biotic pattern, the altered surface geometry and networks form the occupation pattern in the model by described by Duchhart (2007, p.194), in which the triplex-model and the sociophysical model are integrated. By doing an in-depth research on urban landscapes, opportunities for renewed relationships between these two layers can be found which offer possibilities for sustainable climate adaptive design solutions to the ailing urban water systems.

understanding urban landscapes

A thorough analysis of the occupation and a-biotic patterns leads to understanding of the urban landscapes. Subjects examined are: relief, soil, water systems, sewer systems, historic geography, urban landscape morphology, and planned future landscape developments.

The design solutions based on this in-depth analysis of the a-biotic and occupation patterns of urban landscapes change the sociophysical organisation principle. Where landscape was subjected to form and function, in the landscape-based design approach landscape is seen as object, as a basis for form and function. The changed sociophysical organisation results in increased public awareness and eventually even to cultural and political shifts. In other words, with opportunities offered by the landscape, it is possible to influence the social organisation principles (cultural, political, and economical).

These social organisation principles can have a large influence on the natural organisation principles (biotic & a-biotic subsystems) as humans have a large influence on nature, especially in a highly urbanised country as the Netherlands. In such a way one can say that a shift in balance from technocratic static towards the natural dynamics has a circular effect; the renewed relation with the landscape, changes the sociophysical organisation principle which has a positive effect on the natural and social organisation principle.

circular effects

Thus, a thorough research on urban landscapes as starting point, leads to sustainable waterways and climate adaptive urban landscapes, which in turn can increase public awareness and thereby influence social organisation principles. Subsequently, this important anthropogenic influence can have a positive effect on the natural organisation principles.

To show to what extent the sustainable water-ways contribute to adapting the cities to the changing climate, calculations need to be made of future storage and discharge assignments. The following paragraphs describe the methods used for making these calculations.

3.7.2 NORMATIVE PRECIPITATION VALUES

The chance that in a certain period of time precipitation exceeds average amounts of rainfall is called the probability value. Based on statistics of KNMI-data on frequencies and amounts of precipitation with different probability values, norms are derived that are used by water boards and municipalities to calculate water assignments. Nonetheless, no decisive answer can be given by laws, norms, or rules on what general Dutch normative precipitation values are.

probability value

The Dutch urban water managements for example measure the functioning of the sewerage based on a rainstorm that occurs on average once every two years. With heavier storms that occur for example 1/10 or 1/25 years, serious hindrance is caused, while rainstorms with an occurrence frequency of 1/50 years can even cause serious (economic) damage (Buishand and Wijngaard, 2007).

In the 'Nationaal Bestuursakkoord Water' (NBW) various norms have been set for different types of land uses. For the built environment 0% of the soil surface is allowed to be flooded with a 1/100 year rainstorm (Ministerie van Verkeer en Waterstaat et al., 2003). However, no values are given on the duration of the rainstorm. Is the norm based on a short 5-minute cloudburst? Or on a longer period of rain spread over 48 hours? And what norm should be used in the context of climate adaptation in cities? In the next paragraph will be explained which norms are used for further calculations in this theses.

In the rare situations that a 24-48 hour rainstorm with a statistical repetition time of 1/100 years occurs, the 'Wet Tegemoetkoming Schade' (WTS) sets in. This law guarantees compensation by the Dutch government for damage due to floods, earthquakes or other disasters (Dijkstal, 1998; KNMI, 2010). According to the KNMI-statistics a 1/100 year 48-hour rainstorm can result in 92mm of rain on a random place in the Netherlands (Wijngaard et al., 2005). The government does not compensate damage caused by rainstorms with repetition frequencies higher than 1/100 year.

'wet tegemoetkoming schade'

1/100 year 48-hour rainshower

Therefore cities should at least be able to deal with 48-hour rainstorms with a repetition frequency of 1/100 year. This corresponds with the NBW norm and will therefore be used as norm for calculations. Thus, water assignments for the urban landscapes will be calculate based on 48-hour rainstorms with a 1/100 year frequency.

1/100 year 2-hour rainshower

However, within the urban landscapes the total percentage of sealed surface is relatively high and can directly cause water problems due to runoff. Therefore normative values for a cloud burst should be considered as well. The KNMI gives values for these rainstorm events that occur in less than two hours (Buishand and Wijngaard, 2007). Thus, within cities the water systems on a smaller scale must at least be able to deal with a 1/100 year rainstorms within 2 hours.

3.7.3 REGIONAL DIFFERENCES IN PRECIPITATION

normative precipitation values

In the Netherlands average amounts of precipitation vary regionally. KNMI-statistics show the normative precipitation values per region for periods longer than 24 hours. In fig. 4.15 these regions are illustrated. These norms with corresponding values refer to the current situation. The KNMI however also gives prognoses for the different climate scenarios. Figure 4.15 shows the different precipitation norms (Groen, 2007).

Based on the KNMI norms and predictions on climate change, the 1/100 year frequencies for the year 2100 can be calculated for the different parts of the Netherlands (table 4.1)(Buishand et al., 2009).

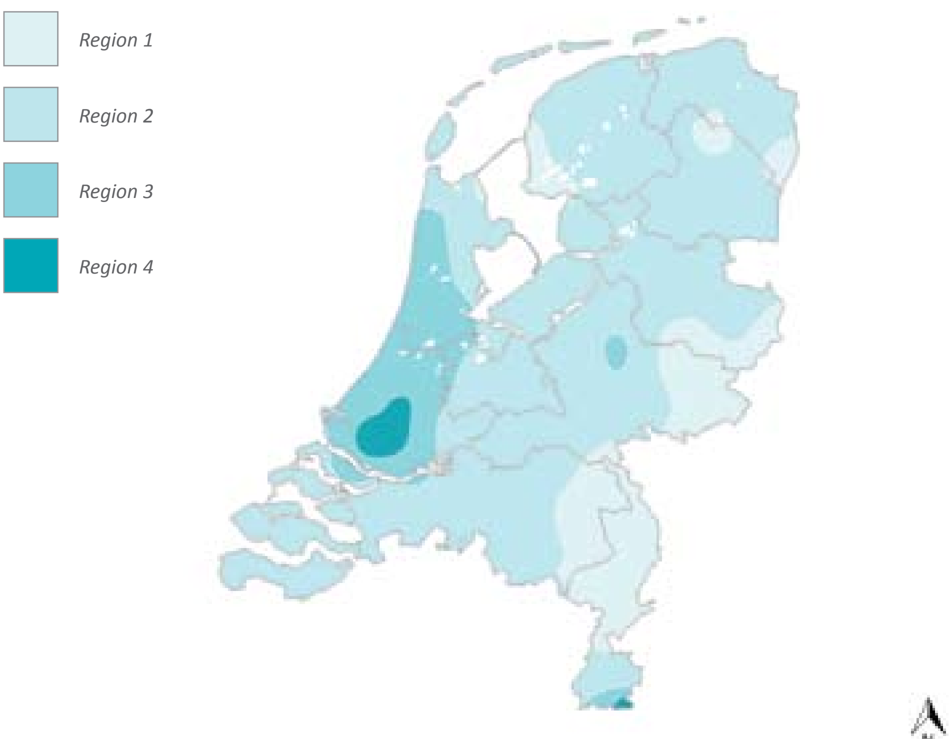

figure 3.18 Regional differences in precipitation norms (based on: Buishand et al., 2009)

table 4.2 Current and future precipitation values.
**ratio 2010:2100 for 1h and 24h, derived for 2h and 48h in W2100 scenario*
***ratio 2010:2100 for 24h and 48h derived for the regional values in W2100 scenario*
****no values were given for 1-2h for the regions, therefore step 2 (**) and step 1 (*) are combined*

1/100 year frequecy	2010	W2100	Region 1 (W2100)	Region 2 (W2100)	Region 3 (W2100)	Region 4 (W2100)
1h	43mm	66mm	61***	66***	71***	75***
2h	48mm	74mm*	68***	74***	79***	84***
24h	79mm	122mm	113**	122**	131**	139**
48h	92mm	142mm*	133**	142**	153**	162***

The values used for calculations differ. As described previously, urban landscapes should be able to cope with a 48-hour rainstorms. Furthermore, 2-hour cloudbursts result in very high pressure on urban water systems and these peaks should be stored on a smaller, loca scale to prevent peak disharges on the main system.

3.7.4 DETERMINING THE WATER ASSIGNMENTS

Important aspects that determine the water assignment for a city are the soil surface properties. These determine how much water can infiltrate and how much water runs off to other areas. On built up surfaces for example less water can infiltrate into the soil than on open fields. Thus, it is important to know the ratio between permeable and impermeable surface. The ratio is calculated in two steps, at first the relative amount of sealed surface area (buildings, roads, etc.) and open soil surface (parks, fields, etc.) is calculated based on topographical maps and aerial photographs.

permeable/impermeable ratio

The second step is to more precisely determine the ratio between permeable and impermeable soil surfaces for the built-up areas. For this, a grid method is used. Based on 100x100m boxes on representative areas with grids of 5x5m, the ratio between permeable and impermeable areas throughout the city s determined. The runoff coefficient for impermeable surfaces this coëfficient is 1 (100% runoff), while for the permeable areas it is 0.3 (30% runoff) (BIM, 2007).

grid method

Thus, the precipitation norms give the amount of rainwater in a certain area for a certain period of time, of which some will infiltrate. The ratio between permeable and impermeable surface combined with runoff coefficients results in the remaining water assignment for an urbanised area.

infiltration capacity

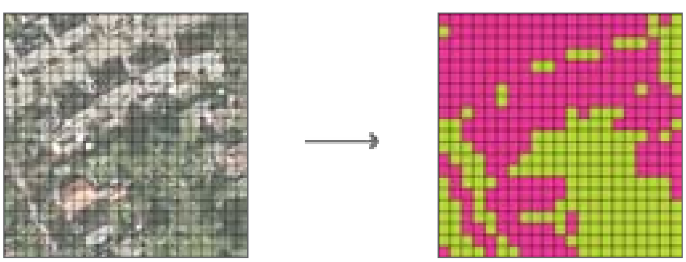

figure 3.19 Grid method results in ratio permeable/impermeable surface (based on: Google Earth, 2010)

3.7.5 FORMULAS

Combining the data described in the previous section with specific calculation models derived from the guide to hydrological calculations published by the 'Vereniging van producenten van betonleidingsystemen', lead to formulas for further calculations.

storage assignment

The normative rain shower (N) on the permeable and impermeable surface areas (A), minus the amount of water that can be discharged via the sewage system (S) and via waterways (W) gives the total storage assignment (Ra.).

$$Ra. = (N*A_{permeable}*C_{permeable}) + (N*A_{impermeable}*C_{impermiable}) – S – W$$

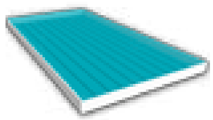

figure 3.20 Olympic swimming pool contains 2500 m³ of water

To make the storage assignments more visible, these are expressed in olympic swimming pools, equal to 2500m3. Depending on the available space and on the design solutions, volumes (m³) for retention can be calculated with general formulas

(e.g. volume= height*surface area). The possibilities for retention can now be compared with the assignment. In such a way more can be said on how much of the assignment can be met.

table 3.3 Explanation calculations

Symbol	Explanation	Calculation	
Ra	retention assignment (m^3/s)		
S	discharge via sewage system	**A_{total} * (7mm + (0.7mm * t))**	
W	discharge via water ways	Q * ((3600 * t)	
Q	flux of water (m^3/s)	$A_{profile}$ * v	
N	normative rainshower (m)		
V	volume (m^3)		
A_{total}	total surface area (m^2)		
$A_{permeable}$	permeable surface area (m^2)		
$A_{impermeable}$	impermeable surface area (m^2)		
$A_{profile}$	profile of water ways (m^2)		
C	runoff coefficient (fraction)		
$C_{permeable}$	runoff coefficient permeable surface (fraction)		
$C_{impermeable}$	runoff coefficient impermeable surface (fraction)		
W	discharge via waterways (m^3)		
t	time (hour)		
v	velocity of water (m/s)		

3.7.6 WORKING TOWARDS SOLUTIONS

Based upon the opportunities urban landscapes offer, site-specific concepts for waterways to climate adaptation are developed. These strategies form the basis for further design of strategic plans for the broader urban landscapes, and solutions on a more detailed scale.

A representative part of the concept is chosen based on three parametres. Urban characteristics such as urban densities and structures, open spaces within a city with high potential for climate adaptation, and specific landscape properties such as relief, soil, and hydrology are combined. A design is made for this representative part of the urban landscape, in which the conceptual strategy is related to the previously described parametres. Thereby the strategy becomes more concrete and the new waterways to climate adaptation are connected to the urban landscape. Finally, calculations are made and designs are adjusted in such a way that sustainable waterways to climate adaptation are achieved. The following section will discuss basis for the calculations of the designs.

urban density , open spaces, and landscape properties

Nevertheless, the scale of this plan is still too large to test if the proposed solutions actually can work, and no visual images can be given to show how spatial quality is improved. Therefore, it is important to zoom in on the representative typologies of the new waterways. These places are designed into more detail, visualisations are made of the proposed solutions, and it is calculated whether they can work in our proposed way.

representative typologies

Thus, research forms the base for initial conceptual design strategies, which in turn forms the basis of a spatial plan. The proposed design solutions are researched and tested. Research and design are intertwined throughout the process, from design by research to research by design. The following two chapters show how the above described working method is applied to both Enschede and Gouda, two different cities in different landscapes.

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[4]

A RENEWED BROOK SYSTEM FOR ENSCHEDE

Enschede is located in the area of Twente in the eastern part of the province of Overijssel. It is the 14th biggest municipality of the Netherlands with 157.797 inhabitants. The total surface area of the municipality is 142.75km² of which 140.95km² is land and the remaining 1.80km² is surface water (CBS, 2009). One of the characteristics of Twente is the fragmented relief; on a short distance there are relatively large differences in height, soil types and water systems.

4.1 URBAN LANDSCAPE MORPHOLOGY

In time the landscape of Enschede has been (trans-) formed into the urban landscape as we know it nowadays. Enschede is situated on an East-West sloping moraine. The highest point of this moraine is slightly east of the historic city centre and about 60 metres above NAP, while the lowest point of the city is around 25 above NAP (AHN, 2010). The moraine is the hydrological border between the watershed of the 'Regge en Twentekanaal' and the watershed of the 'Dinkel' (P. Lems and G.D. Geldof, 2002). In this section the formation of the urban landscape of Enschede will be discussed.

4.1.1 PLEISTOCENE

formation of moraines

During the Saalian ice-age a several hundred metres thick ice sheet slowly moved over Twente and other parts of the Netherlands. This ice sheet pushed forward clay, sand and gravel that formed the moraines. In later periods, the ice-sheet moved over the moraines and boulder clay was deposited on top of the moraines. During the warmer Eemian period, which followed the Saalian period, parts of the moraines eroded due to the melting of the ice sheet. During the last ice age, the Weichselian, Twente transformed into a polar desert and large amounts of sand from the dried up bed of the North Sea were deposited on the area (Waterschap Regge en Dinkel, 2010).

The land-ice cover during the Saalian period was of great importance for the contemporary height differences in the landscape. The land-ice formed moraines that are up to 85 metres above NAP (Berendsen, 2005).

boulder clay

The largest part of the subsoil of Enschede consists of boulder clay, a residual of the land-ice cover in the Saalian period. The structure of the boulder clay is highly variable, from sandy loam to loamy sand with loam as the main material. As an effect of the highly variable soil structure the permeability of the soil is, generally spoken, bad. On the higher parts of the moraine, the boulder clay reaches the surface; on the flanks the boulder clay is covered with sand and eroded material from the moraine. In these sandy areas boulder clay lenses can be found and in the brook valleys badly permeable clay and loam layers are deposited (P. Lems and G.D. Geldof, 2002).

4.1.2 HOLOCENE

During the Holocene period, the climate became warmer and wetter again. As a result of these changes in climate, peat bogs were formed in the lower areas of Twente and

figure 4.1 Height map, where dark grey illustrates the higher, and light grey illustrates the lower parts

in the stream valleys. Furthermore sand was blown away changing the morphology of the landscape and creating wind drift dunes (Waterschap Regge en Dinkel, 2010). This period had relatively little influence on the landscape of Twente compared to the Pleistocene period. In recent history however, the landscape changed further due to the growing anthropogenic influence.

4.1.3 RECENT HISTORY

Little is known about the early history of Enschede. However, more is known about the history that dates back to the early Middle Ages when a settlement was located on the place of the contemporary city centre. In the late middle ages, Enschede was a city of wood, mud, and dung. Built-up from these highly flammable materials, the village completely burned down in 1517 and again in 1750. During the 18th century however, the economy in Enschede started changing. Trade and the textile industry became more and more important and in the early 19th century the city was expanding rapidly (Enschede-stad.nl, 2008). In 1850 the steam engine was introduced, resulting in economic growth, while the amount of factories grew rapidly and the population quintupled between 1870 and 1900.

urban growth and textile industry

The city of Enschede is situated on the west slope of the moraine, probably to make the best use of the clean runoff water from the moraine. The availability of this clean water was important for the development of the textile industry. The textile industry used the clean water to bleach and paint linen. Due to this industrial use, the water became polluted and unusable. Industry started to use clean groundwater from deeper lying layers. The use of groundwater for economic purposes with dropping

availability of clean runoff wter

groundwater levels as a result was attended by housing development in the lower, and formally wetter, areas of the moraine and many of the brooks within the city were ditched, built-up or closed. The original brook structure in the city disappeared (P. Lems and G.D. Geldof, 2002).

disappearing brook system

In the 20th century the textile industry collapsed, and between 1970 and 1980 most factories were demolished and most former industrial areas were built-up. As a result of de disappearance of the textile industry less groundwater is pumped up, and the groundwater levels are slowly rising again and returning to the pre-industrial values.

rising groundwater levels

Where within the urban landscape most brooks have disappeared in the 19th and 20th century, in the surrounding landscape many brooks have been canalised to make land more suitable for agriculture. An intensive and technocratic water discharge system was created, furthermore the water quality decreased as a result of both industrialisation and agriculture (Waterschap Regge en Dinkel, 2010).

canalisation

In short, human interference in Enschede resulted in the disappearance of most brooks within the urban landscape and canalisation of most brooks in the rural landscape, thereby removing the natural discharge system. As most water pumping is stopped nowadays the groundwater is rising again.

figure 4.2 Historic brook system around 1850 (based on: Geudeke et al., 1990)

0.75 3 km

4.2 FORMER BROOK LANDSCAPE ENSCHEDE

Where Enschede and its surroundings used to be characterised by a dense brook system, human interferences radically altered and replaced this water discharge system. The following paragraphs describe the contemporary water system both on the regional and the urban scale.

4.2.1 REGIONAL WATER SYSTEM

The surface water in Twente consists of a complex system of waterways. The watershed on top of the moraine in Enschede forms the source of the water system of Twente. The 'Twentekanalen', 'de Regge', and 'de Dinkel' are the largest waterways in Twente and form the basis for a categorisation in main catchment areas. The area of Twente consists of 5 catchment areas, 'de Laaglandregge', de 'Stadsregge', 'de Dinkel', 'het Twentekanalen-systeem', and 'the Vecht-deelsysteem' (appendix 1). The aim is to discharge most urban water via 'de Stadsregge' and to use 'de laaglandregge' to discharge the rural water (Waterschap Regge en Dinkel, 2010).

watershed on the moraine

catchment areas

The 'Twentekanaal' and the 'Kanaal Almelo-De Haandrik' are not part of the catchment area of the 'Regge' but they have a function in the water catchment of the 'Regge'. On the one hand, surplus water is discharged via these canals. On the other hand, the canals are used for the inlet of water in dry periods (Arcadis Heidemij Advies, 1998). The moraine also plays an important role in the water supply for Twente as water seeps from the moraines towards lower lying areas. As a result of the seepage, groundwater levels on the moraines drop seriously during summer periods (Voorbereidingscommissie Enschede-Noord, 2007).

The moraine plays an important role in the regional groundwater system. Generally spoken, the moraine is an infiltration area. Rainwater flows through the soil in both eastern and western direction. Due to the badly permeable layers close to the surface, the storage capacity of the soil is limited. The relatively steep slope and the natural drainage system, make that the water is discharged rather quickly. This causes high peak discharges that quickly disappear again after precipitation periods (Voorbereidingscommissie Enschede-Noord, 2007). Figure 4.3 illustrates the regional water system described above.

quick discharge

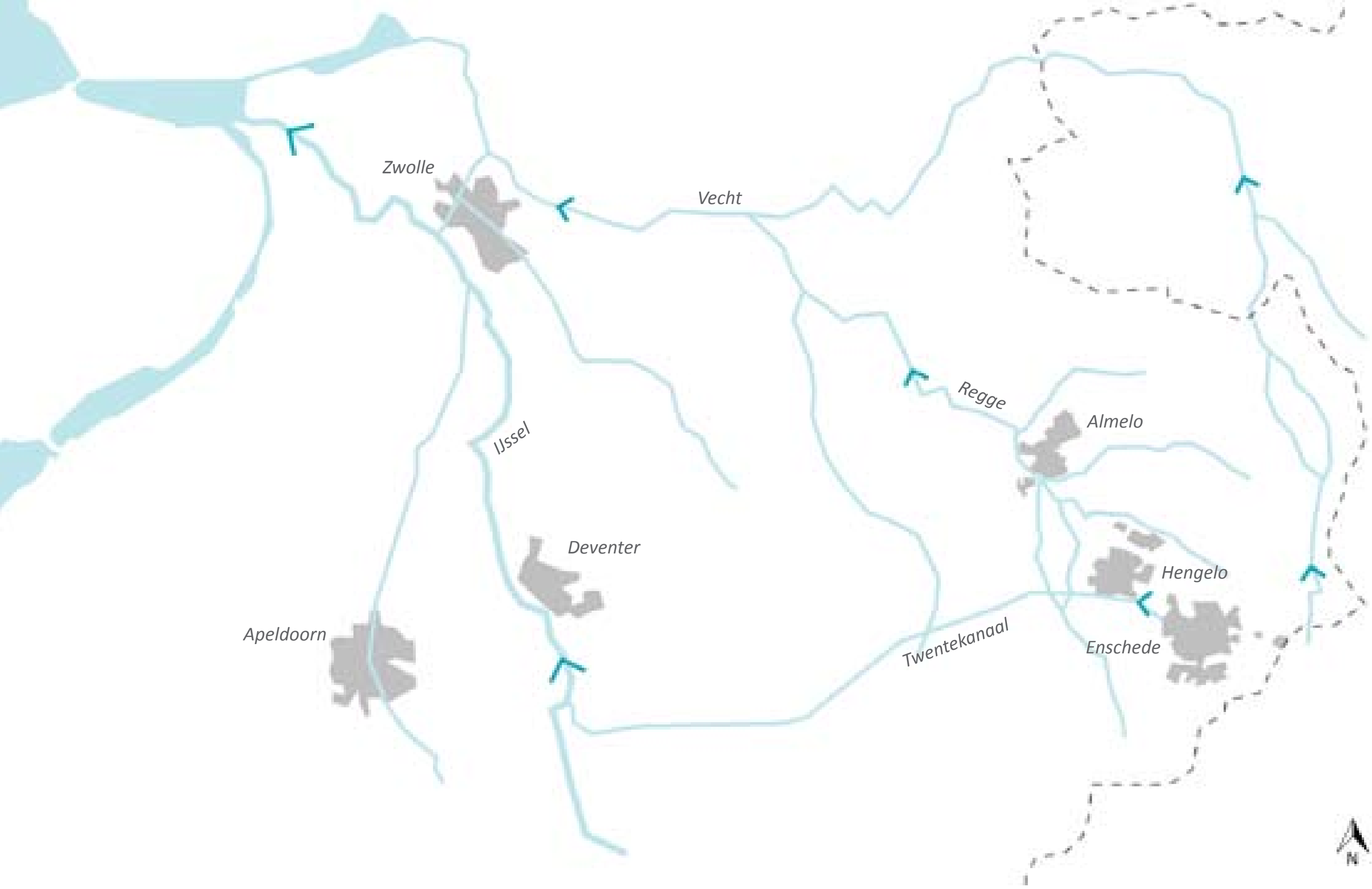


figure 4.3 Regional water system

4.2.2 URBAN WATER SYSTEM

As said, the moraine forms an important watershed for the Twente region but also for the urban water system the moraine is of great importance. From the watershed on the moraine, the eastern part discharges water via the 'Elsbeek' towards 'de Dinkel'. The western part discharges via diverse brooks to 'de Koppelleiding' which is connected with the 'Twentekanaal'. Due to the shallow layers of clay and boulder clay on the moraine, rainwater cannot permeate into the soil very well. This causes small-scaled alternation of seepage and infiltration areas (Voorbereidingscommissie Enschede-Noord, 2007).

bad permeability of the soil

The infiltrating water higher on the moraine travels a relatively short distance through the subsoil as boulder clay layers prevent deep infiltration. On the lower parts of the moraine the water seeps out again. The relatively thin layer of covering sand makes that changes in the water system (seasonal influences, water abstraction, etc.) are quickly visible (P. Lems and G.D. Geldof, 2002).

Formally, precipitation surpluses (rainwater minus infiltration and evaporation) were discharged via brooks on the flanks of the moraine towards lower lying grounds. Humans modified this natural discharge system for agricultural and industrial purposes. This lowered the naturally high groundwater level in Enschede. After that, urbanisation in Enschede has had a major influence on the contemporary water system. In the rural area surrounding the city, the brook system, although canalised, is relatively intact, but within the urban tissue the structure has almost completely disappeared (P. Lems and G.D. Geldof, 2002).

modified discharge system

Originally, a relatively high groundwater table characterised Enschede, natural brooks and manmade waterways discharged the water. However, in the contemporary highly urbanised situation many of these brooks and waterways [surface water] have been replaced by an artificial discharge, by means of a drainage system (P. Lems and G.D. Geldof, 2002). Furthermore groundwater levels have been artificially lowered by means of pumping stations connected to the sewage system resulting in summer groundwater levels down to 12 metres below ground level (Waterschap Regge en Dinkel, 2010).

artificially lowered groundwater levels

Interestingly, large parts of the newer built-up areas of Enschede have a separated sewage system. Rainwater is collected and transported to swales or infiltration ponds and gray water is transported via the sewage system towards cleaning installations. Especially the newer part of the city, on the eastern slope of the moraine is equipped with a sophisticated system of swales, infiltration ponds, and separated sewage systems. Most old parts of the city still have a mixed sewage system where problems occur in periods of extreme precipitation.

separated sewage system

swales and infiltration ponds

4.3 ENSCHEDE'S AILING WATER SYSTEM

The former brook landscape of Enschede has disappeared and is replaced by a technocratic water system consisting of sewers and pumps. This system however, in combination with the highly urbanised landscape, the relief, soil, hydrology, and climate is inadequate proven by several flooding events in and around Enschede, while drought related problems are quite severe in summer periods as well. This section will discuss these contemporary and future problems.

4.3.1 CONTEMPORARY PROBLEMS

sewage overflows

Enschede is already facing some problems, mainly related to the urban water management. Due to the large surface of built-up area in the city, rainwater infiltration in the soil is further decreased and therefore rainwater is discharged via the sewage system. Heavy rain showers put high pressure on the sewage system and causes overflows as is seen in summer 2010 when a heavy rainstorm resulted in flooding in many parts of the city. When these overflows occur, dirty sewage water is discharged directly on to the surface water in and around the city, which gets polluted (P. Lems and G.D. Geldof, 2002).

rising groundwater level

The groundwater level in large parts of Enschede was artificially lowered due to groundwater abstraction for industrial use. However, reduced groundwater abstraction after disappearance of the industries led to a rise of the groundwater level causing flooding problems in Enschede. Especially in the lower, western, parts of the city and areas, with boulder clay lenses in the subsoil lead to periodic groundwater problems, resulting in flooding. To solve this problem, excess water is pumped into the sewage system, which has two negative consequences; the pressure on the sewage system increases even further and the clean groundwater is mixed with the dirty sewage water.

Thus, flooding problems are not only related to the city's geographical location (on the slope of the moraine with boulder clay lenses), but to a great extent with canalisation and the disappearance of the natural water system as well.

periodic droughts

Apart from the problems related to the high groundwater table and the decreased natural discharge capacities, Enschede is also suffering from periodic droughts. Instead of storing water, it is quickly discharged or it runs off the impermeable built-up surface of the city, thus less water can infiltrate into the soil. The natural buffering capacity of the landscape is not used. This results in droughts in periods with little precipitation and in floods during wet periods. Moreover, it is likely that the water related problems in Enschede will be amplified as a result of the changing weather patterns.








figures 4.4 - 4.12 Contemporary climate related problems in Enschede

downstream flooding

Due to the quick discharge of water, water accumulates downstream and causes flooding in the lower lying cities such as Hengelo and Almelo. This is a striking example of how contemporary technocratic urban water management passes on problems to other areas instead of solving them locally. Thus, the ailing urban water system in Enschede not only causes problems within the city itself or within the urban landscape, but within the region as a whole.

4.3.2 CLIMATE CHANGE IN ENSCHEDE

Climate change will influence Enschede's urban landscape. Though sea level rise and changing river discharges do not have much impact, the changing weather patterns on the other hand do.

weather extremes

Both the KNMI (2006) and the IPCC (2007) agree that extreme precipitation amounts in summer will increase. The total precipitation in summer will decrease in the KNMI W+ scenario. This means longer periods of drought, with occasionally extreme precipitation. In winter periods the amount of precipitation will increase and the total yearly amount of precipitation will slightly decrease. Thus, as described in the previous section, Enschede already faces problems with both precipitation surpluses and shortages, but if the climate will change, it is likely that these problems will increase in frequency and in magnitude.

4.3.3 FUTURE PROBLEMS

Due to the effects of climate change, it is likely that the contemporary problems in Enschede will be amplified, as weather extremes will become more common. But new problems are likely to occur as well.

increased pressure on sewage system

When rainfall intensity increases, the peak discharge of water will increase as well which will put a high pressure on the sewage system. The capacity of the sewage system in Enschede is not calculated on extreme precipitation peaks. Sewage overflows and 'water on the street' situations already occur quite occasionally and are likely to occur more often (P. Lems and G.D. Geldof, 2002). Especially within and around the city centre the total area of surface water to where rainwater can be diverted is small. During extreme precipitation peaks, water cannot be discharged via the sewers or via surface water, resulting in flooding.

higher urban temperatures

Not only do the quick discharge and the disappearance of natural water systems cause flooding, drought related problems occur as well. Combined with the low groundwater levels this results in watershortage for vegetation, less evaporative cooling, and higher temperatures in the urban landscape.

Moreover, these problems will not only occur within the city, but will be passed on to other cities and the surrounding landscape within the whole region. Thus, by solving the problems directly at the source, problems can be solved within the whole urban landscape. In the next section will discuss how we worked towards waterways to sustainable climate adaptation in Enschede.

4.4 THE RENEWED BROOK SYSTEM

Based on the thorough analysis of the urban landscape of Enschede, site-specific challenges and opportunities are found. To cope with these challenges and to use the opportunities a renewed brook system is proposed. This chapter will discuss the concepts, strategies, spatial plans, and the more detailed design solutions, which altogether form a resilient, site-specific, and spatially qualitative brook system for the urban landscape of Enschede.

4.4.1 CONTROLLED DISCHARGE AND RETENTION

Enschede is situated on an east-west sloping moraine which originally formed the source of many brooks. However, most of the natural brook system has disappeared or is canalised due to human interference especially in the industrial period. Nowadays, the high percentage of impermeable soil-surface, the disappearance and canalisation of brooks, and the dependency on inadequately functioning sewage systems leads to the drought and flooding problems as described in the previous section. The contemporary urban water system mainly focuses on quick discharge of rainwater, while in dry periods water is scarce. To prevent droughts and flooding, the potential of the natural buffering capacity within the landscape should be utilised by increasing infiltration into the soil, which can function as sponge. Furthermore, water should be discharged slowly and controlled, and retention areas should be created to increase storage capacity and reduce the pressure on the main discharge system. Thus, peaks should be flattened and spread out over longer periods of time.

natural buffering capacity

Interestingly in the case of Enschede are the watersheds and catchment areas on the slope of the moraine, the former natural brook system, and the surrounding remainders of the brooks, which give inspiration and offer opportunities for a renewed, resilient, and climate proof urban brook system. Furthermore, the boulder clay layers on the higher areas of the moraine, on which water stagnates, offer chances for storing water. These water retention areas can serve as the sources of the renewed urban brooks. In the lower areas, where water levels can be high due to seepage and accumulation of runoff water, there are also possibilities for retention areas as urban density decreases. By introducing a renewed urban brook system in Enschede, the urban water system is improved and the city can be adapted to climate change.

watersheds and catchment areas

renewed brook system

Based on slope and available space, the brooks can be divided in three characteristics; up-stream, middle-stream, and downstream. The main strategy within this concept is to collect and store water up-stream on the boulder clay lenses where space is

brook characteristics

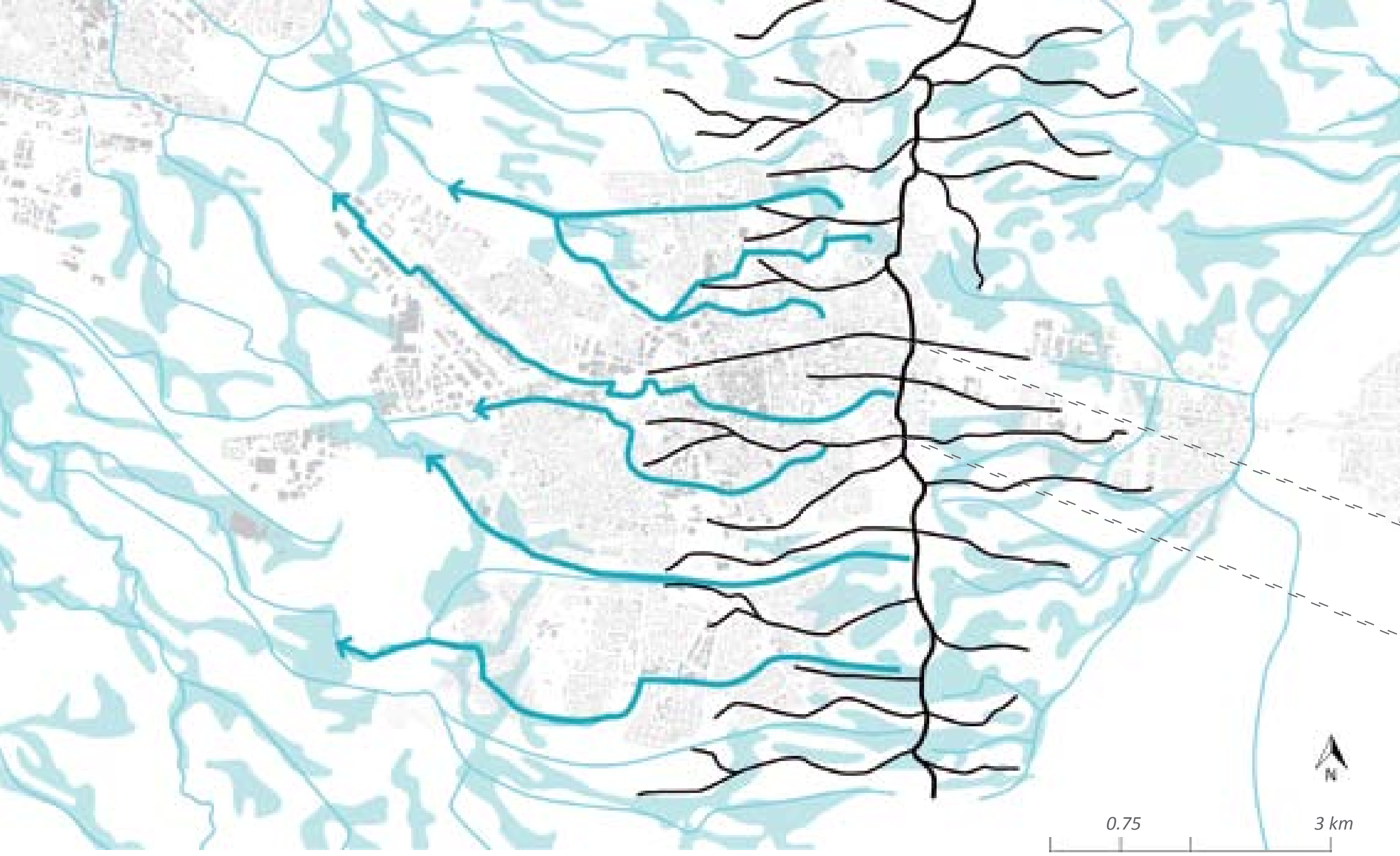


figure 4.13 Renewed urban brook concept. New brooks (dark blue arrows) are connected to the former brook vallys (light blue) in the surrounding landscape.

available, slowly discharge water through the highly urbanised middle-stream of the brook, and store and purify water down-stream where more space becomes available and the velocity of the brook decreases. Finally, purified fresh water can slowly flow into the surrounding brooks.

several possible brooks

Thus, by collecting, storing and purifying water where possible, and slowly discharging it via the renewed brook system where necessary, flooding risks are decreased and the buffering capacity of the urban water system increases, thereby providing water during dry periods. An analysis of the urban landscape, based on density, slope, and available space, showed that there are several possibilities for renewed brooks in Enschede (figure 4.13). To test the concept, more detailed research and design is necessary. Therefore in depth research is done on one of the possible brooks, as is described in the following paragraphs.

4.4.2 THE WATERWAY TO CLIMATE ADAPTION FOR ENSCHEDE

representative example

To make sure the brook is representative for the renewed brook concept the example is chosen in such a way that it covers different urban densities, that there are open spaces which offer opportunities, and that all 3 characteristics of a renewed brook (up-stream, middle stream, and downstream) are represented. For a more elaborate explanation of these choices see appendix 2

micro-catchments

Interestingly, different micro-catchments can be distinguished within the catchment area of the example brook based on the micro relief and the urban tissue. Combined with the previously mentioned urban densities, open spaces, and brook characteristics this results in different typologies along the brook, which have different forms, functions, and local storage assignments. The micro catchments are used to calculate the water assignments within the catchment area of the example brook based upon a 1/100 year 2-h rainstorm (see appendix 3 for the calculations on the new brook in Enschede).

table 4.1 Representativity and typologies of the new brook

Urban density	very low		medium	high		very high			medium
Open space									
Characteristic	downstream				middle stream		upstream		
Function	filtering, buffering and discharge				discharge		retention, source		
Typology	9	8	7	6	5	4	3	2	1

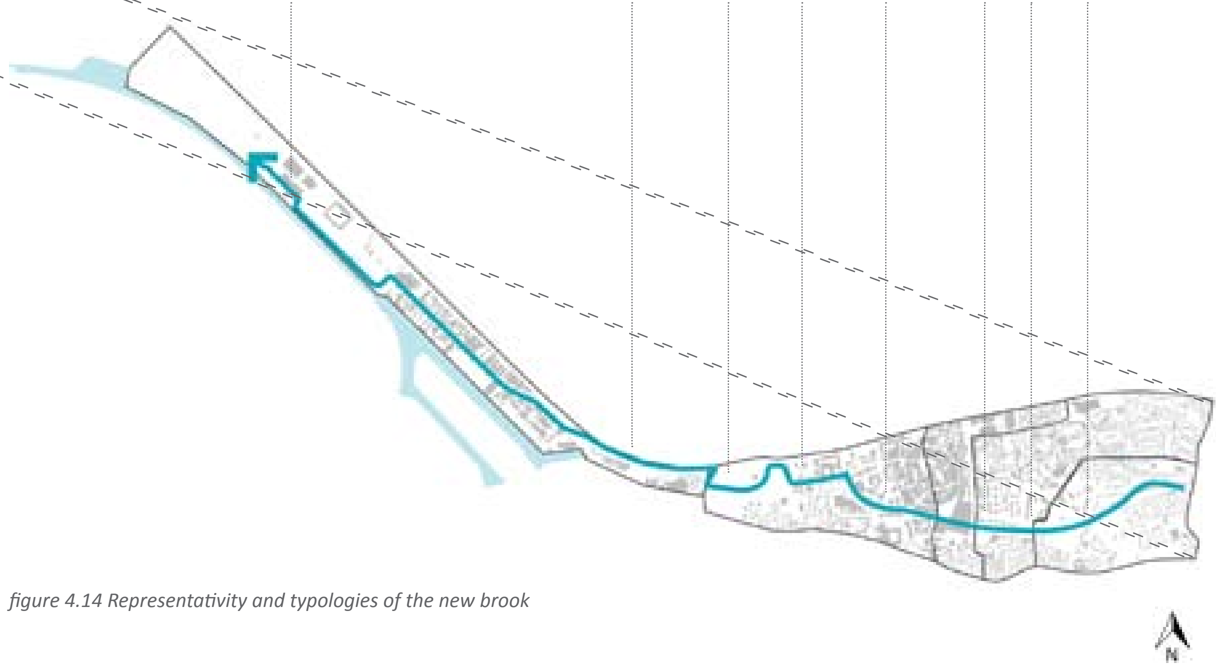


figure 4.14 Representativity and typologies of the new brook

9 typologies

As is shown in figure 4.14 and table 4.1, the new brook can be divided into 9 typologies. On the top of the moraine, there is a rainwater retention pond (1) and a rainwater retention and collection pond in the Blijdensteinpark (2), which forms the source of the new brook. From there the brook flows towards the Van Heek plein (4) via the Boulevard 1945 (3). On the Van Heekplein, in the urban centre, the water is made experiential. From the square the brook continues to the down-stream area near the Saxxion Hogeschool (5), where the rate of flow decreases and a first step in water purification is made. The Volkspark (6) is the next step in filtering the water and in periods of extreme precipitation large amount of water can be stored in the ponds in the park. From the Volkspark the brook continues through an industrial area (7-8) towards Kristalbad (9), a large water filtering area just outside of Enschede.

The most challenging typologies for further research are 1-6, as these are situated in the more densely built-up areas. When challenges in these areas can be met, it is most likely that coping with the challenges in areas 7-8 will not be problematic as these areas are less densely built-up and more space for the new brook is available in these areas. Furthermore, there is an existing plan for the Kristalbad (9) which is already under construction. The new brook will be connected to this water purification area. Therefore areas 1-6 are further researched and a spatial plan is made for these areas as is shown in figure 4.17.

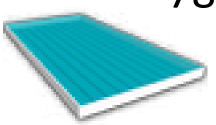
character brook

The character of the new brook is based upon original brook characteristics, the main stream bed is divided in an up/middle/down-stream part and there are branches which supply the main stream with water. In the upstream area, where relatively much space is available, the course of the brook is wide and the visibility is increased by the use of boulders and vegetation. In the middle stream area, which is densely built-up, the course of the brook is narrowed down, plant growth disappears and is replaced with lights which illuminate the brook. In the downstream area, where more space becomes available and the rate of flow decreases, helophyte plants are introduced to start the initial filtering process.

collection from surrounding areas

To supply the new brook with water, it has to be collected from the surrounding areas. To make this process visible; street profiles are altered, gutters are created on squares, and in parks gutters are accompanied with perennial vegetation (figure 4.16).

78 X



4.15 Storage assignment

The total water storage assignment for the catchment area is 195.508 m^3, which equals about a 78 Olympic swimming pools. The brook and the retention areas can solve a great part of this assignment (as will be described in paragraph 4.5). However, to completely solve the assignment the strengths of a landscape-based design approach should be combined with contemporary solutions on climate adaptation, such as swales, green roofs etc.

The spatial plan of this new brook in Enschede illustrates how the concept of a renewed brook system spatially fits within the existing urban landscape. To calculate the percentage of the assignment that can be solved in the different areas of the brook, and to research the possible spatial improvements more detailed designs of the typologies 1-6 are made which will be briefly discussed in the next section.

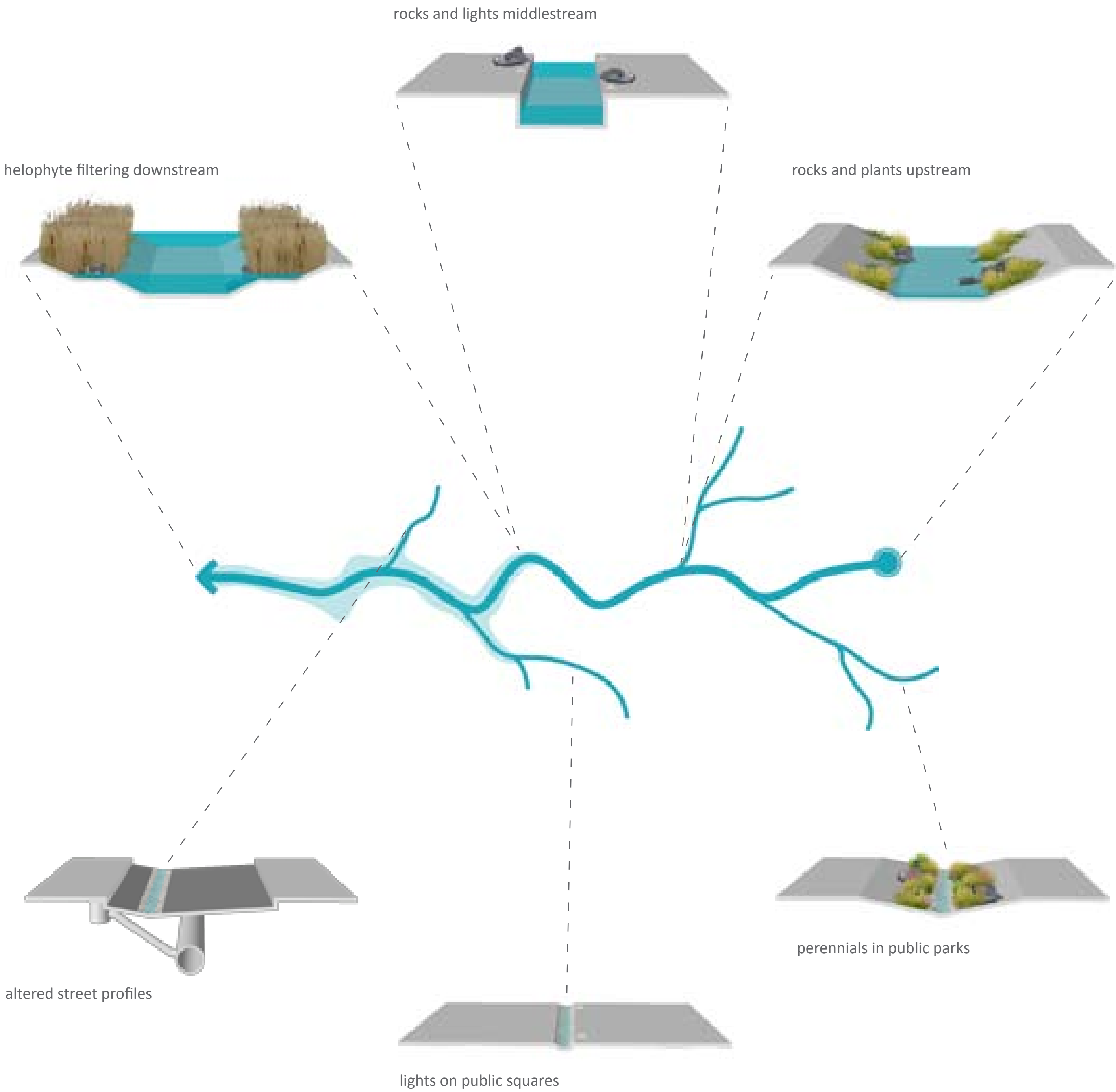


figure 4.16 Character of a renewed brook based upon a natural brook structure. With different characters in the up/middle/downstream parts of the brook and different types of 'branches' connected to the main stream supply the brook with water.

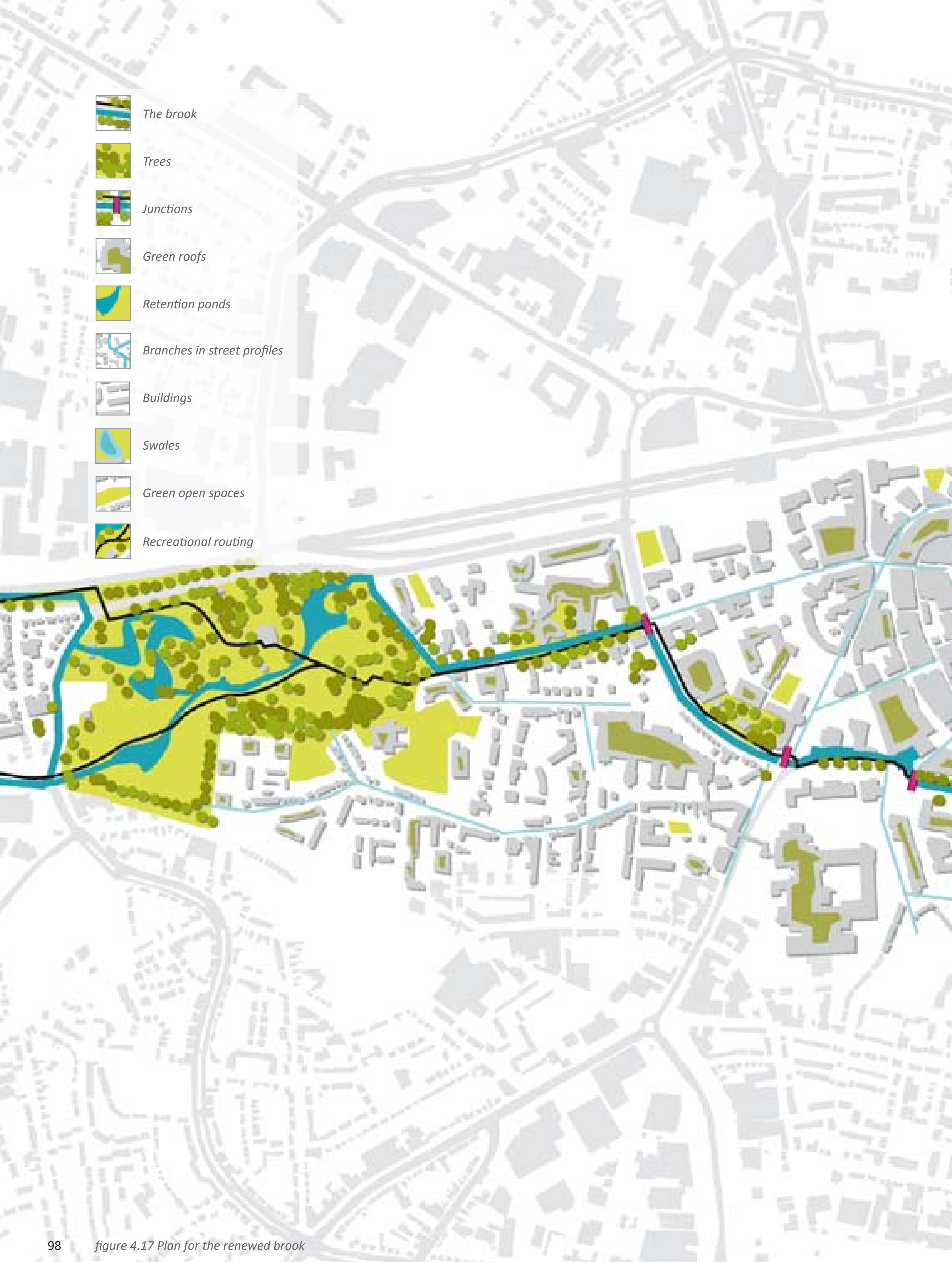


figure 4.17 Plan for the renewed brook


N
0.1
0.4 km

4.5 DETAILED DESIGNS

This section will briefly discuss the more detailed designs of typologies 1-6 (table 4.1) for the new brook in Enschede. Location and character of the different typologies will be described, partly based on the analysis as found in appendix 2. Furthermore, specific storage assignments are calculated based on a 1/100 year 2-h normative rain shower to decrease the peak discharges, the 2h rain showers put very high pressure on the sewage systems and should therefore be stored on this local scale, as described in chapter 4.

design principles

Furthermore, chances for water storage, discharge, and retention are sought for, based upon landscape characteristics such as height differences, open spaces, and directions of water flow. This results in design principles which are explained by means of photoshop collages and birds-eye views.

4.5.1 BLIJDENSTEINPARK AND SURROUNDINGS

The area of the Blijdensteinpark is located just west of the top of the moraine. The slope of the moraine is still visible in street profiles and in the relatively large parks that characterise the area such as the Wooldrikspark and the Blijdensteinpark. The urban density in the area is medium.

source of the new brook

As the area is located near the top of the moraine, the Blijdensteinpark and the surrounding area form the source of the new brook. Therefore, water should be stored and retained in the area. Boulder clay lenses, which most likely can be found in the subsoil of the Blijdensteinpark and surrounding area, offer chances for water retention as water stagnates on these lenses. However, it is not known where these boulder clay lenses are exactly situated.

significant height differences

The height differences in the area are still significant (figure 4.20). Based upon these height differences, potential water flow directions can be derived (figure 4.21). Open space in the area (figure 4.22) offers chances for creating water retention areas (figure 4.23).

figure 4.18 Location of Blijdensteinpark (dark blue) and surroundings (based on: Google Earth, 2010)

figure 4.19 Blijdenstein park (photograph by authors)

By altering the street profiles as described in section 4.4, rainwater that falls on the streets can be transported to the retention areas where it can be stored. Eventually, private gardens and rainwater from roof surfaces can be transported via the streets toward the retention ponds. The most important of these retention areas is the Blijdensteinpark, indicated in figure 4.23. Water from a large part of the area can be transported to and stored in this park, which functions as the main source of the new brook.

water storage in retention ponds

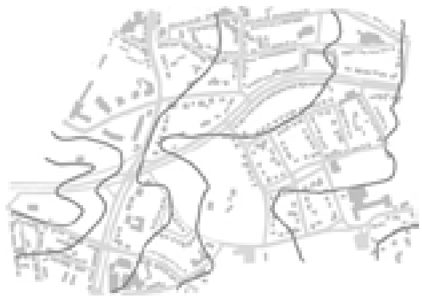


figure 4.20 Height differences (1 m interval)

figure 4.21 Flow directions

figure 4.22 Open spaces

figure 4.23 Possible water retention areas

using micro-relief

connection with the new brook

In the Bijdesteinpark the retention pond is created based upon the micro-relief in the park (figure 4.24). When completely empty, about 97% of the total storage assignment for the area, which is 25.726 m^3 or about 10 Olympic swimming pools, can be stored in the park. On the lowest point of the park, the retention pond is connected to the new brook via a mechanical weir which makes slow discharge of water possible (figure 4.25). With a completely filled retention pond, a water flow of 0,05 m/s in the brook is guaranteed for 36 days.

Blijdenstein as water retention park

As figure 4.27 and 4.28 illustrate, the Blijdensteinpark is transformed into a water retention park. Water comes in via altered street profiles, is transported through te park via vegetated gutters and is then stored in the retention pond. Seasonal differences in water levels and the flowing water in the gutters make water and climate dynamics visible and experiential thereby creating a new atmosphere and new playing possibilities for children.

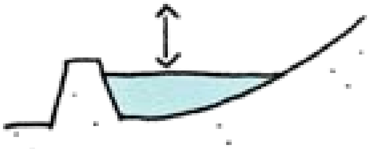


figure 4.24 Retention pond based on micro-relief

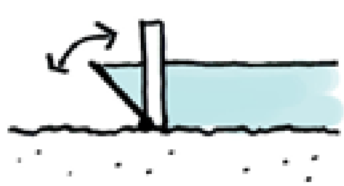


figure 4.25 Mechanical weir to regulate water levels

figure 4.26 Swales for retention and infiltration

However, as it is not desirable to completely empty the retention pond; the 97% of the water assignment cannot be stored, nor can a flux of water be guaranteed for 36 days. To meet the storage assignment, other retention areas should be created as well or water has to be discharged to downstream areas. As these retention areas cannot be connected to the brook, they function as swales, where rainwater from the surrounding areas is collected and slowly infiltrates into the soil (figure 4.26).

guaranteed flux in the new brook for 36 days

figure 4.27 Water storage in park Blijdenstein

figure 4.28 Renewed Blijdenstein park as the source of the new brook

4.5.2 BOULEVARD 1945

Boulevard 1945 connects the eastern part of Enschede with the city centre. The boulevard itself is a wide avenue with separated driving lanes and a double bus track. The urban density of the surrounding area is very high with little public space.

brook incorporated in the road profile

Within the plan for the new brook, Boulevard 1945 plays an important role as the course of the new brook is created within the profile of this road. The brook starts at the retention pond in the Blijdensteinpark and then flows in western direction towards the city centre.

figure 4.29 Boulevard 1945 (dark blue)and the surrounding area (based on: Google Earth, 2010)

figure 5.40 Current, paved, profile of Boulevard 1945 (photograph by authors)

The main function is discharging water, not only from the Blijdensteinpark but also from the area surrounding Boulevard 1945. The boulevard is located on the steeper part of the moraine, based on height differences (figure 4.31) flow directions can be derived (figure 4.32). Water from the surrounding area flows towards the low-lying Boulevard 1945. By altering the street profiles rainwater can thus be directed towards the new brook.

limited potential for local water storage

To decrease discharge peaks, water still has to be stored on a local scale. However, as there is only limited open space within the highly urbanised area (figure 4.33) there are only limited retention possibilities (4.34).

partial removal of the bus track

To create space for the brook, one of the bus tracks is removed. The bus schedule for Boulevard 1945 indicates that in both directions only 6 busses per hour pass by on the busiest moments, which is minimal compared to for instance some places in Utrecht where more than 25 busses pass by in both directions.

figure 4.31 Height differences (1 m interval)

figure 4.32 Flow directions

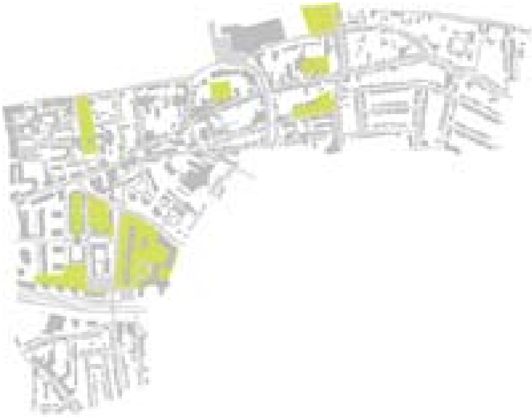


figure 4.33 Open spaces

figure 4.34 Possible water retention areas

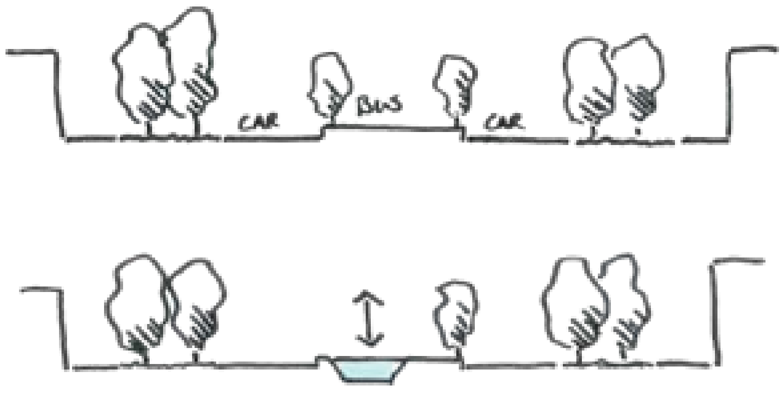


figure 4.36 Maximum and minimal rate of flow

figure 4.35 Changed profile of Boulevard 1945

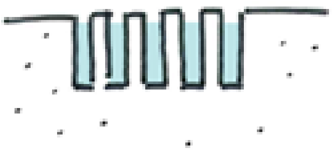


figure 4.37 Special gutters prevent flooding

discharge assignment

By the removal of the bus track, space becomes available and the profile of Boulevard 1945 can be changed to incorporate the new brook (figure 4.35). The minimal size of the new brook depends on the discharge assignment. This discharge assignment is 42.692 m^3 or about 17 Olympic swimming pools, based upon the normative 2-h rain shower on the sub-catchment area connected to Boulevard 1945. Water from the higher Blijdenstein area is taken into consideration, but this is only minimal as most of the 2-h rain shower can be stored in the retention areas.

A storage assignment of 42.692 m^3 results in a water flux of 5.9 m^3/s. Within the new profile of Boulevard 1945 the maximum width of the new brook is 7 m, where a profile of 5 m^2 can be created, thereby easily meeting the discharge assignment with a maximum rate of flow of 1.2 m/s. The water storage in the Blijdensteinpark as described in the previous paragraph guarantees a minimum water flow of 0.05 m/s for 36 days (figure 4.36).

visible and experiential climate dynamics

The new profile with the brook gives Boulevard 1945 a renewed character. Climate dynamics become visible and experiential as is illustrated in figures 4.38 and 4.39. In periods of heavy rainfall the brook grows and flows vividly while in dry periods the discharge is minimal and the brook flows gently between the boulders and vegetation. Changed street profiles discharge rainwater from the surrounding streets towards the brook, and special gutters prevent Boulevard 1945 from flooding (figure 4.37).

potential flooding in downstream areas

Although the discharge assignment for the area surrounding Boulevard 1945 is easily met, it might not be desirable to quickly discharge all water directly as this might cause flooding problems in downstream areas. Therefore the new brook should be combined with other measurements to decrease the peaks. The possibilities for retention ponds are limited, which calls for measurements such as green roofs and the promotion of rain barrels and permeable gardens. Figure 4.40 shows the renewed profile of Boulevard 1945 as entrance to the city.

figure 4.38 High water levels in the new brook during a period of heavy rainfall

figure 4.39 Gentle water flow during summer periods

figure 4.40 New brook incorporated in the profile of Boulevard 1945 creates a new atmosphere for the eastern entrance of the city.

4.5.3 VAN HEEKPLEIN AND THE CITY CENTRE

The Van Heekplein is located in the heart of the city centre, it is a dynamic square surrounded by stores. The weekly market is held on the square and on a regular basis larger events such as concerts take place. The urban density of the area surrounding the Van Heekplein is very high and space for climate adaptive interventions is limited.

limited available space

assignments added up

The Van Heekplein is located in the middle stream area of the new brook, where, available space for the new brook is limited. The main function of the brook in this area is discharging water. The discharge assignment for the area surrounding the Van Heekplein is 16.100 m^3 which seems limited compared to the 42.692 m^3 assignment for Boulevard 1945. However, both assignments should be added up, as water from the area surrounding Boulevard 1945 is discharged to the Van Heekplein via the new brook. This results in a total discharge assignment of 58.792 m^3 or approximately 24 Olympic swimming pools.

figure 4.41 Van Heekplein (dark blue) and the city centre (based on: Google Earth, 2010)

figure 4.42 Van Heekplein (www.artez.nl)

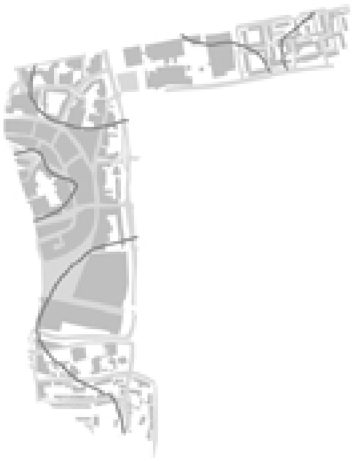


figure 4.43 Height differences

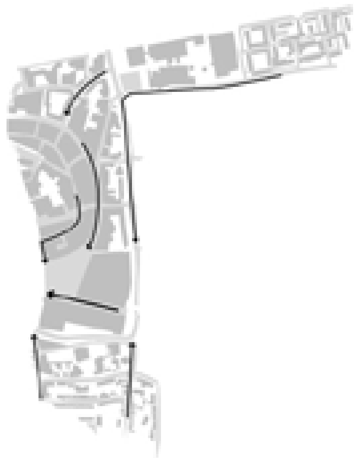


figure 4.44 Flow directions

figure 4.45 Open spaces

figure 4.46 Possible water retention areas

Due to the limited available space, the profile of the new brook narrows down compared to the profile of the upstream part of the brook. Combined with the increased amount of discharge this results in a rate of flow of 16 m/s (see appendix 3 for elaborate calculations) which is much higher than the 1.2 m/s calculated for the new brook in Boulevard 1945. 16 m/s is a water flow the new urban brook in Enschede cannot cope with. Therefore, discharge should be decreased which makes water retention very important.

limited retention possibilites

Unfortunately, possibilities for retention ponds are limited in the area (figure 4.45 and 4.46) making the call for water retention in the area surrounding Boulevard 1945 legitimate. In the city centre surrounding the Van Heekplein investments should be made in local water storage and retention. The large amount of flat roof surfaces offers opportunities for storing substantial amounts of water by means of green roofs.

new waterbody

Where the surrounding area has limited potential for creating retention ponds, the Van Heekplein does offer opportunities. Based on the height differences in the area (figure 4.43) and the possible water flows (figure 4.44) a large water body is proposed which is connected to the new brook. This water body gives an opportunity for creating awareness on the climate dynamics among the many people that visit the square.

accentuated slope

To accentuate the slope of the square the brook pops out of the landscape and is connected to the new watebody by means of a small waterfall. This way, both the landscape characteristics and the climate dynamics are accentuated (figure 4.48).

Rainwater that falls directly on the square is treated in two ways, first of all pavement underneath (existing) trees is replaced with permeable pavement which makes infiltration possible (figure 4.49), secondly special gutters are created on the square as is described in paragraph 4.4 which transport water towards the waterbody (figure 4.50). At nighttimes these gutters are accentuated by lights.

new atmosphere

reduces UHI-effect

The new water body however not only accentuates the landscape and the climate dynamics, it creates a new atmosphere for the Van Heekplein as is shown in figure 4.47. The added trees create more shade in summer days and evaporative cooling from the waterbody results in lower temperatures, reducing the urban heat island effect. After the waterfall connects the brook to the water body, the brook submerges to create a traffic passage after which the brook re-emerges again and continues its journey towards the downstream areas. The submerged part of the brook is accentuated by the use of cobblestones in the street profile as illustrated in figure 4.47 and 4.51.

figure 4.47 Renewed atmosphere of the Van Heekplein

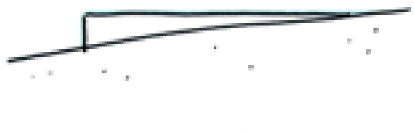


figure 4.48 Accentuation of height differences

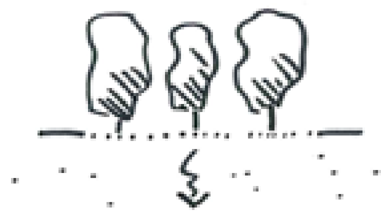


figure 4.49 Infiltration possibilities

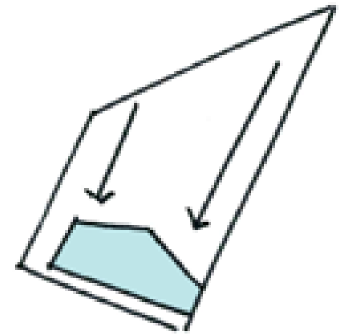
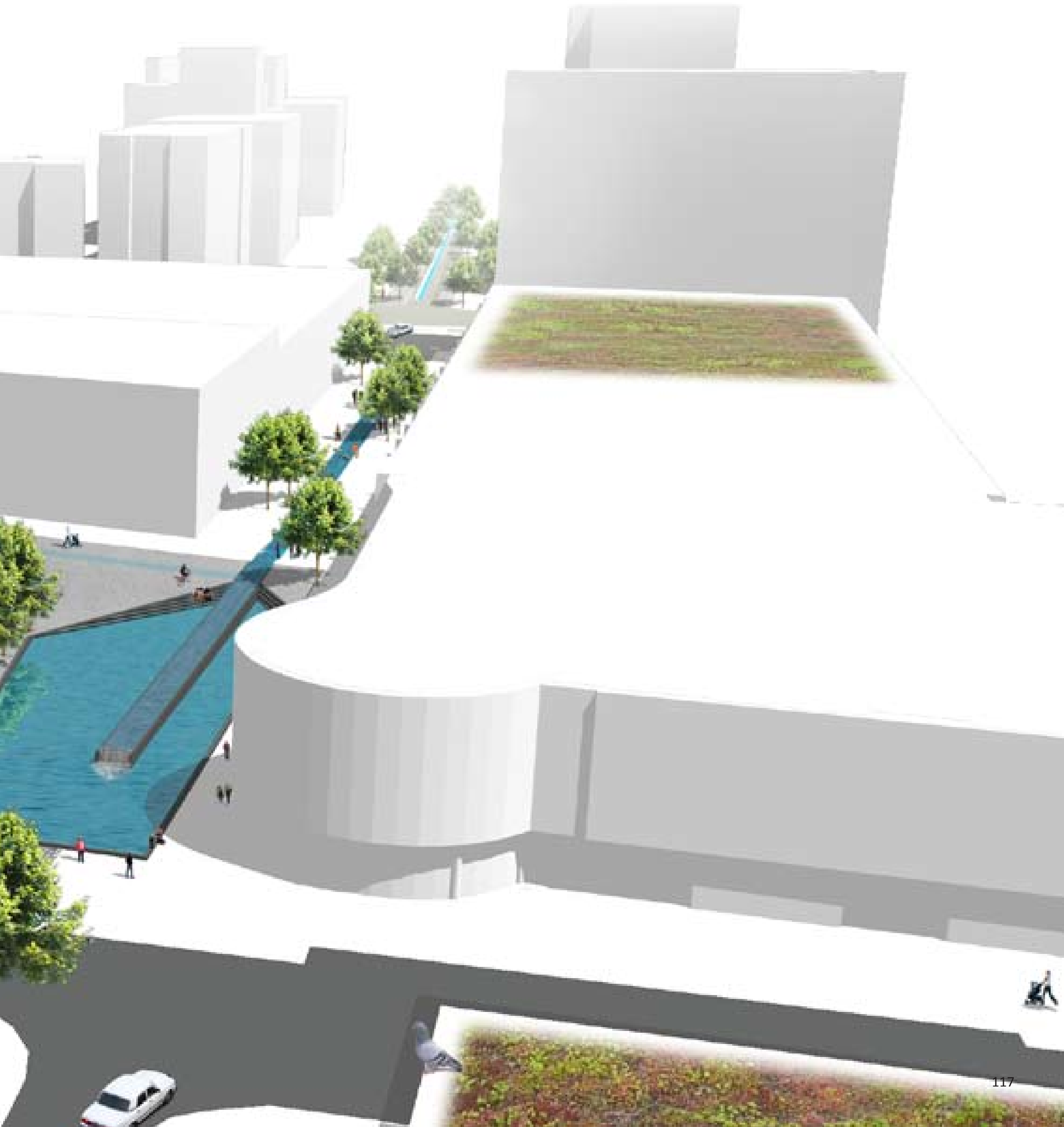


figure 4.50 Flow directions on the Van Heekplein towards the new retention pond

figure 4.51 Waterbody on the Van Heek plein connected to the new brook.



4.5.4 VOLKSPARK AND THE SURROUNDING LOWER AREA

decreased slope

From the passage of the city centre, the brook continues through the middlestream to end up in the area surrounding the Volkspark. In this area the slope of the moraine decreases significantly compared to the upstream and middlestream parts of the new brook (figure 4.54). Furthermore, the urban density decreases compared to the city centre and the available open space increases (figure 4.56).

storage, retention, and cleaning possibilities

The decreased slope results in a decreased rate of flow which, combined with the increase of available open space, offers chances for the storage and retention of water. The profile of the brook is widened and a first step in cleaning the urban runoff water is possible in the downstream areas

figure 4.52 Volkspark (dark blue) and the surrounding area (based on: Google Earth, 2010)

figure 4.53 Volkspark (http://image07.webshots.com)

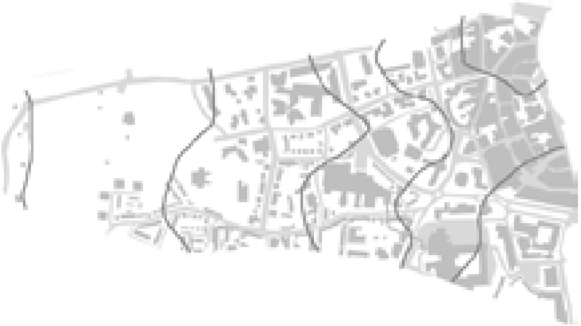


figure 4.54 Height differences

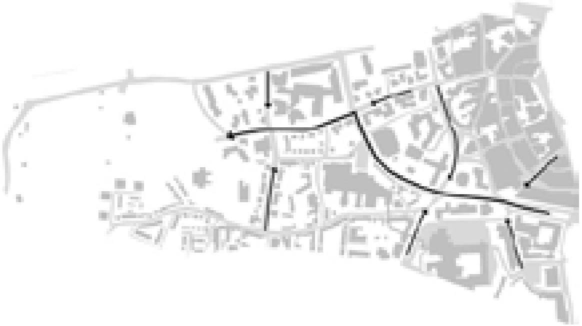


figure 4.55 Flow directions

figure 4.56 Open spaces

figure 4.57 Possible water retention areas

The storage and retention of water is essential for the new brook to function as all the discharged water from the catchment area accumulates in the downstream area from where it is further discharged via the industrial area towards the surrounding landscape.

water accumulation

The total storage and discharge assignment for the Volkspark and the surrounding area is 86.744 m^3 equal to nearly 35 Olympic swimming pools. Within the area surrounding the Volkspark there are several possibilities for retention ponds, and the park in itself offers an opportunity for major water retention (figure 4.57). Furthermore, the profile of the brook is widened where possible. Based on the possible waterflows (figure 4.55) the new brook passes the Saxion Hogeschool where there is a first possibility for

figure 4.58 Saxion Hogeschool (www.appienschede.nl)

widened brook profile

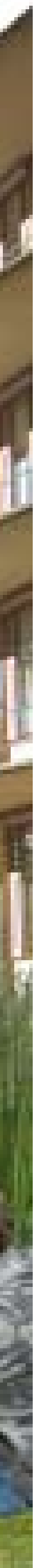
widening the brook profile and thus increasing the volume of the brook. In periods of heavy discharge this profile fills up and thereby decreases pressure on the system (figures 4.59 and 4.61)

helophyte vegetation

The widened profile of the brook is accentuated with boulders and flower rich helophyte vegetation (figure 4.62). As the flow of water decreases, a first step in filtering can be made. Furthermore, the new vegetation gives the area surrounding the Saxion Hogeschool a new atmosphere.

figure 4.59 Widened brook profile along the Saxion Hogeschool

figure 4.60 Water storage pond in Volkspark



From the Saxion Hogeschool the new brook continues towards the Volkspark where a major water storage and filtering pond is created based upon the existing park structure. Within the Volkspark there is a pond located in the deepest parts of the park. The new brook is connected to this pond, and the surroundings of the pond are altered so that a fluctuating water level becomes possible, based on the principle as described for the Saxion Hogeschool (figure 4.61). This way a fluctuation of one metre becomes possible which results in a potential water storage of 45.753 m^3 in period of heavy rainfall (see figures 4.63 and 4.64 for the potential fluctuating water level).

fluctuating water level

The banks of the pond are planted with helophyte vegetation and special helophyte fields are incorporated in the new park structure in order to filter the polluted urban runoff water before it is further discharged towards the Kristalbad and the landscape surrounding Enschede.

Figure 4.60 shows the new character of the Volkspark with the helophyte banks and a vegetated gutter transporting water from the surrounding residential areas towards the retention pond.

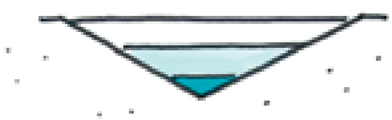


figure 4.61 Widened brook profile for water storage during periods of heavy rainfall

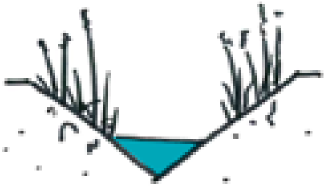


figure 4.62 Helophyte vegetation for filtering

4.6 CLIMATE ADAPTIVE ENSCHEDE

Based upon the more detailed research and design on the representative parts of the new brook some conclusions can be drawn, but questions emerge at the same time. First of all, the potential for the creation of a new brook shows that the landscape-based design approach, with the search for site-specific challenges and solutions, is a valuable mean in the process of adapting Enschede to the changing climate.

visibility of dynamics

Moreover, the climate dynamics become visible again. Where most rainwater discharge is hidden in the sewage system nowadays, the design interventions in Enschede bring the rainwater discharge back to the surface, create infiltration possiblities and increase the buffering capacity. Thereby making it visible and experiential, revealing the climate dynamics, and increasing public awareness and spatial quality. But not only are the climate dynamics revealed, spatial quality is increased at the same time.

public awareness

Calculations have shown that 63% of a 2h precipitation peak can be stored within the profile of the new brook and the retention ponds in the Blijdenstein park, the Van Heekplein, and the Volkspark. 37% of the precipitation peaks still needs to be stored in a different manner and the question is how this assignment can be met. The mentioned smaller retention ponds contribute their part, but a great deal of the remaining storage assignment needs to be stored on a local scale level, by means of rain barrels, permeable gardens etc. In other words, increasing public awareness and willingness is essential in the process of adapting Enschede to the changing climate

The renewed brook, combined with local scale water storage, can cope with extreme precipitation peaks. Furthermore, retention of water, especially in the upstream areas, has a positive buffering and cooling effect in relation to summer droughts.

more new brooks

A substantial part of the city of Enschede can be connected to the new brook, which is a test case for the renewed brook concept for whole city. Within the urban tissue there are other possibilities for new brooks and although not thoroughly researched it is likely that these can be implemented in the same manner as the researched brook.

Implementation of the new brooks results in the renewed, climate adaptive, brook system for Enschede as is illustrated in figure 4.64.

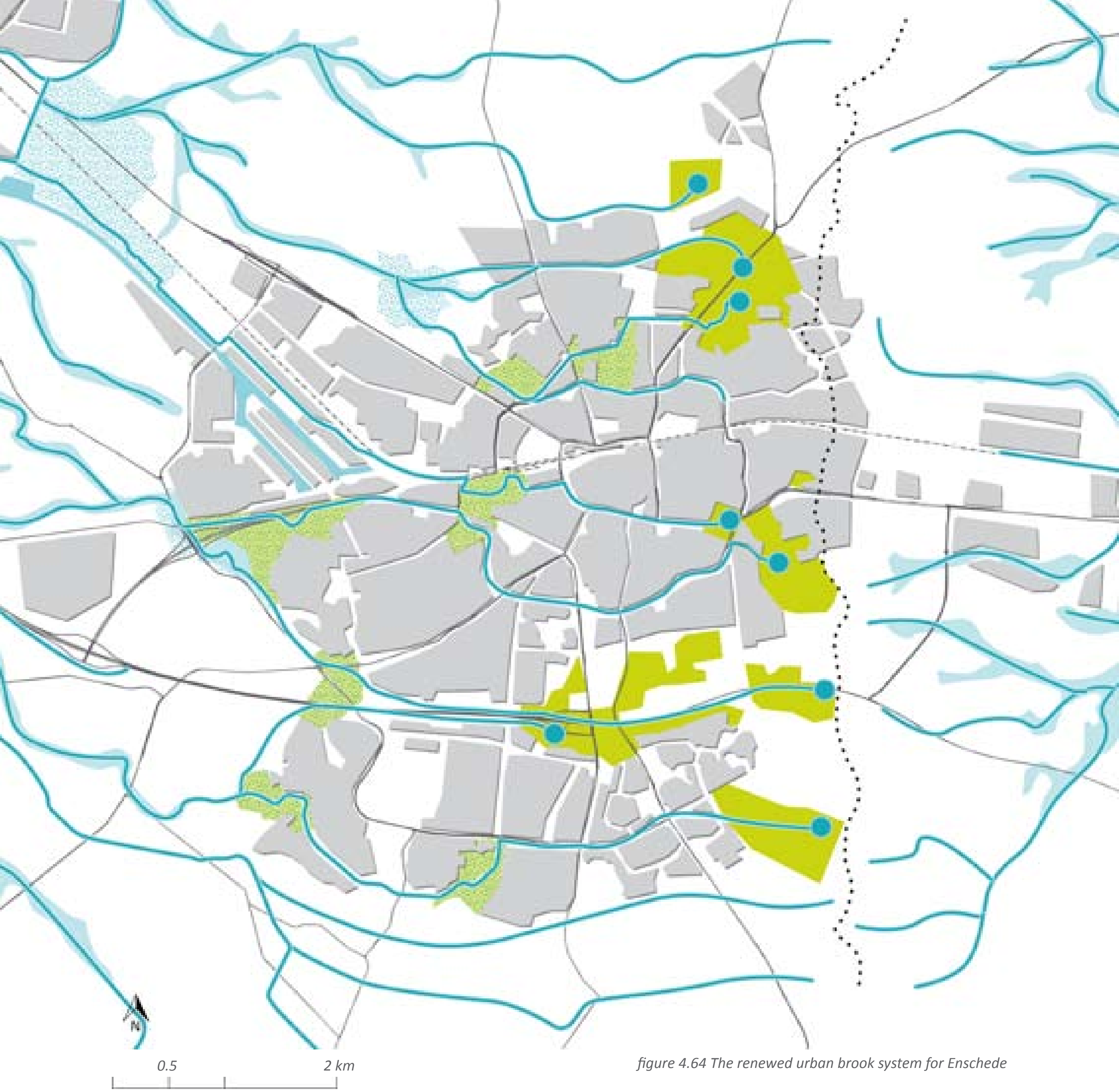


figure 4.64 The renewed urban brook system for Enschede

Upstream retention, brook sources

Downstream retention, water purification

Stream valleys

Brooks

Main water shed

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[5]

GOUDA'S URBAN WATER NETWORK

Gouda is located in the metropolitan area of the 'Randstad' in the province 'Zuid'Holland'. It is the 48th biggest municipality of the Netherlands with 71.167 inhabitants. The total surface area of the municipality is 18.10km² of which 16.86km² is land and the remaining 1.24km² is surface water (CBS, 2009). The city is clammed between the 'Hollandse IJssel' in the south, the 'Gouwe' canal in the west, and the 'Reeuwijkse plassen' in north-eastern direction. The landscape surrounding Gouda can be characterised as a typical Dutch peat landscape; long straight plots, a lot of ditches and high water levels.

5.1 URBAN LANDSCAPE MORPHOLOGY

In time natural and human processes have shaped the urban landscape of Gouda. Initially natural influences made it possible for humans to settle here. People adapted themselves to the natural environment. However, anthropogenic influences on the landscape increased rapidly. The natural environment was modified to human needs, and has eventually led to the urban landscape of Gouda as we know it nowadays. In this section we will discuss the morphology of this landscape.

5.1.1 PLEISTOCENE

sediment deposits

During the Weichselian ice-age a thick layer of sand and gravel was deposited in the area surrounding Gouda. This sediment was brought in via old waterways of the rivers Rhine and Meuse. The layer of sand and gravel lies between 18 and 20 metres below NAP nowadays (Bex, 2010). The peat landscape that characterises Gouda and its surroundings came into existence during the Holocene period.

5.1.2 HOLOCENE

peat growth

During the Holocene, the sea-level started to rise again due to melting of the land-ice. In the zone between the coastal area and the higher parts of the Netherlands a peat layer developed on top of the Pleistocene deposits, in time this layer could become several metres thick (Berendsen, 2005).

Water from the peat landscape was discharged via a system of peat streams, which discharged onto the rivers that flowed through the vast peat landscape. In the area of Gouda, the 'Gouwe' was a peat stream which connected to the 'Hollandse IJssel', which then discharged to the sea. The 'Hollandse IJssel' was a branch of the river Rhine that flowed through the peat landscape. Both the river Rhine, excessive rainfall in the peat landscape and the sea influenced the water level in the 'Hollandse IJssel' (Bade et al., 2009).

Where the sea regularly inundated the areas close to the coastal zone, this was not so often the case in the landscape surrounding Gouda. The peat layer remained intact and is only covered with clay along the banks of the 'Hollandse IJssel' & the 'Gouwe'.

5.1.3 RECENT HISTORY

The period in which people started to exert their influence on the development of the landscape at Gouda started around 1000AD. People started living on the higher riverbanks at the point where the Gouwe connected with the 'Hollandse IJssel' in the middle of a vast, swampy peat landscape. At around 1200AD the Gouwe was connected with the Oude Rijn to improve trade and transportation routes. Consequently, the small peat village rapidly grew and became an important town for shipping and trade between North- and South Holland (Arends, 2007). In this period Gouda became one of the richest cities of the Netherlands. To accommodate the growth of Gouda, land was reclaimed and new polders were created (Bade et al., 2009).

connection between the Oude Rijn and the Gouwe

Initially this area was still situated above sea-level, therefore it was relatively easy to drain these lands naturally. However, due to peat oxidation, which started after draining the lands, the land slowly subsided and 'natural' drainage became difficult due to stagnating water. Thus, artificial drainage was necessary. Sluices were used to discharge water at low-tide into the 'Hollandsche IJssel', and later windmills would pump out the water. Protection against flooding was required as well, resulting in the construction of dikes of which the oldest were built in the 11^{th} century (Hoogheemraadschap van Rijnland, 2006). To further improve the drainage of the city, canals were dug out during the 14^{th} century. Back then, these canals defined the outer edge of the town, while nowadays these canals define the inner city. The canals were also used as sewerage and occasionally sluices were opened to flush the town and refresh water in the canals, this continued to be done until 1950's (Bade et al., 2009).

artificial drainage

canals

figure 5.1 Height map

deep land reclamations

The human draining practices, which lasted for centuries, resulted in most of Gouda being situated 1.5 – 2 metres below sea-level. Furthermore, there are 2 deep land reclamations characterising the surroundings of Gouda: the Middelburg- and Tempelpolder up north which is down to 5,5 metres below sea-level and the Zuidplaspolder west of Gouda which is the lowest point in the Netherlands with 6 – 7 metres below sea-level (AHN, 2011).

advanced drainage system

The continuous subsiding of the soil and the necessity to keep dry feet resulted in polders with an advanced drainage system. The eighty-year war against Spain (1568 – 1646) resulted in further developed of the water- & polder system. More and bigger sluices were constructed to improve the passage of large war-vessels through and around Gouda. One could say that economy, war and necessity shaped Gouda over time (Bade et al., 2009). The close relation with, and dependability on water remained until deep in the 19th century. However, during the 20th century the role of water for both economic and hygienic purposes became less important. As described in chapter 1, during the 20th century people relied more and more on technical inventions such as electric pumps, sewage systems and increased infrastructure. Transport on water became less important and as a result many canals were filled up. Furthermore, the city expanded into the lower and wetter polders which traditionally were not suitable for living. The close relation with water Gouda once had slowly disappeared, and is not visible anymore (Arends, 2007; Bade et al., 2009).

canals filled up

Nevertheless, the surrounding water landscape of Gouda is still characterised by the so called ‘strokenverkaveling’ with long small plots and dense water networks with high water levels.

figure 5.2 historic canal structure (based on: Geudeke et al., 1990)

0.5 2 km

5.2 WATER LANDSCAPE GOUDA

Being situated below sea-level in the peat soils, the landscape of Gouda can be characterised as a water landscape. There is a high dependence on the supply and discharge of water to maintain the fixed water levels. The following section describes both the regional and the urban water system of Gouda.

5.2.1 REGIONAL WATER SYSTEM

Gouda is located along the 'Hollandse IJssel' and the 'Gouwe' canal, both fed by the river Rhine. The main function of these waters is to ensure the water supply and discharge of water for Gouda. A large part of the area controlled by the waterboard Rijnland is discharged via the Hollandse IJssel. The Gouwe is connected to the Hollandse IJssel and is an important link between the hinterland and the Hollandse IJssel (figure 5.3). The Hollandse IJssel is connected with the Nieuwe Maas and the Nieuwe Hollandse Waterweg through which water is discharged to the sea (Gemeente Gouda et al., 2003; Tamboer, 2007).

connection with the hinterland

The connection point of the Gouwe canal with the Hollandse IJssel is important for the waterboard Rijnland as an underwater barrier prevents salt water from intruding further into the hinterland. As fresh water is lighter it floats on the salt water, the barrier then stops the salt water. However as the salt-water pressure increases due to the rising sea-level there is a chance that the barrier will lose its function in the future. Furthermore during dry periods there is an inlet of brackish water (Kolk, 2010).

salt water barrier

The water level of the Hollandse IJssel is influenced by both the tidal working of the sea and by discharges of the river Rhine, and can fluctuate between NAP -0.85 m and +1.90 m. The average low water level is NAP -0.30 m and the high water level is NAP +1.50 m (Waterschap Rijnland, 2010).

During extreme high water levels (>NAP +2.25m) the storm surge barrier at Krimpen aan de IJssel is closed to prevent flooding in Gouda and other cities along the Hollandse IJssel. This storm surge barrier is the first constructed part of the Delta Works. The closure occurs on average 5 à 6 times per year to protect the hinterland. However, there is a disadvantage resulting from closure of the storm surge barrier, as water surpluses in the region cannot be discharged onto the Hollandse IJssel during these periods (Janse and Burgdorffer, 2005). This means that during extreme precipitation during storms, protection against stowing water from the sea might conflict with the discharge water from the hinterland.

storm surge barrier

figure 5.3 Regional water system, water supply is indicated with pink arrows, the discharge directions are indicated in dark blue arrows.

5.2.2 URBAN WATER SYSTEM

The main function of the urban water system is the supply and discharge of water in order to prevent water related problems such as flooding and sewage overflows. In Gouda the urban water system has an extra function, which is to prevent peat oxidation by maintaining a high water level. The functioning of the urban water system will be described in the following paragraphs.

sub -boezem

The water supply mainly comes from the Hollandse IJssel, which together with the Gouwe canal is part of the Rijnlands boezem system. A normal boezem system consists of a boezem level and different polder levels. However, in Gouda there is a sub-boezem, the Stadsboezem, which has an intermediate water level between the polder levels and the main boezem level (Hoogheemraadschap van Rijnland, 2006).

stadsboezem as intermediate step

The 'Stadsboezem' provides water to the polders through the main waterway in the city itself and has a fixed water level of NAP -0.70m. Water is let in from the Gouwe and the Hollandsche IJssel and is diverted into the Stadsboezem, which in turn spreads the water in the deeper polders through a denser system of waterways. If water has to be discharged from the polders during for example rainy periods, water is pumped towards the 'Stadboezem' and from here discharged onto the Hollandsche IJssel. In this system the 'Karnemelksloot' is an important link as it has to process all water that has to be provided or discharged from a large part of Gouda and of all of the Reeuwijkse plassen (Gemeente Gouda et al., 2003).

different polder levels

The water system of Gouda consists of the historic city centre surrounded by eight polders with each a different fixed water level varying between NAP -2.30m and -0.70m. At eleven points water is let in the different polders and at ten pumping stations water is discharged into the boezem system and the Hollandsche IJssel. Water in the polders is mainly transported via the main waterways. Furthermore, smaller sub-waterways can further spread or collect water (Tamboer, 2007). (appendix 4)

Sewage systems are important for the discharge of water for cities. In Gouda, most areas have a mixed sewage system, only the newer parts of the city have a separate sewerage. Gouda however, has another system that is unique in the Netherlands. A large part of the mixed sewage system in Gouda is 'opgeboeid' (figure 5.4). This means the sewerage is permanently filled with wastewater, while in regular sewage systems the water is directly transported to the wastewater treatment plant. This system is a necessity, because houses in Gouda subside along with the soil, which results in breaking connections and leaks in the sewage system. As a results of these leakages the sewage systems works as a drain, transporting groundwater to the wastewater treatment plant. This is unwanted as it both decreases the functionality of the treatment plan and, more important, the groundwater level is lowered. This in turn leads to peat oxidation, rot of wooden foundations, and soil subsidence. Keeping the sewage filled with wastewater prevents these problems.

'opgeboeid' sewage system

leaking sewage system

Once a while the sewage system is flushed with surface water to empty the sewers and refresh the water. A problem of the 'opgeboeid' sewage system is that extreme precipitation cannot be discharged easily, causing overflow of the sewerage. Another problem is a permanent pollution of the soil and groundwater, because the wastewater leaks through the broken connections of the sewerage. Nevertheless, this system functions better than it would if it were not 'opgeboeid', it is the lesser of two evils (Gemeente Gouda et al.; 2003, Tamboer, 2007).

permanent groundwater pollution

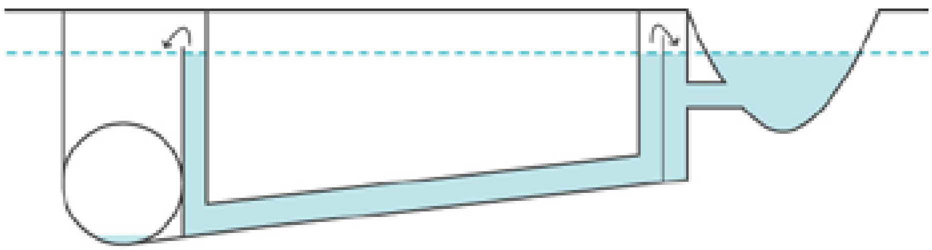


figure 5.4 'Opgeboeid' sewage system which is continuously filled wiht waste water to prevent drainage of the peat soils (based on: Tamboer, 2007)

5.3 GOUDA'S AILING WATER SYSTEM

The water system of the urban water landscape of Gouda is static and technocratic. The whole system is focussed on maintaining fixed water levels, discharging water surpluses as quick as possible, and on reducing damage instead of preventing it. The combination of the static water system in the peaty soils with the disappeared canals, urbanisation, and climate change leads to many problems, which will be discussed in this section.

5.3.1 CONTEMPORARY PROBLEMS

salt water intrusion

Gouda and the surrounding landscape are already facing some serious water related problems. The water level of the Hollandse IJssel is influenced by the North-Sea tides and occasionally salt water intrudes the water system, especially during dry periods when the Rhine discharge is low. At Gouda and in polders along the Hollandse IJssel this can cause problems (Kolk, 2010; Wateren de Hoog and Kruiningen, 2008).

Many farmers in the polders have problems with the intruding salt water. They try to solve this problem by storing fresh water in water tanks in periods of water surplus and use this in dryer periods on their farmlands. The disadvantage of these initiatives is that these water tanks often pollute the water (Kolk, 2010). Furthermore, in cities salt or brackish water can accelerate corrosion, damaging buildings or other structures (Wateren-de Hoog and Kruiningen, 2008).

stability of peat dikes

In the summer of 2003, after a period of extreme drought, there was a dike breakthrough of a peat dike at Wilnis, which illustrates that a dike breakthrough can occur suddenly and unexpectedly in dry periods. In the summer of 2010 several cracks in different peat dikes were found and a dike breakthrough could be prevented. Thus, drought can weaken peat dikes and forms a continuous threat for landscapes surrounded by such dikes as the landscape of Gouda.

A general problem cities built on peaty soils have to deal with, is the struggle with the water levels. If water levels are too high, basements and crawl spaces are flooded, but if water levels are too low, wooden foundation poles start rotting and the peaty soil can oxidise, resulting in soil subsidence. Consequences of the subsiding soil are leaking sewage systems and breaking of water works. Therefore water levels are revised every ten years in the 'peilbesluiten' to suit both the wishes of the inhabitants and to meet the requirements for the functioning of the system, without causing too much damage (Hoogheemraadschap van Rijnland, 2006).

figures 5.5 - 5.13 Contemporary climate related problems in Gouda

fixed water levels

The 'peilbesluiten' in Gouda result in fixed water levels, with little fluctuation possibilities. Therefore during dry periods water has to be supplied. This can cause problems, especially for rural areas, as water is scarce in dry periods and cities always have priority. During wet periods however, water has to be directly discharged to prevent flooding problems in Gouda. Occasionally, during extreme precipitation flooding problems occur, as the water flow in the city is not optimal and the sewage system cannot process the water. There are many culverts in the urban landscape that slow down the water and many waterways are inadequately maintained, resulting in plant growth which slows down the water flow even more and silts up the waterways. The pumping capacity at the pumping stations is sufficient, but the maximum rate of flow determines whether water can be discharged quickly enough or not (Hoogheemraadschap van Rijnland, 2006).

culverts and inadequatly maintained waterways

poor water quality

Furthermore, water quality in Gouda is poor due to the leaking and overflowing sewers. Stormwater runoff and ships pollute the water as well and the inlet of water from the Gouwe and the Hollandse IJssel (which is of relatively poor quality) deteriorates the water quality even further. As a consequence of the poor water quality, ecological values of the water system are negatively influenced. Eutrophication and built up riverbanks worsen this problem (Tamboer, 2007).

seepage

The deep land reclamations surrounding Gouda face another water related problem, as these lay more than 3 metres deeper than the surrounding polders there are problems with seepage. This seepage problem is not only an issue in the land reclamations but also in the surrounding polders as the seepage water is distracted from these polders (AHN, 2011; Groen, 2008).

limited storage possibilites

The last important problem that will be discussed for Gouda is the limited water storage possibilities. During extreme precipitation parts of the city are occasionally flooded. This flooding is the result of many other problems all together; the inadequately functioning sewage system, the silted up waterways which are grown over by plants, the many culverts that slow down the flow of water, and the fixed water levels that make fluctuation impossible (Gemeente Gouda et al., 2003).

5.3.2 CLIMATE CHANGE IN GOUDA

Climate change will influence Gouda's urban landscape. First of all, possible sea-level rise will influence the water levels of the Hollandse IJssel, which will on average be higher. With a sea-level rise of 85cm as predicted in the W+ scenario, the high tide water level of the Hollandse IJssel will be NAP +2.35m by the end of this century. This means the storm surge barrier will have to be closed at least twice a day in a normal situation. Obviously, this is not possible and desirable so other solutions will have to be found for this problem. This will have major influence on the discharge of water surpluses of the region, especially during extreme precipitation or wet periods. An expected increase of discharge of the rivers will influence the water level as well. Though not as much as the sea. A low discharge of 2000m³/s versus a high discharge of 10.000m³/s measured at Lobith changes the water level in the Hollandse IJssel with 30cm (Janse and Burgdorffer, 2005; Kolk, 2010).

Both the KNMI (2006) and the IPCC (2007) agree that extreme precipitation peaks in summer will increase and that the total amount of precipitation in summer will decrease in the KNMI W+ scenario. This means longer periods of drought, with occasionally extreme precipitation. This has consequences for water supplies, but also for discharge when precipitation peaks occur. The summer of 2010 illustrates these problems. For winters the total amount of precipitation will increase. Moreover, the precipitation over longer periods will increase, which will cause discharge problems for rivers as the Rhine. Gouda already faces many challenges related to water surpluses and shortages, but if the climate will change, these problems will only be amplified and new problems will emerge.

5.3.3 FUTURE PROBLEMS

Due to the effects of climate change, it is likely that the contemporary problems Gouda is facing will be amplified, as weather extremes will become more common. But the changing climate will also bring new problems for Gouda in the future.

amplification of contemporary problems

First of all, due to the potential sea-level rise and increase of the peak discharges of rivers, the protection of the water barrier at Krimpen aan de IJssel will not offer sufficient protection for the hinterland anymore, unless it will be closed more frequent. This however is unwanted for two important reasons, first of all it is problematic for transportation over water, and secondly, the discharge of water is not possible if the barrier is closed. When closure of the storm surge barrier occurs simultaneously with a precipitation peak, water cannot be discharged onto the Hollandse IJssel, which has serious consequences for Gouda (Kolk, 2010).

As winters are expected to be wetter and summers are expected to have more extreme precipitation peaks, more water will have to be discharged. With a closed storm surge barrier this is not possible as the pressure on the inner side of the barrier would increase to levels the barrier is not calculated for, risking the barrier to break (Kolk, 2010). Furthermore, due to the fixed water levels storage possibilities on available surface water within the city and in the surrounding landscape is limited as well.

too much pressure on storm surge barrier

On the other hand, periods of (extreme) drought will become more common as well. Water levels will have to be maintained at the fixed level to prevent soil subsidence and rot of wooden foundation poles. This situation already poses problems and will only become worse. Gouda has no fresh water buffer and is dependable on the supply of water from the river Rhine and its branches, just as many other towns and regions. With little rain however, the availability of water in the rivers is minimised as well. This results in the strange situation where the availability of water becomes scarce in one of the wettest regions of the Netherlands.

water shortage

A problem that will make the situation even worse is the soil subsidence. By the end of this century the soil can have subsided with 1 metre and this leads to several problems (Geofoon, 2010). Pressure from sea will increase, resulting in more salt seepage. If the soil is lower this will become even worse (Groen, 2008). Furthermore, the water pressure on the dikes of the peat polders will increase as well. The peat dikes, which can become weak in dry periods, might not even be able to withstand pressure in their current state. Gouda will only become deeper, water around the polders will become higher, and water from above will fall heavier and longer while the storage possibilities disappear. New waterways to climate adaptation have to be found.

soil subsidence

5.4 THE RENEWED WATER SYSTEM

Based on the site-specific challenges and opportunities, renewed waterways to sustainable climate adaptation are found. This section will discuss the concepts, strategies, spatial plans, and the more detailed design solutions, which altogether form a resilient, site-specific, and spatially qualitative water network for the urban landscape of Gouda.

5.4.1 INVERSION AND RETENTION

As discussed previously, Gouda is situated in the low-lying peat area in the western part of the Netherlands where a functional water system is of great importance. Water is pumped out from the polders up onto the Hollandse IJssel and from there eventually into sea, while in dry periods scarce and brackish water is let in to prevent soil-subsidence. There is a paradox in discharging fresh water in wet periods, while it is commonly known that there is water scarcity in the summer periods. Therefore, in a more sustainable water system a buffer should be created to deal with weather extremes; water storage in winters, and fresh water supply for the surrounding landscape in extreme droughts (figure 5.14).

paradox

An interesting feature of the water landscape of Gouda are the land reclamations 'Tempelpolder' and polder Middelburg, which are situated three metres lower than the surrounding landscape and 5.5 metres below NAP. These polders offer opportunities for water retention so that a renewed, reversed, cyclic water system can be created in which the contemporary water system is more or less turned around and in which water is not discharged out of the system, but stored, filtered, and re-used instead.

renewed, reversed, cyclic water system

When working towards designs for such an ambitious concept, several aspects within the water system need to be changed. First of all, both polders north of Gouda (Middleburg- and Tempelpolder) will have to be changed into water retention areas for the whole region in which water is collected, stored, purified, and re-used.

Secondly, in order to collect water from both the surrounding landscape and the urban landscape of Gouda, water networks have to be improved. This means creating more connections, wider canals,and decreasing the amount of culverts and other bottlenecks (such as dense plant growth) which will result in optimal networks for water flow towards the new retention polders.

improved network

However, during extreme precipitation peaks pressure on this network is so high that there is a risk of flooding withing the urban landscape of Gouda.To prevent this flooding a last modification is necessary; where possible within the urban tissue, peaks

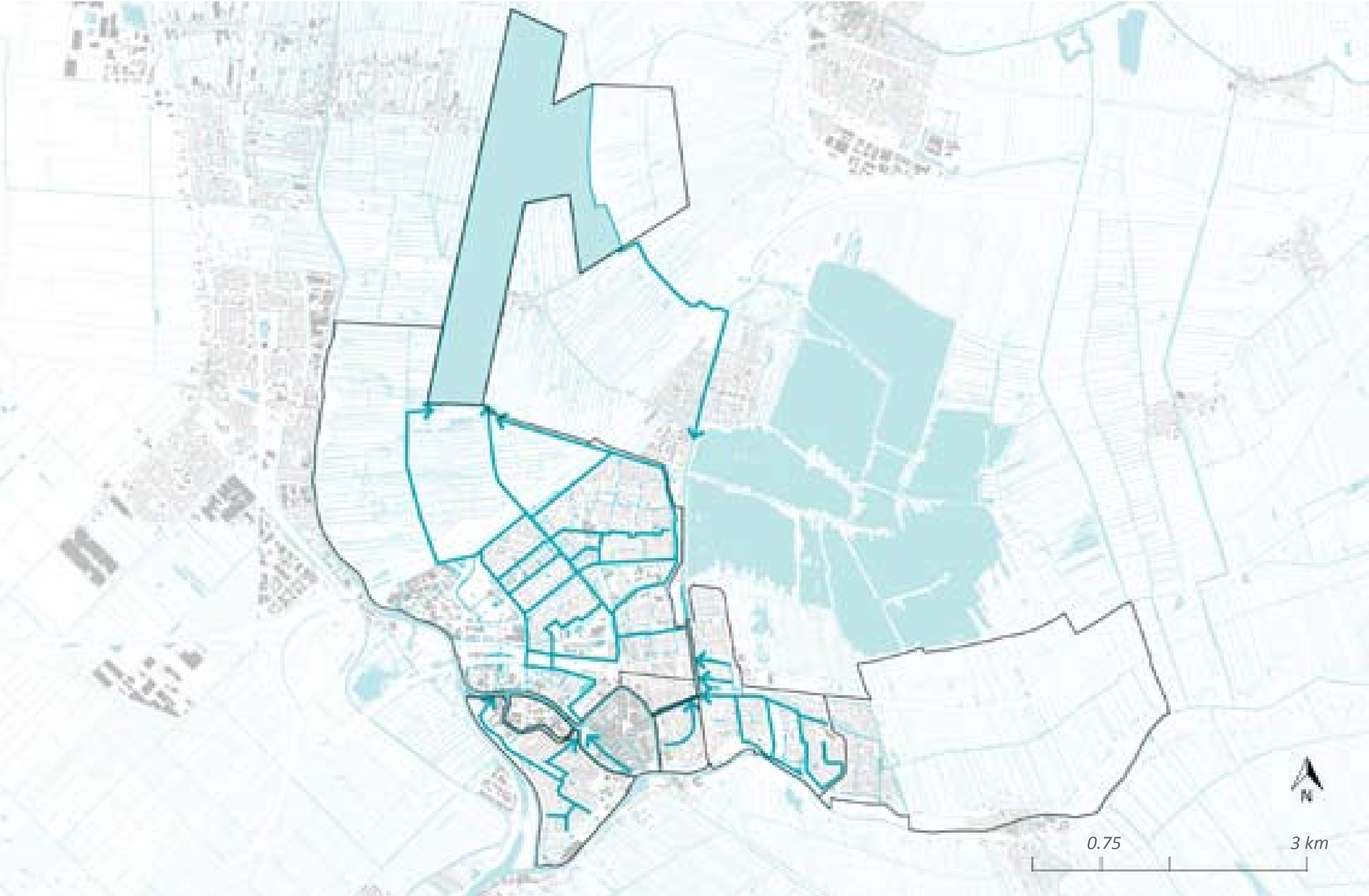


figure 5.14 Renewed, inversed watersystem for Gouda with retention in Middelburg- and Tempelpolder

should be decreased by locally storing rainwater. This is difficult though, as no water can be stored within the soil or on surface water due to the high and fixed water levels. As a solution to this problem water can be stored above ground water level in raised water pressure canals and ponds.

local storage

In the following paragraphs the new retention area in the Middelburg- and Tempelpolder and the renewed waternetwork for Gouda will be discussed.

5.4.2 MIDDELBURG- AND TEMPELPOLDER

The Middelburg- and Tempelpolder have a total surface area of 5.31km² and are situated between Waddinxveen, Boskoop, Bodegraven, and Gouda. The main land use is agrarian with 81% of the area being grassland. One of the main problems in the deep lying polders is brackish seepage which from here spreads into the surrounding polders via the interconnected water networks. As described in the previous section, the region has to deal with many problems related to water quality and quantity. Therefore, a water buffer for the region is desirable. Using the Middelburg- and Tempelpolder as retention area will reduce the brackish seepage, act as water buffer for dry summer periods when the demand for fresh water is high, and in wet periods water surpluses can easily be collected and stored (Groen, 2008; TNO, 2006).

retention area

In order to determine the total storage assignment the total surface area of the surrounding connected polders (55.39km²) should be multiplied with the normative storage assignment

1/100 year rain shower in 48hours, which gives a total storage assignment of 8.474.670m², which equals 3.389 Olympic swimming pools. Although this seems to be a lot, the total area of Middelburg-and Tempelpolder is large and deep enough to store water for the whole region during extreme wet periods (appendix 5).

figure 5.15 Middelburg- and Tempelpolder (Google Earth, 2010)

Within this new water retention and purification area four basins are distinguished which each have a different function related to the filtering of the water. Furthermore, each area represents a phase of the historic polder landscape. In the first basin water from the surrounding landscape is collected and stored (figure 5.16). This water is of low quality, as it carries pollutants washed off the urban soil-surface and nutrients

sedimentation

from the surrounding agrarian landscape. Due to the low flow rates, larger particles can settle. This first basin represents the lakes that could be found in these landscapes. Furthermore, this area is perfectly suited for recreational use such a canoeing, rowing etc.

figure 5.16 First basin: settlement of heavy particles and potential for sailing and rowing

From here the water flows into the second basin in which the water is purified by peat forest vegetation (figure 5.17). In this peat forest landscape fine particles with high concentrations of phosphorus are retained and nutrients are processed by the vegetation (Whigham et al., 1988). At the same time carbon-dioxide is stored, which is not only beneficial for mitigation of climate change, but which can be profitable for farmers as carbon-dioxide storage are be subsidised (Walthie et al., 2007). Furthermore, through this new peat forest polder a route for hikers or cyclers offers recreational opportunities for many people. In wet periods, the water levels will be higher and people can canoe through this area.

purification

figure 5.17 Second basin: first step in filtering and potential for walking and canoeing

The final step in the water purification process is letting water flow through the helophyte filters consisting of reed beds in the third basin (figure 5.18). Common known reed, the 'Phragmites' plant, "improves the microbial conditions in its rhizosphere under which nutrients can be immobilized or eliminated from the plant/soil-system and an organic load can be decomposed" (Ostendorp, 1993, p.152). From here fresh purified water can flow to the fourth basin.

helophyte filtering

In the last basin the fresh water can be stored until it is required in dryer periods in for example the Reeuwijkse plassen, the city of Gouda, or other areas in the surrounding landscape that have to maintain the fixed water levels or require fresh water for their ecosystems (figure 5.19).

water storage

figure 5.18 Third basin: helophyte filtering and potential for walking and birding

figure 5.19 Fourth basin: water retention and potential for walking

recreational landscape

Thus, the plan for the Middelburg- and Tempelpolder results in a new functional recreational landscape where people can walk, cycle, and row, in which at the same time water can be stored, purified, and re-used (figure 5.20). The farmers who currently own the land can be subsidised for carbon-dioxide storage, maintenance of the new retention area, or start business in the recreational sector. Another possible function of such a settlement lake is floating glasshouses. In this way the economic function of the area can be sustained.

However, before the water from the urban landscape of Gouda reaches the new retention area, it has to be collected and transported through the city. The strategies for the renewed water system within the urban landscape will be discussed in the next paragraph.

5.4.3 THE WATERWAY TO CLIMATE ADAPTATION FOR GOUDA

optimise water flow

To collect and transport water within the urban landscape of Gouda, the water networks have to be improved and densified to optimise the water flow towards the Middelburg- and Tempelpolder. For the new network this means more connections and wider canals have to be realised and culverts or other bottlenecks should be removed or replaced by bridges.

representative example

To test whether it is possible to renew the water network of Gouda and to test how such a renewed network works, more detailed research and design is necessary. To make sure that the part of the network that is further researched is representative for Gouda the example is chosen in such a way that different urban densities are represented and that there are open spaces that offer opportunities for densification of the network. For a more elaborate explanation of the choice for this example see appendix 6.

8 typologies

Based upon urban density and open space within the urban tissue 8 typologies can be distinguished which are further researched (figure 5.21 and table 5.1). Within the city centre a new canal is created (1) with a potential for waterstorage above groundlevel. From the new canal the water flows to a deeper polder, through a residential area (2) towards the Van Bergen IJzendoornpark (3) which is connected to the renewed discharge network. From the park the network continues (4) towards the railway-embankment (5) which forms a major obstruction in the network between the northern and the southern part of the city. From here the network continues through large scale residential areas (6 and 7) where there is potential for water storage above groundwater level to end up along the Bloemendaaseweg (8) which is the main connection toward the Middelburg- and Tempelpolder.

In the following section, the typologies 1, 3, 5, 7 and 8 will be more elaborately discussed while the solutions for the remaining typologies 2, 4 and 6 will be briefly mentioned.

table 5.1 Representativity and typologies for the renewed water network

Urban density	medium			high				very high
Open space		(green)			(green)		(green)	
Function	discharge and storage of peak precipitation							
Typology	8	7	6	5	4	3	2	1

figure 5.21 Representativity and typologies for the renewed water network

character of network

The character of the new discharge network is based upon the original polder structure and vegetation (figure 5.22). As the network is densified, the amount of water in Gouda increases. Furthermore, existing canals are widened making water visually more present in the city. To even further accentuate the water network, the banks of the canals are planted with flower rich peat vegetation. To optimise the water flow many culverts and other bottlenecks are removed and replaced with bridges.

The high water levels in Gouda make water storage in ponds, swales, and many other contemporary methods impossible. However, for the network to be functional, extreme precipitation peaks need to be stored. The previously mentioned water storage above groundwater level offers opportunities for both storing more water in existing canals and for the creation of raised water pressure ponds. These retention ponds can be connected to the discharge network by means of special gutters which can also transport street water to the discharge network.

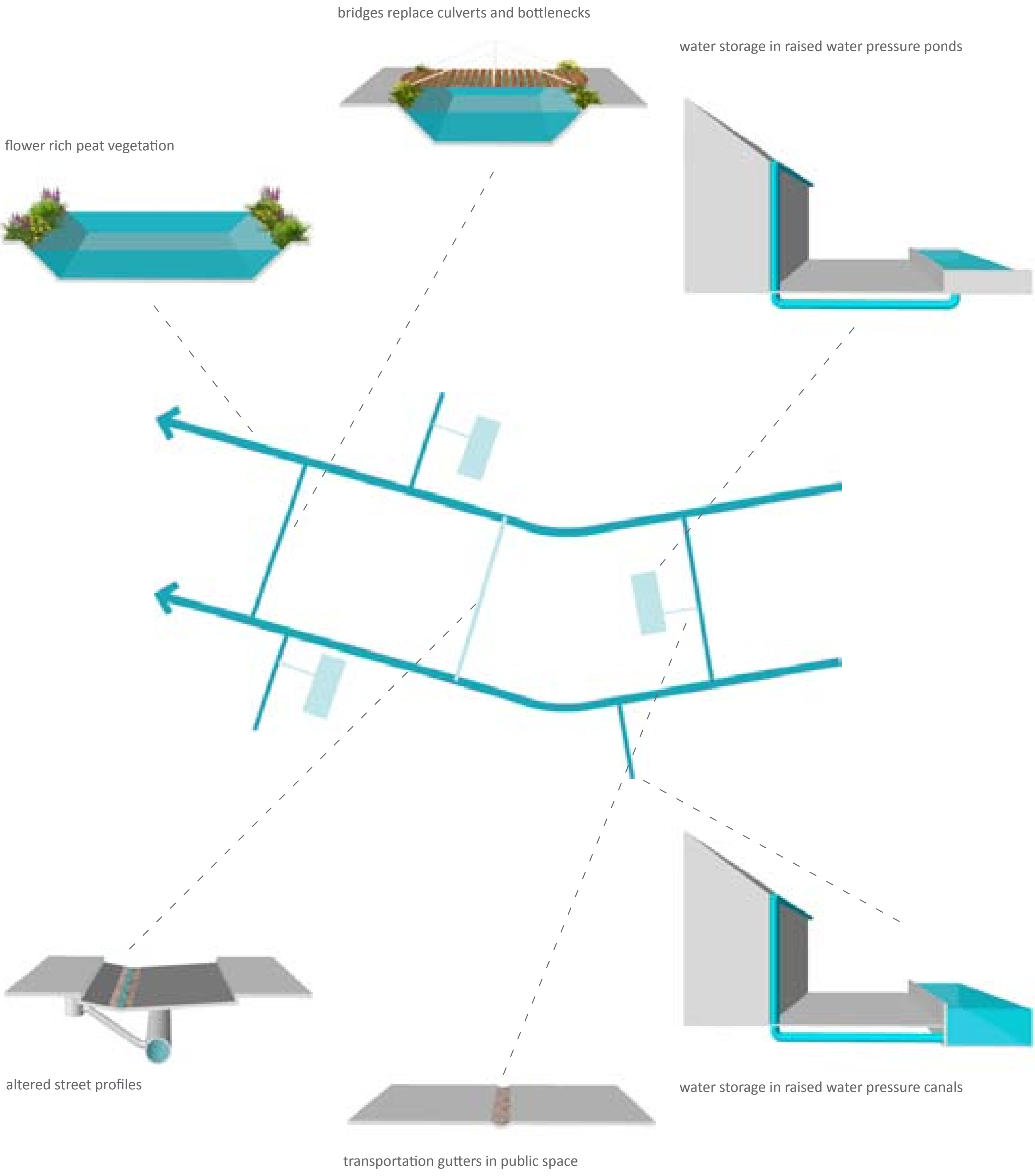
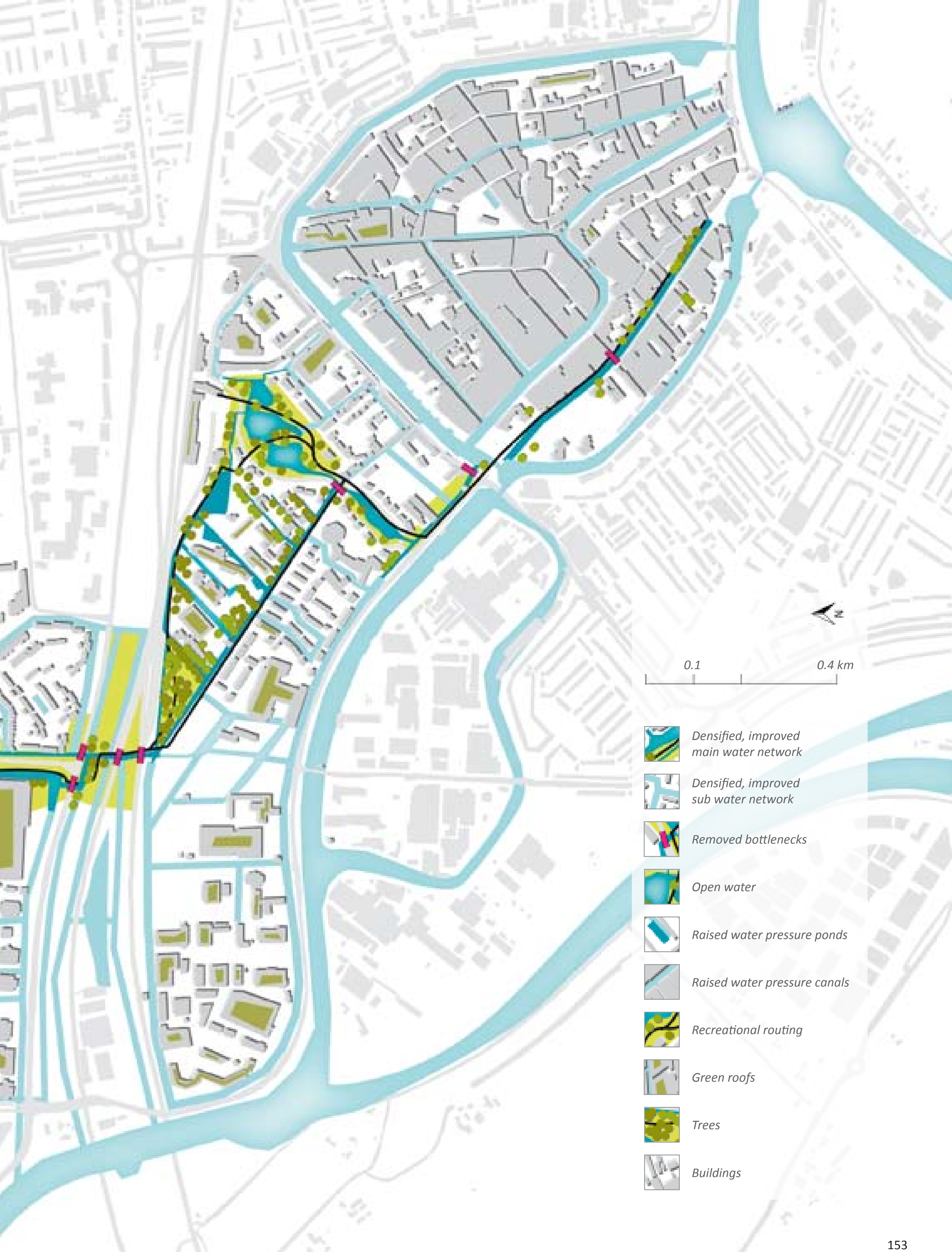


figure 5.22 Character of a renewed discharge network based upon the existing polder structure. Different retention possibilities and different orders of discharge canals



0.1
0.4 km
Densified, improved main water network
Densified, improved sub water network
Removed bottlenecks
Open water
Raised water pressure ponds
Raised water pressure canals
Recreational routing
Green roofs
Trees
Buildings

5.5 DETAILED DESIGNS

This section will briefly discuss the more detailed designs of typologies 1-8 (table 5.1) for the renewed water network of Gouda. Location and character of the different typologies will be described, partly based on the analysis as found in appendix 6. Furthermore, based upon the existing water network and open spaces, opportunities for densification of the network are sought and new connections are made.

design principles

Where possible, the specific above groundlevel storage assignments are calculated based on an 1/100 year 2hour normative rain shower to decrease the peak discharges, The 2hour normative rains shower is used as these rainshowers put extreme high pressure on the new discharge network. This all results in design principles which are explained by means of photoshop collages and birdseye views.

5.5.1 RAAM AND CITY CENTRE

free flow towards lower polders

The city centre forms the highest part of Gouda but is still located 0.70 metres below NAP. Within the plan for the renewed water network for Gouda the city centre is the first link from where the water can freely flow towards the surrounding lower lying polders.

limited available space

The urban density in the city centre is very high which makes that open space is scarce. The existing water structure consist of the 'stadboezem' surrounding the centre and some canals that flow through the city centre (figure 5.24). The amount of open water is minimal, especially when compared to the historic canal structure (figure 5.25).

figure 5.24 Existing water structure

figure 5.25 Historic canal structure (based on: Arends, 2007)

figure 5.26 Raam (dark blue) and the surrounding city centre (based on: Google Eart, 2010)

figure 5.27 Double parking row in the street profile of Raam (photograph by authors)

As the city centre consists of many historic buildings on wooden poles, there is an high water level to prevent the poles from rotting. Furthermore fluctuation of the water level is minimised which altogether put a very high pressure on the 'opgeboeide' sewage system, which is already at its limits.

The limitation of available open space makes it difficult to create new waterways that can decrease pressure on the sewage system, but there are some possibilities based upon the historic canal structure (figure 5.28). However, to re-create some of the historic canals some concessions have to be made, street profiles have to be altered and the amount of parking lots will decrease.

re-creation of historic canals

figure 5.28 Potential retention areas

figure 5.29 Bottlenecks within the existing water structure

One of the places with the highest potential for re-creating a historic canal is Raam. This street consists of two driving ways separated by a double row of parking lots (figure 5.26). By altering the street profile and removing half of the parking lots, space becomes available to create a raised water pressure canal (figure 5.30), in which water from the surrounding roofs can be stored during precipitation peaks thought a system of connected vessels (figure 5.31).

raised water pressure canal

The roof surface of the houses surrounding Raam is approximately 20.000 m^2 which results in a storage assignment of 1580 m^3 for 2h precipitation peaks, which can be easily met with a potential water level rise of 75 cm within the new canal (figure 5.32).

visibility of climate dynamics

By creating new canals in Gouda, the cities' rich history with, and the dynamics of, water become visible and experiential again as is illustrated in figures x and x. Water levels fluctuate depending on the amount of rainfall and during periods of drought, the water levels can even drop to NAP -0.70 m, which is the fixed water level accounted for the city centre. Furthermore new uses can be assigned to the above groundlevel canals as is illustrated in figures 5.33 and 5.34.

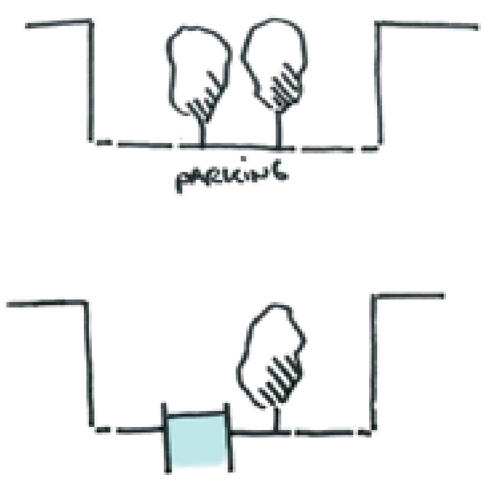


figure 5.30 Altered profile of Raam

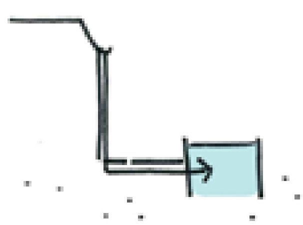


figure 5.31 Storage of rooftop water via connected vessels

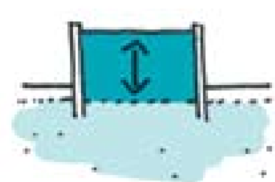


figure 5.32 Potential water level rise is 75 cm, minimal water level is -70 cm NAP

Apart from potential for reconstruction of canals, there are also some bottlenecks within the water structure of the city centre (figure 5.29). Problems occur as all inlet and discharge water for Gouda and the Reeuwijkse plassen is transported through the narrow canals connected to the 'stadsboezem'. Widening the canals is not possible as they are located within the densely built-up city centre. However, the inversion of the network and the retention in Middelburg- and Tempelpolder already decreases pressure on the bottlenecks as there is no or little discharge towards the Hollandse IJssel. The inlet of water is decreased as well, as large amounts of water can be re-used from Middelburg- and Tempelpolder.

figure 5.33 New canal in the profile of Raam; water becomes visible and experiential

figure 5.34 New canal in the profile of Raam; new atmosphere and new uses

5.5.2 VAN BERGEN IJZENDOORNPARK AND RAILWAY CROSSING

The Van Bergen IJzendoornpark, the surrounding residential areas, and the railway-crossing are located in one of the lower lying polders surrounding the city centre. Water from the city centre can freely flow towards this area and no pumping is required (see appendix 4).

Although the urban density is high, there is a substantial amount of open spaces (figure 5.37) which have potential for densification of the existing water structure (figure 5.38). A first opportunity for the densification lies in the Van Bergen IJzendoorn park (figure 5.36), which contains a large body of water. However, the only connections with the surrounding water structure are by means of narrow culverts. Thus, the connections to

densification of water network

figure 5.35 Van Bergen IJzendoorn park (dark blue) the surrounding area and railway crossing (light blue) (based on: Google Earth, 2010)

figure 5.36 The Van Bergen IJzendoornpark (www.panoramio.com, photograph by archengigi)

figure 5.37 Open space

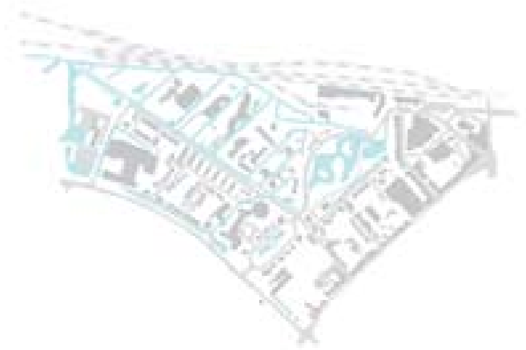


figure 5.38 Existing water structure

connection with surrounding water sturctures

the surrounding water structures are minimal and the park is not yet part of the larger water network as proposed for Gouda. By replacing these bottlenecks (figure 5.42) with bridges and creating new connections (figure 5.39) with the surrounding water structure the discharge capacity of the network is increased.

site-specific atmosphere

Furthermore, the banks of the canals and waterbodies are planted with helophyte and flower rich peat vegetation to clean the water and to accentuate that the area is part of the renewed water structure. The proposed interventions show that with minimal effort, existing water structures are connected, the water system becomes more solid, and more site-specific atmospheres are created (figure 5.43 and 5.44).

Not only is the Van Bergen IJzendoornpark connected to the surrounding water structure, but also in the area surrounding the park the water structure is densified to create a rigid urban water network as is shown in figure 5.45.

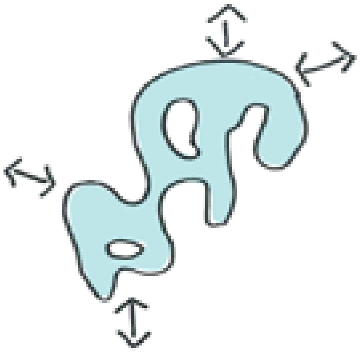


figure 5.39 Improved connections with the surrounding water structure

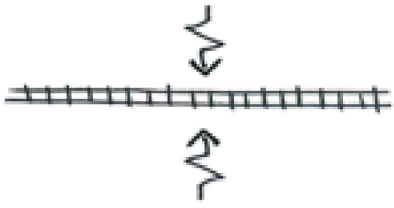


figure 5.40 Raiway embankment as a barrier between the north-south connection

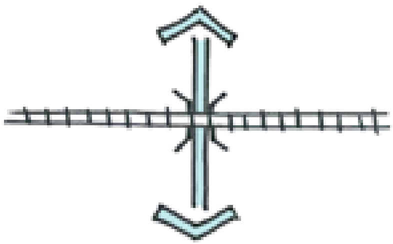


figure 5.41 New connection between north and south

figure 5.42 Bottlenecks withing the existing water structure

A major obstruction in this water network is the double railway embankment between the northern and southern part of Gouda (figure 5.40). For the new water network to be functional, connections between the northern and the southern part of the city have to be made (figure 5.41). Figure 5.45 shows an example of how such connections can be realised. Not only are the obstructions removed, but at the same time a hidden part of the city is rediscovered. In between the two railway embankments there is a small peat forest which offers opportunities for extensive recreational use such as walking and fishing.

north-south connection

figure 5.43 New connections and site-specific vegetation in the Van Bergen IJzendoornpark

figure 5.44 Van Bergen IJzendoornpark as part of the renewed water network

figure 5.45 Improved water network and a new connection between the northern and southern part of Gouda

5.5.3 RESIDENTIAL AREA

When sufficient connections between the northern and southern part of Gouda are realised, water can freely flow from the southern part of the city with high polder levels, towards the northern part of the city where polder levels are lower.

densification in open space

The urban density is medium with an alternation of residential and industrial areas. Within the urban tissue there is open space (figure 5.48) with potential for densification of the existing water structure (figure 5.49) which is necessary as the amount of water to be transported through the area is substantial. Apart from the densification of the water structure, there are bottlenecks that need to be removed for the new water network to function, as is illustrated in figure 5.50.

figure 5.46 Residential area in the northern part of Gouda (based on: Google Earth, 2010)

figure 5.47 Poor quality of existing public space (photograph by authors)

figure 5.48 Open space

figure 5.49 Existing water structure

figure 5.50 Bottlenecks within the existing water structure

figure 5.51 Potential water retention areas

To remove the bottlenecks, the larger existing canals are connected (figure 5.52), culverts are removed (figure 5.53), and existing waterways are widened (figure 5.54) in order to increase the volume of water that can be discharged towards Middelburg- and Tempelpolder. This especially happens in the open spaces within the urban tissue as the open spaces offer opportunities to create water structures of size.

water structures of size

Apart from the larger bottlenecks indicated in figure 5.50, there are many small culverts and bottleneck that should be removed as well. However, as the location of these bottlenecks is not exactly known, and these will not be problematic for the new network to function, we will not elaborate on these smaller bottlenecks.

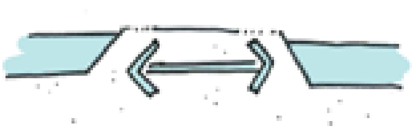


figure 5.52 Improved connections with the surrounding water structure

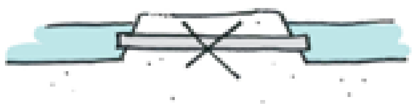


figure 5.53 Raiway embankment as a barrier between the North-South connection

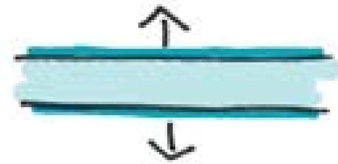


figure 5.54 Widened waterways

poor quality of public space

To decrease the pressure on the renewed water network, especially during periods of extreme precipitation, water should be stored where possible. Within the residential area with a stamp-like layout, there are many opportunities for local water storage (figure 5.51). Within the stamps currently there are open spaces which add little value to the public space; paved surface and low quality vegetation (figure 5.47).

raised water pressure ponds

These areas are transformed into raised water pressure ponds in which water from the surrounding roof surfaces is stored during periods of rainfall (figure 5.55). Calculations show that a potential water level rise of 75 cm within the new ponds is sufficient to store 2h precipitation peaks from the surrounding roof surfaces. In dry periods, the stored water is slowly discharged via gutters within the public space towards the new water network from where it is further discharged towards the Middelburg- and Tempelpolder.

different functions

The creation of raised water pressure ponds offers potential for increasing the spatial quality of the surrounding residential areas. Different functions can be assigned to the ponds; from soccer fields to playgrounds, and from floating gardens to water worlds offering new playing opportunities for children and giving new atmospheres to the residential areas (figure 5.56). All ponds have in common that they fill up with water in periods of rainfall as is illustrated in figures 5.57 and 5.58.

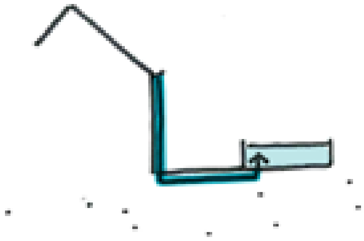


figure 5.55 Raised water pressure ponds

figure 5.56 Raised water pressure ponds not only store water but also increase spatial quality and offer new playing opportunities for children

figure 5.57 New water network as a park structure within the residential area 'Bloemendaal' with the raised water pressure ponds connected to the network

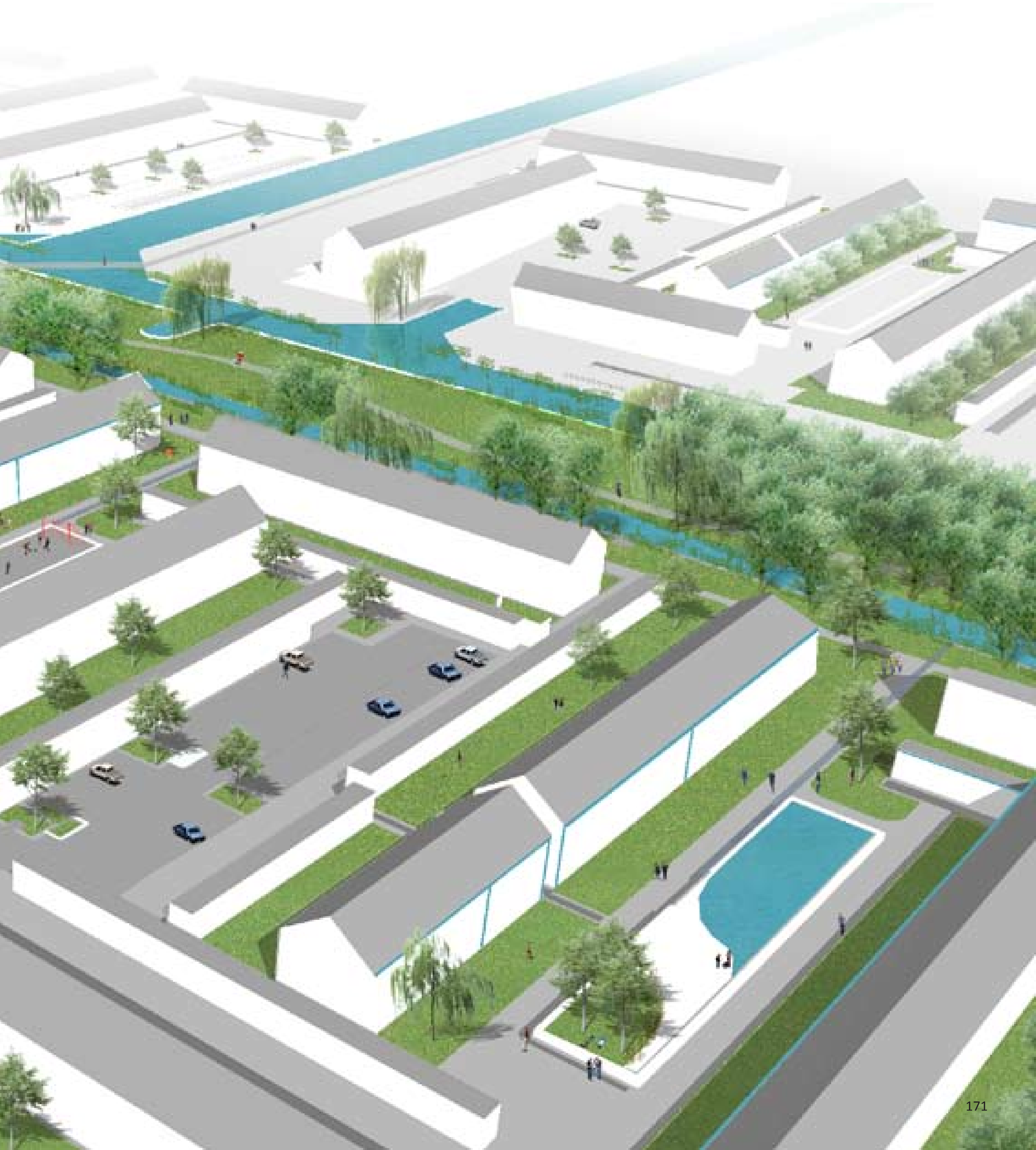


figure 5.58 Climate dynamics become visible when the raised water pressure ponds fill up during periods of rainfall

5.5.4 BLOEMENDAALSEWEG

main discharge canal

The Bloemendaalseweg plays an important role within the new discharge network for Gouda because it is one of the main connections between the city and the Middelburg- and Tempelpolder. Water from large parts of the city has to be discharged through canals on both sides of the Bloemendaalseweg.

relicts of original landscape

The Bloemendaalseweg and the houses on both sides of the road are relicts from the original polder landscape. The original and dense water structure still exists in the area, as is indicated in figure 5.63. The urban density in the area is very low which makes that there is a lot of open space surrounding the Bloemendaalseweg (figure 5.63).

figure 5.59 Bloemendaalseweg as a connection to the Middleburg- and Tempelpolder (dark blue) (based on: Google Earth, 2010)

figure 5.60 Contemporary profile of the Bloemendaalseweg (Google streetview)

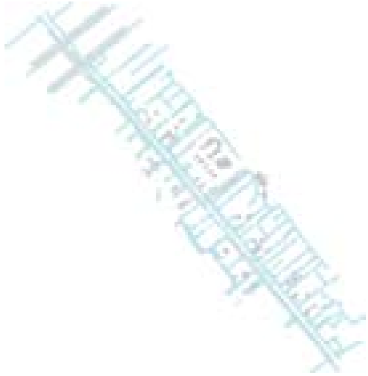


figure 5.61 Existing water structure

figure 5.62 Open space

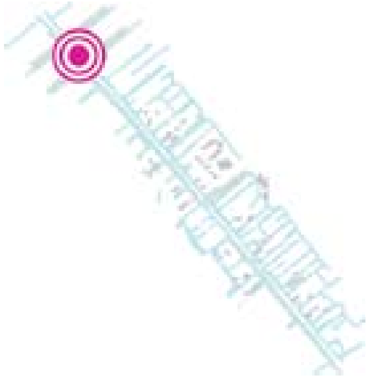


figure 5.63 Major bottleneck at the crossing with the A12 highway

upgrading existing waterways

The existing dense water structure and the ample open space offer chances for upgrading the existing waterways to the sizes that meet the discharge assignment. To realise these goals, culverts need to be removed as well as the span of most bridges in the area of the Bloemendaalseweg needs to be increased (figure 5.65). Most bridgeheads stand 'in' the water which narrows down the profile of the existing waterways and decreases the potential discharge (figure 5.64).

major bottleneck

Apart from the small bottlenecks described above, there is a major bottleneck at the crossing of the discharge canals with the A12 highway. The A12 consists of separated drive lanes on large embankments where the Bloemendaalseweg crosses underneath (figure 5.59). The north-western crossing is wide and works fine, however the south-eastern crossing is very narrow.

The narrow crossing turns out to be problematic as in the contemporary situation the canals are narrowed down to half their size while the canals have to increase in size for the new waternetwork to function. Therefore, the south-eastern crossing with the A12 is widened so that the size of both discharge canals can be increased (figure 5.67 & 5.68).

window towards the landscape

The Bloemendaalseweg is an important recreational route towards the polders surrounding Gouda. When the Middelburg- and Tempelpolder are transformed into a new recreational area the importance of the route will only increase. By widening the A12 crossing a window towards the surrounding polder is created which enhances the attractiveness of the route and connects Gouda with the surrounding landscape.

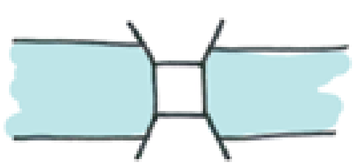


figure 5.64 Contemporary bridges

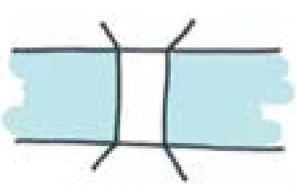


figure 5.65 Increased span widht of bridges

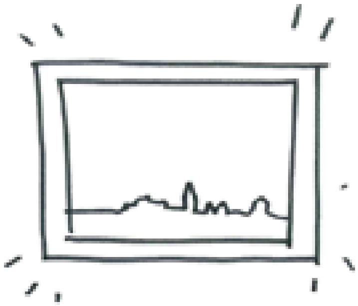


figure 5.66 A12 crossing as a window to the surrounding landscape

5.67 Bloemendaalseweg as discharge canal and recreational connection to the Middelburg- and Tempelpolder

figure 5.68 A12 crossing as window towards the polders surrounding Gouda

5.6 CLIMATE ADAPTIVE GOUDA

On the basis of the research and design of representative parts of the new water network we draw the following conclusion: Within the urban landscape of Gouda there is potential for the creation of a renewed and intensified water network. Landscape characteristics are used to create an inversed cyclic network that flows from the polders with the highest water levels via the connected polders towards the deeper Middelburg- and Tempelpolder, where water is filtered and stored for possible later use. This way the total amount of required pumping is decreased and the original water system is reversed.

Calculations show that a 48-h precipitation peak can easily be stored in Middelburg- and Tempelpolder, however to decrease peak discharges on the renewed water network, water is temporarily stored in raised water pressure ponds and canals. Thereby peak discharges are decreased, climate dynamics become visible again, and pressure on the sewage system is decreased. Rainwater discharge is brought back to the surface thereby making it experiential. Simultaniously, the design interventions aim at increasing the quality of public space.

increasing public awareness

The renewed water network for Gouda, with the large retention area in the surrounding landscape combined with peak precipitation storage in raised water pressure ponds and canals, can cope with predicted future precipitation extremes. The stored and filtered water from Middelburg- and Tempelpolder can be used in periods of drought to supply the city and the surrounding areas with clean, fresh water. Thereby reducing the dependency on discharge from the Hollandse IJssel for fresh water supplies, and preventing the inlet of brackish water during periods of drought.

As is shown by the detailed designs for Gouda, the water structure in the city can be transformed into a flexible, intesive water network. The detailed designs are chosen in such a way that they are representative for Gouda, thus it is likely that the transformation of the water structure can be applied to the whole urban structure.

rigid water network

Transformation of the contemporary water structure of Gouda into a cyclic water network combined with water storage in Middelburg- and Tempelpolder and inversion of the discharge direction results in a climate adaptive waterway for Gouda as is illustrated in figure 5.67.

0.5 2 km

figure 5.67 The renewed, cyclic water network for Gouda (1:50.000)

Improved water network

Densified water network

Water storage in Middelburg- and Tempelpolder

Reeuwijkse plassen

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RESULTS

This thesis started with a focus on climate change in the Netherlands. Especially the urban context seemed interesting which resulted in research and design on Enschede and Gouda. Different cities in different landscapes on which the landscape based design approach to climate adaptation in the urban context is tested. Both the results of the research and design process and the applicability and concequences for other Dutch cities are discussed in this chapter

6.1 DIFFERENCES AND SIMILARITIES

In this thesis the importance of site-specificity, in both solutions and problems, is often mentioned. However, after thorough research and design on two case studies we see some similarities in the site-specific strategies as well. The proposed design solutions for both case studies are based upon the well known three-staged strategy; store, retain, and discharge (Unie van Waterschappen, 2002), however the strategy is used in a different manner. In this section we will briefly discuss the similarities and differences between the strategies, concepts, and design solutions of the two case studies.

similarities

The problem analysis for both case studies already shows quite some similarities. In wet periods water is quickly discharged via the urban water system, which in both cases consists of an inadequately functioning sewage systems resulting in sewage overflows and flooding. While in dry periods water is scarce, leading to water shortage

A landscape-based design approach to the ailing urban water systems in Gouda and Enschede has resulted in site-specific climate adaptive solutions; a renewed brook system on the sloping moraine in Enschede and a cyclic water network in the peat landscape of Gouda. But when we compare the renewed brook system with the cyclic water network, some similarities can be seen.

Within the cyclic water network of Gouda there is no, or only little, discharge on the regional scale, as the system is based on retention of water for re-use in later periods. On a smaller scale level however, there is discharge from within the city towards the Middelburg- and Tempelpolder. To decrease the pressure on the water network, precipitation peaks are stored in raised water pressure ponds and canals. Thus, for Gouda the main strategy is to locally store water where possible, and then discharge it from the urban tissue via the improved and densified water networks towards the retention area, where the water is purified and stored for later use.

In the strategy for the renewed brook system for Enschede water is captured and stored locally within residential areas and in larger open spaces in the upstream areas at the source of the brooks. From here water is slowly discharged via the brooks towards retention ponds in the downstream area of the city. In the retention areas runoff water is purified after which it flows into the surrounding landscape.

local storage, slow discharge

In both cities the strategy is to store water on a local scale level, slowly discharge it within the renewed water system, and finally purify and retain the water, after which it can be re-used. With this strategy the buffering capacity of the local landscape increases and the dependency on surrounding landscapes decreases. Thus, problems are solved locally without placing a burden on the landscape.

Apart from the similarities in the main strategies, there are major landscape-based differences in the concepts for the two case cities which are determined by relief, soil, and hydrology, but also by urban characteristics such as urban density, available open spaces, and city structure determine.

landscape-based differences

The concept of a renewed brook system which works for Enschede, would not work for Gouda due to the high fixed water levels, minimal height differences, and less open spaces. The same accounts vice versa. In Enschede, the creation of an interconnected cyclic water system is impossible, due to low groundwater levels and the height differences which rules out the concept of a cyclic system.

The most important difference between the two concepts is the relation with the surrounding and underlying landscape. The cyclic water system for Gouda actively seeks connection and interaction with the surrounding landscape, by means of water retention in the Middelburg- and Tempelpolder. In Enschede however, the connection with the surrounding landscape is reactive, as problems are solved within the urban tissue to decrease pressure on the surrounding landscape and downstream cities.

active connection

reactive connection

6.2 SIGNIFICANCE OF RESEARCH AND DESIGN

A renewed brook systems in sand landscapes

location of cities in sand landscapes

A generalised conclusion resulting from the desk study described in chapter 3, is that sandy soils in the Netherlands increasingly have to deal with drought related problems, due to dropping groundwater levels (Directoraat-Generaal Water, 2009; Planbureau voor de Leefomgeving, 2009). Furthermore, quite some cities in the sand landscapes are located on the transition zones between the higher and lower parts of the Netherlands, where litte brooks join before they flow into the greater rivers. On these transition zones water accumulates resulting in flooding risks (Directoraat-Generaal Water, 2009).

applicability of renewed brook concept

Basically, the problems in cities in sand landscapes are caused by the replacement of natural (dynamic) water systems by static technocratic systems. Brooks have disappeared or are canalised, permeable soil surfaces are sealed due to urbanisation, and sewers discharge rainwater out of the system. This results in reduced buffering capacity of the landscape, in which flooding occurs in wet periods, while in dry periods drought related problems are more common. The proposed plan for a renewed brook system in Enschede deals with these issues and increases the buffering capacity of the landscape. It is likely that similar problems occur in comparable urban landscapes. Therefore, we expect that the main strategies and concepts for Enschede are applicable in comparable cities.

unique landscape characteristics

Nevertheless, the landscape in Enschede is quite unique within the Netherlands. The location on a moraine and the height difference of 30m between the highest and lowest point of the city are special and site-specific features in the landscape (AHN, 2011). Furthermore, boulder clay lenses are found in the subsoil of Enschede on which water stagnates. In hintersight, these site-specific features make that Enschede may not havebeen the best case study for climate adaptation in cities on sand landscapes. But, on the other hand, each and every (urban) landscape has some unique site-specific properties, which ought to be researched and designed when adapting the site to climate change. The strength of the landscape-based design approach lies within the recognition of the site-specificity.

A cyclic water network in peat landscapes

In general, it can be stated that in the Netherlands water is becoming increasingly scarce due to hotter and dryer summers, while in wet periods water is pumped out onto sea (Klein Tank and Lenderink, 2009). This has consequences for cities within peat landscapes, where two common problems can be distinguished; soil subsidence (peat oxidation) due to water shortages in dry periods, and flooding in wet periods due to high and fixed water levels and inadequately functioning urban water systems (Antheunisse et al., 2008). Therefore, solutions as proposed for the urban landscape of Gouda, in which bottlenecks in the water network are removed and where water is stored for later use in a deeper polder, might be useful for other cities in similar landscapes. Most cities in the peat landscape are located (relatively) close to deeper land reclamations for potential water retention. However, the feasibility of these polders for water storage differs based upon land use.

common problems in peat landscapes

applicability of renewed water networks

The relatively small, deep, and extensively used polder with few inhabitants situated near Gouda offers rather unique opportunities and one might question how representative this case city is for other cities within peat landscapes. However, as mentioned previously, each urban landscape is unique with site-specific problems and opportunities and for each and every city site-specific research ought to be carried out. Nevertheless, the design solutions resulting from the landscape-based design approach in the urban landscape of Gouda can be inspirational in similar cases.

unique site-specific opportunities

Thus, the case study of Gouda is representative to a feasible extent. The urban layout and the connections to the surrounding landscape differ per city, but generally speaking the solutions proposed for Gouda can be applied to other cities located in low-lying peat landscapes.

Climate adaptation and primary safety

As the title of this thesis already suggests, the focus of this research is on adapting (ailing) urban water systems to climate change from a landscape-based perspective. The problems dealt with are related to water and focus on increased or decreased precipitation. Initially the research and design in this thesis focussed on three case cities: Enschede, Gouda, and Dordrecht. However, by research and design on Dordrecht it became apparent that in the city of Dordrecht the primary safety related to river discharge and sea-level rise is an issue as well. These primary safety issues pose whole new challenges for adapting urban water systems to climate change which we were not able to deal with within the time span of this thesis.

primary safety poses new challenges

Both problems and type of solutions vary between primarily safety issues and healing of urban water systems in the perspective of a changing climate. We expect that these two aspects can be combined into sustainable, integrally functioning, and climate adaptive urban landscapes. However, the difference with proposed strategies for Enschede and Gouda is that in Dordrecht the primary safety issues have to be solved at first before the urban water system can be transformed into a sustainable waterway.

different problems and solutions

In order to acquire a more complete knowledge base on the whole range of climate adaptation possibilities in Dutch urban landscapes, research should be carried out on coastal and riverine cities, as well as on other landscape types. The landscape-climate research (chapter 4) and the two case-studies (chapter 5 and 6) in this thesis form a starting point for further research and design on climate adaptation in Dutch cities.

Potential for climate adaptation on the national scale

As became clear in the previous paragraph, both the solutions for Enschede and Gouda are based upon the store, retain and discharge strategy. However the way the strategy is implemented differs based upon site-specific landscape characteristics. Furthermore it became clear that the choice for Enschede and Gouda as case cities might not have been the best one possible but still some generalised conclusions can be drawn about the use of a landscape based design approach on the national scale.

positive influence on surrounding landscape

The effects of the proposed solutions not only improve the cities itself but also positively influence the surrounding landscape. The fresh and filtered water that is stored in Middelburg- and Tempelpolder can for instance be used to supply the surrounding argicultural area in periods of drought. Especially when the approach for Gouda is applied to other cities in the low lying peat landscapes this can decrease the expected pressure on the fresh water supply in the future.

The same accounts for the solutions proposed in Enschede. By storing and retaining as much water as possible within the city the risk of flooding in cities downstream, such as Hengelo and Almelo, is decreased. If such a strategy would be applied on other cities in sand landscapes this would drasticly decrease the peak discharges from these landscape toward the lower lying river landscape.

One could thus say that the influence of applying a landscape based design approach in adapting urban water systems to climate change reaches further than the urban boundaries and has a positive effect for the surrounding landscape and even the whole Netherlands.

6.3 IMPLEMENTATION STRATEGY

Already many climate related problems occur in Dutch cities, which will become worse if the climate changes. Therefore, the sooner the proposed design solutions are implemented, the better. In this section an implementation strategy for the solutions will be discussed.

Increase public awareness

A landscape-based design approach to the ailing urban water systems results in renewed, resilient, and site-specific waterways which enhance the spatial quality of cities. However, climate adaptation not only asks for good solutions within the public space, but it also requires (private) initiatives on the local scale. Without the implementation of these solutions (such as green roofs, water gardens, and swales) the pressure on the renewed water systems remains high and problems might still occur. Furthermore, without public support and political willingness it is difficult to realise the proposed climate adaptive waterways.

public support and political willingness

Thus, a first step towards sustainable climate adaptation in cities is increasing public awareness on climate change. Only then can climate adaptive measures be applied on all scale levels. The small scaled initiatives on private scale can be initiated relatively easy and are often are even subsidised (Walthie et al., 2007). These solutions can be implemented without complex planning or designing processes. Therefore, local scaled initiatives are a second step towards climate adaptation in cities.

local scaled initiatives

Implementation strategy of the renewed brook system

In the current water system in Enschede, water flows from higher grounds downstream where it accumulates and causes flooding. Furthermore, these quick water discharges result in reduced natural water buffering capacity of the urban landscape, which leads to drought related problems. To prevent these problems, a third step in climate adaptation is to create water retention areas, especially in the upstream areas. This can be done in phases. A fourth step is to create the brooks and connect these with the surrounding landscape. These must be realised at once, as a half finished brook is not functional. The fifth step is to interconnect the retention areas and other parts of the catchment area with the brook.

water retention areas

renewed brook system

For this step the profiles of the roads must be modified to direct water towards the brook and to prevent water flowing directly into the sewage system. The final phase in the implementation strategy of the renewed brook system is to create brooks in other catchment areas of Enschede.

Implementation strategy of the cyclic water network

In the case of the interconnected cyclic water network in Gouda, problems are mainly caused by two aspects. First of all, the disappearance of many canals and the appearance of bottlenecks in the course of time within the water network cause stagnation of water and flooding in wet periods. Secondly, in dry periods water is scarce resulting in peat oxidation, soil subsidence, brackish seepage, and inlet of brackish and polluted water.

peak precipitation storage and densification of water structure

To reduce pressure on the water system three design solutions are proposed; storage of precipitation peaks, removal of bottlenecks, and interconnection and densification of the water network. All three types of solutions can be implemented in phases, as every single bottleneck removed and each water storage basin constructed improves the water network and decreases pressure on the system.

retention and purification area

The last step in the case of Gouda is the creation of the large retention area for the whole urban landscape in which water is collected, stored, and purified for re-use in dryer periods when water is scarce. Although this step is costly, complicated, and requires quite some preparation for the involved municipalities, it is essential for the renewed, reversed and cyclic water network to work.

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CONCLUSION & DISCUSSION

In the hypothesis of this thesis we stated that: ‘a landscape-based design approach to the ailing Dutch urban water systems offers sustainable solutions for adaptation to climate change’. In the following chapter we will discuss how the answers to the research questions helped us to confirm this hypothesis and revealed how a landscape-based design approach contributes to solving contemporary and future climate related problems in Dutch urban landscapes.

CONCLUSION

This thesis started with a fascination for climate change in the water rich country the Netherlands is. Initial research made it clear that the rising sea-level, increased river discharges, droughts and more extreme precipitation will have serious consequences for the Netherlands.

It became clear that especially in the urban context problems are likely to happen as there is an imbalance in contemporary society between the urban and the rural, people and place, and man and nature. The old symbiotic relationship between city and the country no longer exists. Furthermore it became clear that most problems in the city are water related as urban water-systems have disappeared and are replaced by underground sewage systems of which the capacity already reaches its limits.

hypothesis

From our landscape architectural viewpoint this resulted in the hypothesis that: 'A landscape-based design approach offers sustainable solutions for adapting Dutch urban water systems to climate change.'

restored balance

This research indicates that a landscape based design approach restores the balance between the urban and the rural, and man and nature. Applying the landscape based design approach increases the flexibility and absorption capacity of the urban water systems, which results in a dynamic balance between technocratic, static water structures and the natural dynamics and improves the spatial quality within the cities.

More specific landscape-climate research of the Netherlands shows that the impact of climate change varies regionally as a result of differences in landscape properties soil, relief, and hydrology.

climate impact matrix

The proposed landscape based design approach acknowledges the city as part of the landscape. Differences in the underlying and surrounding landscape thus result in city specific challenges related to climate change, one city will face more consequences than the other. The climate impact matrix, in which the potential risk of sea-level rise, increased river discharge, future droughts and more extreme precipitation are assigned to the 48 biggest Dutch cities and agglomerations, revealed the cities that have a high chance of facing problems due to the climate change.

Two of the cities that face a high potential risk are used to test how a landscape based design approach can transform the malfunctioning urban water-systems into sustainable, climate adaptive water-ways. For both Enschede and Gouda, concepts are developed based upon site-specific problems and opportunities. These concepts form the basis for further research and design on strategic plans for the cities and solutions on a more detailed scale.

In-depth research on the landscape of Enschede shows that most problems result from the quick discharge of water as the city is located on the slope of a moraine. Applying the landscape based approach to the city of Enschede results in a new brook system in which more water is stored and retained in order to supply the city with fresh water during periods of droughts.

renewed brook system

For Gouda, the in-depth research showed that the different polders in Gouda all have high and fixed water levels. As a result much water is pumped out of the city in wet periods while in dry periods the city is highly depending on water supply. Applying the landscape based approach in Gouda resulted in an intensified and circular water system in which water is stored and retained in the deeper Middelburg- and Tempelpolder to be used in periods of droughts.

intensified circular water system

In both cases it appears that the landscape based design approach results in a site-specific modification of the well-known store, retain and discharge strategy. To test whether the water-ways offer a solution to the water challenges calculations are made on the predicted precipitation peaks and potential storage capacities. 1/100 year 2h and 48h precipitation peaks in 2100 are used to make these calculations. Within the city of Enschede there is sufficient open space to store and retain a large part of the calculated storage assignment, for Gouda however the situation is different. Due to the high fixed water levels storage possibilities within the city are limited but the Middelburg- and Tempelpolder offers opportunities for storage in the surrounding landscape. For both Gouda and Enschede it appears that the proposed solutions are sufficient to cope with a large part of future storage assignments, however private initiatives remain essential to completely adapt the cities to the future climate.

store, retain, discharge strategy

The choice for Enschede and Gouda was not only made as a result of the climate impact matrix but the geographical location was important as well. Gouda, located in the low lying peat landscape and Enschede in the higher sand landscape are 2 of the most different locations in the Netherlands. This shows that the landscape based design approach is not only applicable to one specific case but that the approach can also be applied to other cities in similar landscapes and even to other cities in different landscapes, thus to the whole Netherlands.

applicability

The proposed waterways for Gouda and Enschede are not only sustainable and climate adaptive, but also make the water and climatic processes more visible and experiential within the city. The water-ways educate people which can result in more willingness to realise initiatives such as rain barrels, green roofs and the use of permeable materials on their private properties to decrease pressure on the new water-ways.

visible and experiential

restored symbiosis

Thus, with a landscape-based design approach the symbiosis between the city and the underlying and surrounding landscape is restored. Opportunities for climate adaptation offered by the landscape are used, resulting in healthy, resilient, and site-specific waterways to climate adaptation, in which climate processes become visible and experiential.

DISCUSSION

The proposed concepts for sustainable and climate adaptive waterways for Enschede and Gouda are promising however there are some uncertainties and constraints.

First of all it appears that for the new water networks to work there is a dependency on other water storage and retention alternatives to decrease peak discharges. As stated, there is a need for private initiatives but also other contemporary water storage initiatives need to be supported. Strategies thus need to be laid out to generate more involvement from local inhabitants.

The calculations used are made to the best of our abilities as landscape architects however we are not educated meteorologists or hydrologists, therefore it is likely that there is a rate of uncertainty within the calculations. However, we believe the calculations we made give a good estimate to test the applicability of the proposed interventions.

The concepts, strategic, and detailed designs are visions, not definite designs. Since this thesis focusses only on parts of the cities of Gouda and Enschede, this work does not pretend to be complete, the case studies are starting points for further research and design. Although applying the landscape based design approach to Enschede and Gouda made clear that this approach is a valuable mean to adapt these cities to the changing climate, more research needs to be done on both cities in similar landscapes to test whether the used approach is applicable in similar cases and on cities in different landscapes to see whether the approach can be applied to cities all over the Netherlands.

For the proposed designs to be realised and for the whole concept to be applied on a larger scale, both political and communal willingness is essential.

APPENDICES

The CD-ROM in the back cover of this book contains:

- A digital version of the thesis
- Presentation posters
- Appendix 1: Water system Enschede
- Appendix 2: Explanation of the choice for the detailed brook design
- Appendix 3: Calculations Enschede
- Appendix 4: Water system Gouda
- Appendix 5: Calculations Gouda
- Appendix 6: Explanation of the choice for the detailed design of the network

In this report we try to find solutions to adapt the Dutch urban water-systems to the changing climate. With a landscape-based design approach the symbiosis between the city and the underlying and surrounding landscape is restored. Opportunities for climate adaptation offered by the landscape are used, resulting in healthy, resilient, and site-specific waterways to climate adaptation, in which climate processes become visible and experiential.