Green, comfortable, attractive and climate resilient Utrecht Centre-West area

SSD – Deep Dive Utrecht
Opportunity 3

27 January 2016

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Summary

To assist Utrecht Municipality and Jaarbeurs fair and exhibition centre in developing plans for a green, comfortable, attractive and climate resilient Utrecht Centre-West area the SSD-DDU Opportunity 3 team[1] assessed projected developments of the urban program in this area, quantified the climate vulnerability of the area and investigated blue-green adaptation alternatives to strengthen the physical, economic and social functioning of the area. After disclosing the available data on the project area and making an inventory of best practices to inspire potential developments we investigated the vulnerability of the area and formulated the adaptation assignments for flooding due to extreme rainfall, for drought and heat stress in the light of the projected changes in climate. Identification of the vulnerable vital objects, networks and population groups in the area - in order to be able to provide them extra protection - turned out to be hard; data were scattered over many organizations and desks.

To strengthen the climate resilience and meanwhile make the area more green, comfortable and attractive, the services, benefits and opportunities of blue-green adaptation measures were identified, as well as the water conditions – water quantity and water quality – required to be able to harvest such benefits. Special attention was given to the opportunities provided by a rooftop greenhouse. The rooftop area of the Jaarbeurs fair and exhibition centre is very large; active use of this space for food production and as an accommodation area would be welcomed. And constructing a greenhouse could be one of the ways to go.

To investigate to what extent the adaptation assignments can be met by implementing blue-green adaptation measures in the project area representatives of the municipality, of the Jaarbeurs and the project team co-created three adaptation alternatives: A Green Development alternative, a High Urban Density alternative and a Maximizing Benefits alternative. Results of the Adaptation Support Tool show that the water storage and retention assignment and peak flow reduction assignment are solvable, although with substantial investments. Heat stress reduction objectives are achieved at the most vulnerable sites, certainly if the adaptation measures are supplied with extra water during hot dry spells. Other benefits of the proposed adaptation measures were assessed in a qualitative way, as the uncertainties in preferences and on size and construction do not allow for a quantification of the benefits. But the economic, social, environmental and health benefits of the projected adaptation measures seem attractive for the stakeholders – municipality, water authority, Jaarbeurs, other local businesses, residents and visitors.

Most of the proposed adaptation solutions can be combined with adaptation measures proposed in the field of traffic management in the area – cars, bicycles and pedestrians -, and in the field of closing thermal energy cycles and electric power generation using PV or PVT elements.

[1] SSD-DDU Opportunity 3 team: The team of Deltares and TNO experts working on the Climate-KIC project Smart Sustainable District – Deep Dive Utrecht and that focused on strengthening the climate-resilient, green and attractive nature of the Utrecht Centre-West area.

In cooperation with Utrecht Municipality and Jaarbeurs, plans can now be elaborated in more detail by making choices at a conceptual level, deepening the vulnerability analysis and making more detailed (preliminary) designs of the adaptation measures, so that their effects and effectiveness can be assessed in more detail. An improved quantification could then be made of the heat stress reduction, of the irrigation water demand in summer, of the impact of adaptation measures on groundwater regime and trees, of costs and of benefits for the relevant stakeholders.

1. Introduction

1.1 Objectives and structure of SSD - Deep Dive Utrecht

The objective of the *Smart Sustainable District* - Deep Dive Utrecht (SSD-DDU) is the co-development of plans for the redevelopment of the Utrecht Centre-West area. Most of the office buildings, housing and exhibition halls in this district of Utrecht were built in the 1960s, at a time that energy efficiency of buildings was not yet on the political agenda. Shopping areas are not up to date, and traffic and water infrastructure are outdated. Therefore the municipality of Utrecht formulated an ambitious redevelopment plan together with the business community and local citizens. Phase 1 (Utrecht Centre-East, see Fig. 1.1) of the project is in execution, while phase 2 – Centre-West - is in the planning and decision phase (timeline 2015-2016); that is why we will concentrate attention on this project area (Figure 1.2). Phase 2 concerns the redevelopment of the south-western part of the area. Apart from the municipality, the major stakeholder here is Jaarbeurs, the main exhibition & conference centre in the Netherlands.

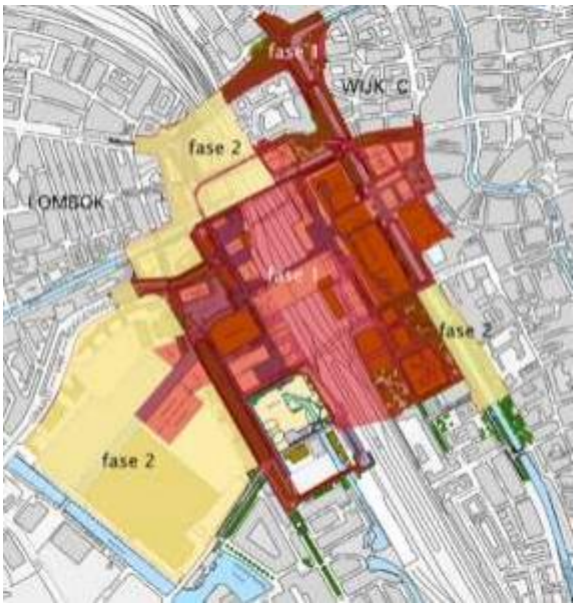


Figure 1.1. Reconstruction area Utrecht Centre. Fase 1 = Centre-East; Fase 2 = Centre West

The sustainability ambition for the area is high; energy efficiency, renewable energy and climate adaptation measures are important targets. The municipality has a private interest in 'factor 4 solutions'[2], deployed on/in their newly acquired grounds. Leading transformation principles to achieve this include:

1. Energy neutral district
2. Climate robust and green, attractive district
3. Attractive, liveable, accessible areas, 24/7

General aim for the redevelopment is to turn this district into an attractive, lively, safe, climate-neutral, multipurpose area, connecting the historic city centre with the areas south-east of the district. Commitment from the area's users (residents, travellers, commercial tenants and occupiers) is essential for successful redevelopment.

Four SSD co-development Opportunities for factor 4 solutions were prioritized by the district leads for 2015-2016:
1: Hybrid integrated systems for heating and cooling at district level
2: Local use of locally produced renewable (PV) power

[2] Factor 4 solutions: fourfold increase in 'resource productivity', brought about by simultaneously doubling wealth and halving resource consumption (Lovins & Weizsacker, 1997)

3: Green, comfortable and attractive areas
4: Clean and safe personal mobility
This report focuses on the results of Opportunity 3, Green, comfortable and attractive areas, and addresses how results can be integrated with these of the other opportunities.

By the end of 2015 Jaarbeurs was finalizing the master-plan for the redevelopment of its premises while Utrecht municipality started drafting a redevelopment program - Spatial Structure Plan - for the Utrecht Centre-West area. Consequently, our results can be used as inspiration and as building blocks for the decisions on spatial functions, programme, structure, infrastructure, and technologies that are to be taken in the course of 2016.

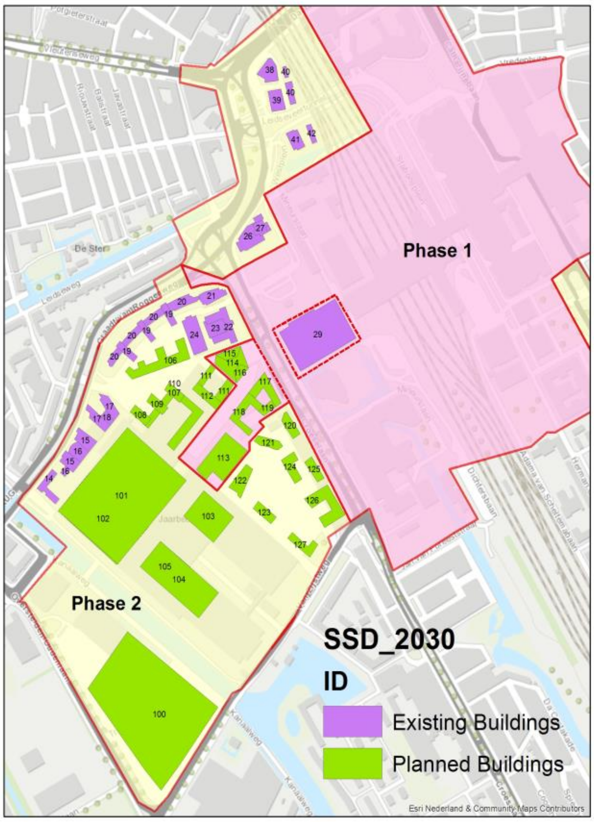


Figure 1.2. SSD project area Utrecht Centre-West including buildings projection 2030

1.2 Objectives of Opportunity 3

The central co-development ambition of SSD-DDU is: Can we develop an integrated design for the open air spaces in the Utrecht Centre-West and Jaarbeurs area based on most recent insights in increasing resilience against the impacts of climate change, reducing noise nuisance, decreasing the concentrations of air pollutants, increasing the biodiversity and improving the use functions of the area, also for the surrounding areas?

Opportunity 3 is aimed at making a widely accepted plan for improvement of the liveability of the project area and for strengthening its climate resilience. To this end we first have to make a vulnerability assessment for the project area covering flooding, drought and heat stress risks. This provides a basis for the climate adaptation assignment for the project area. In parallel, we study the applicability of blue-green adaptation measures, their pros, cons, ecosystem services, costs, benefits and co-benefits. An overview of best practices is made to provide inspiration on their feasibility. Particular subject of study in this case is the applicability of greenhouse facilities on the Jaarbeurs roof. This information is used during one or more design workshops to create a blue-greening plan for the project area.
This blue-green spatial plan is to be matched with the conclusions from the other opportunities. Choices are to be made and priorities defined by both Jaarbeurs and Utrecht municipality. The decision making process is supported by outlining dilemmas and considerations in the final discussion of this report.

1.3 Structure of this report

To achieve the objectives formulated in this first chapter, we will first provide an overview of projected reconstruction activities. As large reconstruction activities are foreseen, these ought to be taken into consideration in every part of the analysis, like the projected climate change. Chapter 2 provides an overview of the methodology, i.e. the tools and data that are used in this study. The report continues with an overview of best practices in creating a green and climate resilient urban environment (chapter 3). The adaptation assignments for flooding by extreme rainfall, for drought and for heat stress are quantified in chapter 4, while chapter 5 is addressing the economic and social opportunities, benefits and co-benefits of blue-green adaptation measures in terms of improving liveability and sustainability. The next chapter is focusing on opportunities for urban horticulture in the project area, in particular related to greenhouses on the roof of Jaarbeurs and other buildings. With all these opportunities in mind chapter 7 provides and inquiry into the spatial planning of adaptation measures and the evaluation of their effectiveness in the light of the adaptation assignment. Chapter 8 is a discussion of the results; uncertainties and knowledge gaps are discussed and their influence on the conclusions is elaborated on. Chapter 9 summarizes conclusions and recommendations of the work that was done. Moreover, in chapter 9 we try to outline an agenda for next steps in the planning and development of the Utrecht Centre-West area.

Advice to readers

Those readers interested in the potential adaptation solutions for the project area are recommended to read the chapters 7 and 8. Chapter 3 could provide them inspiration from realized 'best practice' cases. Backgrounds of the potential adaptation measures, the services and functions they provide and the pre-requisites for application are found in chapters 5 and 6. Readers interested in how the adaptation targets are quantified are referred to chapter 4, while chapter 2 provides insights in methods and models used for analysis and planning.

1.4 Projected reconstruction activities

Both at the terrain of Jaarbeurs and at the public terrain drastic reconstructions are foreseen. The actual premises of Jaarbeurs (350.000 m2) will be split in two: Jaarbeurs will concentrate its activities and be sole owner and exploiter of 270.000m2 (75.000 - 100.000m2 of exhibition facilities, with 2,5 million visitors annually). Jaarbeurs expect to invest over € 300 million over the next decade in the reconstruction of their premises. The municipality will buy and redevelop the second part of 80.000m2 as of 2023. They produced a first 'trial allotment' expected programme and conceptual design for this Jaarbeurs East terrain, as shown in Figure 1.3.

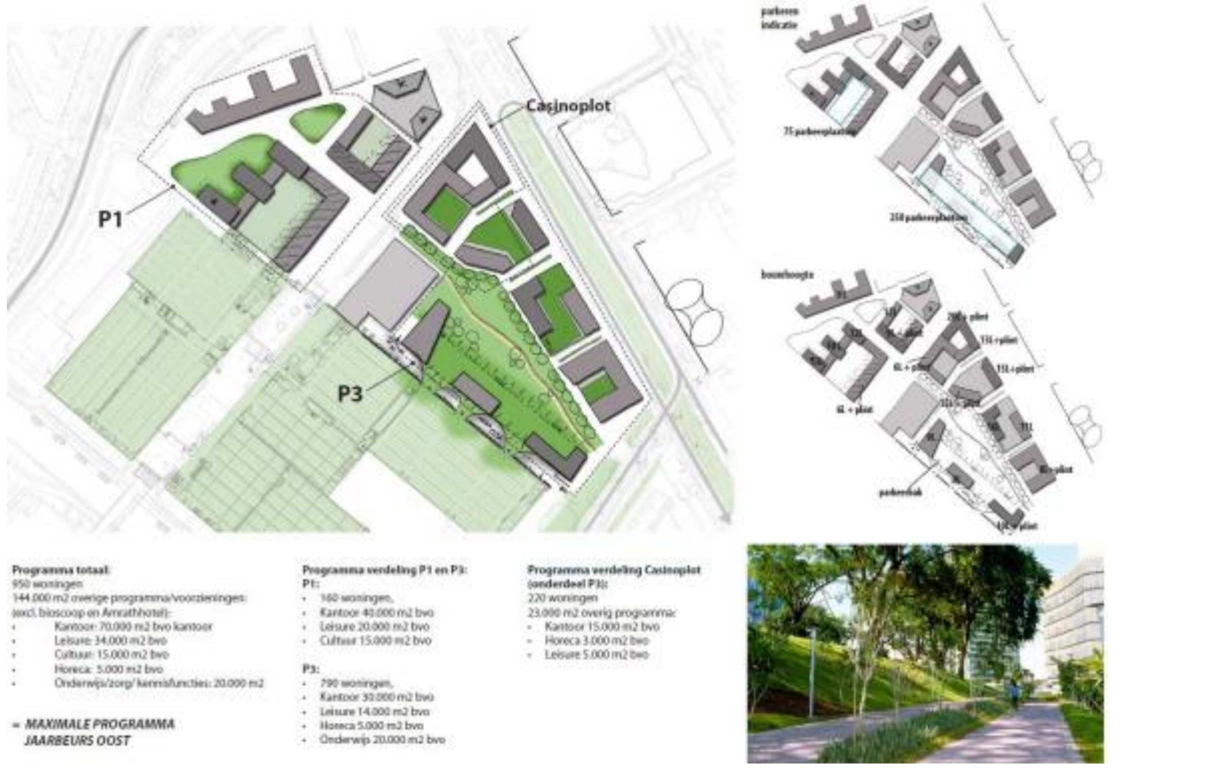


Figure 1.3 Trial allotment and conceptual design Jaarbeursplein East (Municipality Utrecht)

A preliminary urban program for this development was formulated as well. This program however is to be reconsidered when decisions on the actual development have to be made in 5-6 years.

Large reconstruction activities are foreseen in the road and waterway network in and around the Utrecht Centre-West area, in an attempt to reduce car traffic and facilitate bicyclists and pedestrians. The Croeselaan will be turned into a low traffic intensity street, while the Graadt van Roggenweg / Westplein are to be reconstructed to facilitate car traffic and transport of goods into town. Also the Van Zijstweg will undergo major reconstruction.

Construction of a large car parking facility (P6500) is foreseen at the south-west side of the Merwedekanaal, resulting in a significant increase of the number of pedestrians in the project area. Car mobility patterns in the project area will significantly change due to the projected road reconstruction and car park realization. These reconstructions will provide ample opportunity – and space - to implement blue and green infrastructure facilities in order to make the area more climate resilient, comfortable and attractive.

2. Methodology

2.1 Data, adaptation assignment and plan development

A stepwise approach was applied to develop sketches for a climate resilient, green comfortable and attractive Utrecht Centre-West area. To this end we had to make:

- An extreme weather exposure assessment, taking climate change 2030/2050 into account;
- A vulnerability assessment for the project area, covering flooding, drought and heat stress to quantify the adaptation assignment;
- An inventory of vital and vulnerable objects, networks and groups that require extra protection;
- An assessment of potential and desired ecosystem services of potential blue-green adaptation measures and their applicability;
- Conceptual blue-greening plans with sets of adaptation measures that meet the adaptation assignment for the project area.
- A first attempt to quantify benefits and costs of adaptation measures.

Moreover, a detailed assessment has been made on the applicability of greenhouse facilities on the Jaarbeurs roof.

To prepare for the analysis and the design sessions we created

- A data repository for all the data relevant for the design. See [Molenaar, 2015]
- An overview of international best practices. See Chapter 3 of this report.

Our intention was to integrate our plans with the results of opportunity 1, 2, and 4 in order to finalize the plan. This integration however is hindered at the current stage by the fact that both Jaarbeurs and municipality are preparing for some fundamental choices; choices that are required to be able to make a final integrated plan. Issues of these fundamental choices and dilemmas will be addressed in the Discussion chapter.

2.2 Tools and approaches

URBAN WATER BALANCE / DROUGHT STRESS MODEL

The Urban Water Balance Model (UWBM) is a multi-reservoir model to simulate both the urban water system as well as the small urban water cycle (Rutten 2013, Kuijk 2015). Within this project only the water system has been simulated. The model simulates the water system at neighbourhood level at a daily time step. This time step is generally sufficient for simulations investigating the effect of drought. Results of this multi reservoir model gave a good description of the urban water balance for these sites during drought conditions (Kuijk, 2015). In this analysis for Utrecht Centre-West area, the model has been further extended; site-specific adjustments have been made to optimize the UWBM in order to simulate land-use change effects.

The UWBM is conceptualized in reservoirs and links between these reservoirs. All the reservoirs are modelled with the same concept, a linear reservoir with a defined storage capacity. Links are customized according to their function and their dependencies on state of the upstream or downstream nodes. Reservoirs and links can be grouped in different storage systems and connected to other storage systems. A schematization of the model as it is applied in the project area is shown in Figure 3.1.

The model has been forced by a 30 year time series of measured precipitation and potential evapotranspiration for the meteorological institute (KNMI) at De Bilt, some 5 km away from Utrecht Centre West. To simulate the effect of climate change we used transformed 30 year time series for 2050 that were produced by the KNMI according to the 2014 scenarios for De Bilt (Van den Hurk, 2014).

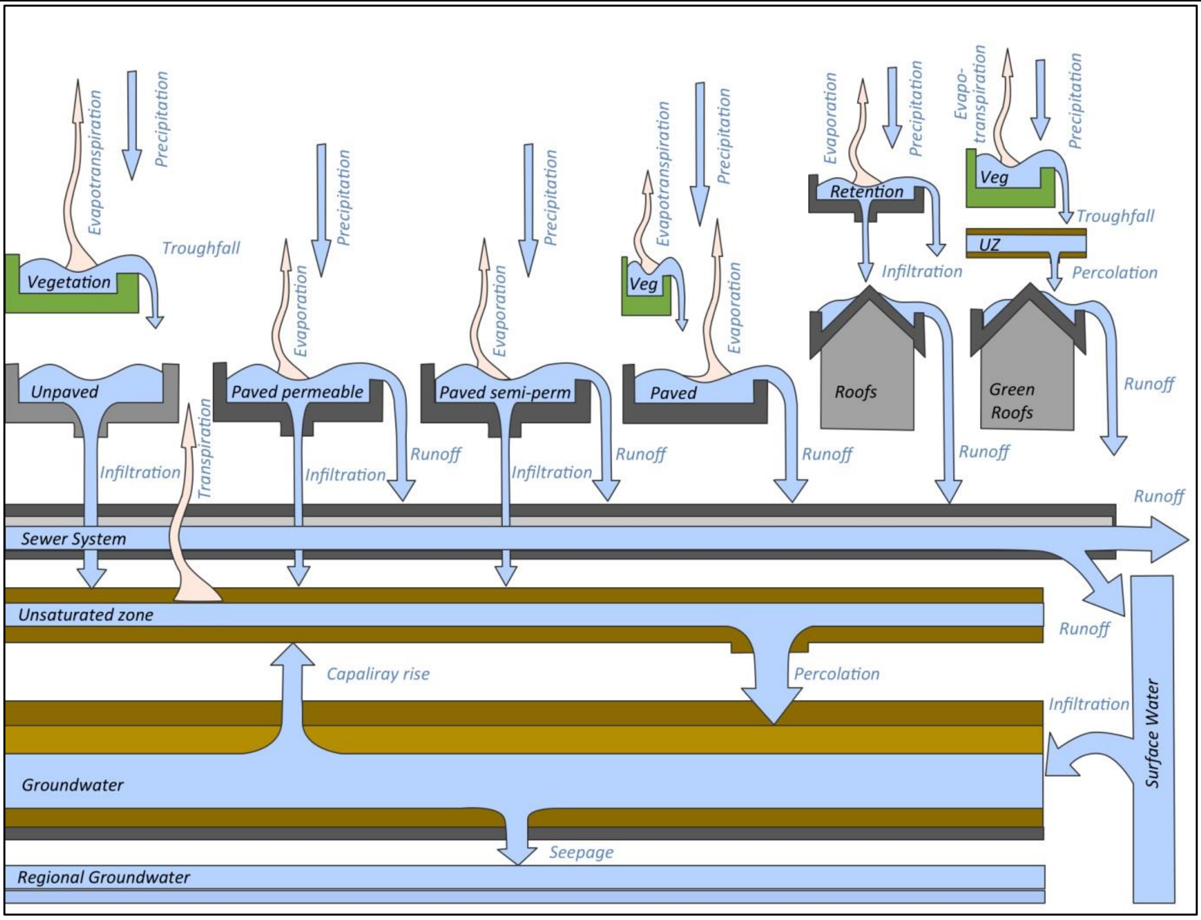


Figure 2.1 Schematization of the urban water balance model as used for the Utrecht Centre-West case.

Site specific parameters of the model relate to the land use in the area, the subsurface (field capacity, permeability and depth of the first aquifer). Other parameters are less site-specific like interception capacity of vegetation, crop factors and infiltration capacity of different paved surfaces. The site specific parameters that can be determined to sufficient precision like land use based on detailed land use maps were not calibrated. A few site specific parameters (interception storages and field capacity and conductivity of the unsaturated zone) have been calibrated using the OpenDA toolkit (www.OpenDA.org). The model has been calibrated on measured phreatic groundwater levels for 2010. Other variables that could have been used for calibration like discharge from drainage systems were unfortunately not measured in the project area.

3Di hydraulic model

3Di is a state of the art computational model to simulate flooding, both fluvial and pluvial. For the hydrodynamic calculations, the Saint Venant equations are solved. An important innovation in 3Di is the so-called quad-tree. The quad-trees are the computational grid cells for which a water level is calculated each time step. The size of the computational grid-cells can differ per location in the computational grid. Therefore the computational grid can be tailored to the situation: Coarse grid cells for the areas that need lees detail (e.g. because it is very flat and the water level will be the same throughout the area) and fine for the areas that need a high level of detail (e.g. for locations with elevation differences, such as dikes and levees). An example of the quad-trees in 3Di is given in the figure below, where it can be seen that the computational grid around the main rivers and canals is much finer than for the other areas.

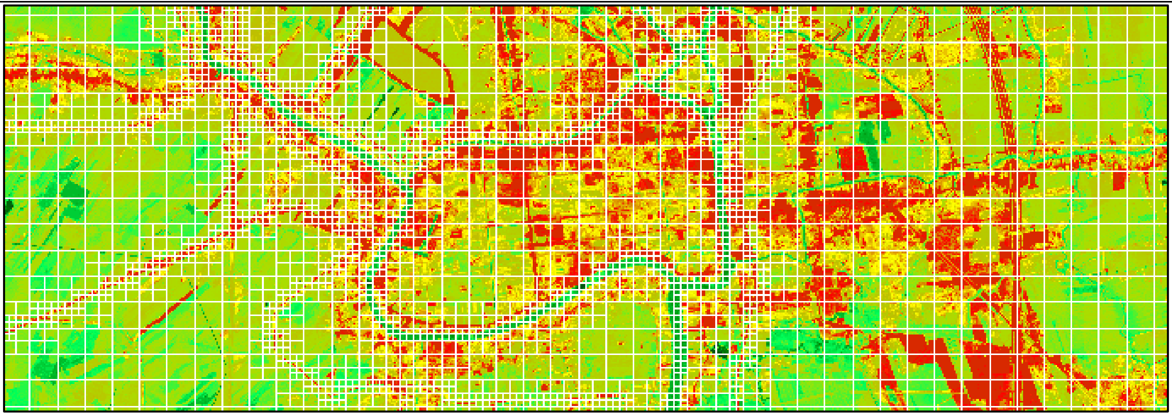


Figure 2.2 Unstructured grid used in 3 Di hydraulic model

Another innovation in 3Di is the use of sub-grids. Although the computational grid might be very coarse, the underlying data (such as the elevation data) can be very high resolution. The detail of these so-called sub-grids is used in the computation. It is used for the visualization (low lying areas within a computational grid cell are filled up first), but also to calculate local variety in bottom friction, or infiltration.

3Di also includes hydrological modelling. The hydrological modelling is based on a simple groundwater model, which is coupled to the surface water model. The user can define if he wants to include the hydrological modelling in the calculations.
This all combined results in very fast and accurate hydrodynamic calculations with realistic visualization. The user also has the freedom to stop, alter and restart the model on the fly. This makes 3Di a handy tool for fast testing scenarios of extreme events- e.g. what happens to overland flow when it starts pouring rain?

STORAGE – DISCHARGE – FREQUENCY (SDF) – CURVES

The SDF curves are determined by a water balance model that contains most urban water flows. Figure 2.3 provides an overview of the applied water balance model; this one is slightly different from the one in Figure 2.1 as it is focused towards extreme rainfall events, while the Urban Water Balance Model is focusing on drought stress.

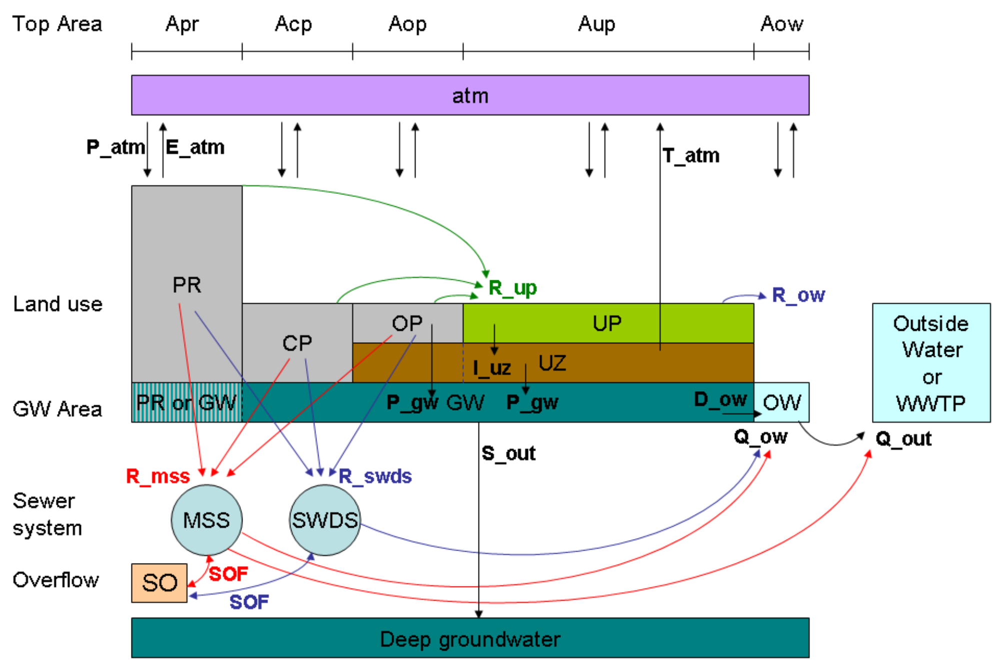


Figure 2.3 Overview of the applied water balance model for assessing storage discharge frequency curves for any particular urban area

Basically the urban area is divided in 5 different surface types:

- PR: Paved Roofs, i.e. buildings of which the floor level can be defined (partially) in or above the groundwater level;
- CP: Closed Paved, i.e. roads or other pavement without infiltration possibilities;
- OP: Open Paved, i.e. roads or other pavement with infiltration possibilities, varying from small (bricks) to high (permeable pavement);
- UP: UnPaved, i.e. unpaved areas varying from public parks to private gardens;
- OW: Open Water, i.e. the urban canal system.

In addition the model contains an unsaturated zone (UZ) bounded by a groundwater level GW), which can exchange water with the open water system (OW). When the storage capacity in the unsaturated zone is completely filled the groundwater level exceeds surface level and water starts running off to the open water (R_ow) when the defined storage capacity of the unpaved area is exceeded. The same occurs when the defined infiltration capacity of the unpaved area is exceeded. When the defined unpaved interception storage is exceeded water starts infiltrating into the unsaturated zone (I_uz). The unsaturated zone exchanges water to the saturated zone either by percolation or by capillary rise (P_gw), depending on defined soil type, moisture content, groundwater level and capacities of the several fluxes. Infiltrating water from open paved areas percolates (in this model) directly to the groundwater (P_gw).

Runoff water from paved areas can flow into a combined sewer system (MSS), a stormwater drainage system (SWDS) or can be disconnected, flowing towards the unpaved area (R_up). The combined sewer system discharges its water (Q_out) to the wastewater treatment plant (WWTP) up to a defined capacity. The water exceeding this capacity flows to the open water (Q_ow), however also limited to a defined capacity. The storm water drainage system discharges its water into the open water (Q_ow) up to a defined capacity. When the discharge capacity of a sewer system is exceeded water is stored in the sewer system. When their defined storage capacities are exceeded both sewer systems can overflow (SO), resulting in water flowing overland into the open water. Finally the urban area can exchange water with the atmosphere (P_atm, E_atm and T_atm), the deep groundwater (S_out) and with external surface water systems (Q_out).

HEAT STRESS MODEL

In the project we have used heat stress maps, resulting from a quick scan analysis, executed by the consultancy TAUW. The calculation model assumes that various types of urban land use influence the outdoor temperature on the local scale. Trees provide a cooling effect through evaporation and shadow. Water has a cooling effect on the air temperature immediately above the water. Through mixing effects the cooling effect extends somewhat from trees or water bodies. Similarly to other urban elements the temperature effect has been simulated: buildings (high and low rise, with a heating effect); green elements with a cooling effect, stony surfaces (heating). It is assumed that these isolated effects can be summed up.

The resulting maps – see section 4.6 - show temperature differences within the project area (at 1,5m) at the end (around 15:00) of a hot summer day. It is assumed there is no wind, as is common during a heat wave in The Netherlands. The temperature scale is qualitative, ranging from much cooler (about 5˚ Celsius cooler) to much warmer (about 5˚ Celsius cooler) compared the surrounding countryside. Intentionally no absolute temperatures are given in the legend, because of variation between hot periods, but nevertheless the maps provide a good indication of differences between streets and neighbourhoods. The maps used in the design workshops (and further in this report, see Chapter 5) reflect the current climate; for a much warmer climate scenario also maps of the 2050 temperature differences are available (these are based on a general temperature increase of 2,1˚ C. compared to the current climate).

CLIMATE ADAPTATION APP

When selecting adaptation measures, the first step is often to create a long-list of possible measures. Adaptation measures with potential are then selected through consultation with stakeholders. To facilitate this process and in order to explore and rank a comprehensive range of adaptation measures, the Climate Adaptation App was created, available at www.climateapp.org and in the Appstore and Playstore. The full list of over 120 measures is ranked on the basis of filters such as the adaptation targets, urban typology, soil properties and other key area characteristics. Figure 2.4 gives a screenshot of the tool. By clicking on a tile a brief description of the measure and its effectiveness as well as some photos or graphics demonstrating the measure are shown.

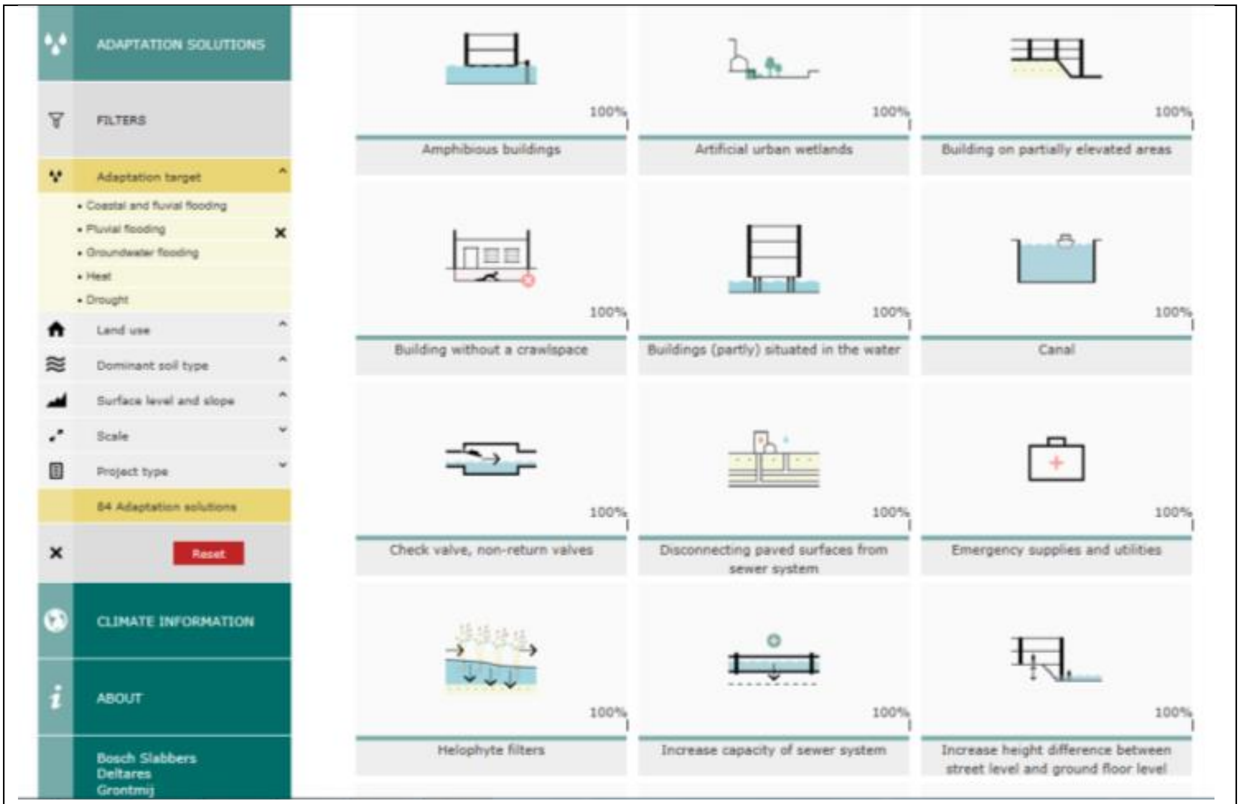


Figure 2.4 Screenshot of the Climate Adaptation App

ADAPTATION SUPPORT TOOL

The adaptation support tool is part of the Adaptation Support Toolbox, a planning toolbox for co-creating a climate resilient and ecologically sustainable urban environment. The AST was developed as part of Climate-KIC's Blue Green Dream project (http://bgd.org.uk/tools-models). The method supports selection of climate change adaptation measures that are suitable for the specific local topography, climate and urban layout. The toolbox also enables the development of an urban adaptation plan that meets stakeholders' needs.

The AST is an interactive software tool that can be used on a map table, a touch screen or a regular computer. Based on local conditions, the AST provides a ranked list of feasible measures for a more climate resilient urban environment. Users can draw measures on a map, for example areas where green roofs might be applied. AST calculates the effectiveness of the measure for water quantity regulation (reduction of runoff) and reduction of heat stress. By allowing the measures to be drawn on a geo-referenced background image (aerial photo or map) the size of the measure can be determined and the effectiveness for water storage and heat stress reduction be calculated. See Figure 2.5.

The effect of the intervention on the occurrence time of a flooding event is estimated based on the storage capacity, a multi reservoir model and meteorological data. The effect of an intervention on heat stress is determined by the local cooling of a measure (based on literature) and the surface area.

The AST has been used in two interactive workshops with the local stakeholders. The results of the tool provide a first estimation on the effectiveness of interventions and can be used as guidance for further design.

Figure 2.5 Layout of the touchscreen of the Adaptation Support Tool

3. Best practices

To inspire planners and decision makers, a concise overview was made of best practices of climate resilient urban design relevant for the restructuring of the Jaarbeurs and/or for the planned new district. A more complete description is available in Keijzer and Bosch. (2015). All cases are also systematically documented on http://eurbanlab.eu/library/ (free registration access). Entering the filter #SSD displays all the best practice cases for the Utrecht Deep Dive.

	Bigshops Dakpark (Rotterdam)
	The largest rooftop garden in Europe, built above a 1.2 km long shopping mall and parking area, covering a 9 m height difference. The park is designed with a high diversity: a Mediterranean garden, a playground and a residents garden. A greenhouse hosts a restaurant. The design of the park is integrated in the existing urban planning: several corridors cross the garden and thereby connect different parts of the neighbourhood. One of the success factors of the project is the combination of societal functions: shopping, parking, green recreation, mobility are stacked in several layers so that all functions can be offered in a single area. Another success factor was the involvement of residents.
	De DakAkker (Rotterdam)
	The "DakAkker" (literally: "Rooftop cropland") is located on the roof of a former office in the city centre of Rotterdam. The DakAkker is the first farm in Europe that grows crops in soils on rooftops and functions not only for its own benefits, but also as a laboratory and pioneer for green roofs elsewhere. The harvested food is delivered to local restaurants and individual citizens. The DakAkker also fulfills an educational function.
	Benthemplein (Rotterdam)
	The Benthemplein in Rotterdam is the first full-scale water square in the world, having an integrated system which drains water from the rooftops towards three basins on the square where it is buffered instead of released directly to the sewage system. The square is created in order to protect the city from sewage overload and other water damage in case of heavy rainfall, but it has also other functions. In warm and wet periods, the square also functions as a cool spot due to the heat buffering capacity of the water. In dry periods, the square can be used for many different sports. Additionally, the square is surrounded by stairs which can be used as a public tribune to make it an

	outdoor theatre occasionally.
	Retailpark InCenter (Landsberg am Lech) The roof of the this retail park has been covered with vegetation and for one third with PV panels. Not the whole roof could be covered with solar panels, due to “inefficiencies” like stairways, ventilation tubes. The vegetation on the roof has several functions, amongst others a water buffering capacity in case of heavy rain fall, and an insulation function for the building below. The vegetation also has a beneficial function for the PV panels, because they are less effective on a hot, black roof (up till 80°C) in summer than on a vegetation covered roof (max. 35 °C). The roof construction company Zinco estimates that this efficiency gain saves about 14000 euros per year. The vegetation and its substrate serves as a structural weight in anchoring the PV panels, which means that no concrete anchoring is needed.
	Binnenheuvel (Tiel) A former industrial area was transformed into a new residential area with apartments, two supermarkets, a two-level parking garage and one of the largest rooftop parks of the Netherlands (12500 m2). This integrated design and multifunctional area use was a forced solution due to lack of space. Additionally, the soil turned out to be too much polluted to build an underground parking. As solution the garage was built on top of partly cleaned soil, so that an elevated park could be created. The park covers the supermarket and some auxiliary buildings which do not require daylight. About 80% of the park surface is covered with vegetation: a diverse mix of groundcover, plants, shrubs and ornamental grasses. After the successful test on the impact of rainfall and water retention on the total construction, the roof is now insured for ten years of “clearing costs” in case of roof damage.
	Podlasie Opera and Philharmonic (Bialystok) The Podlasie Opera and Philharmonic – European Centre of Culture is an extreme example of green urban design: all walls of this building are covered with green vegetation, making it a “green cube”. Also the surrounding area is developed with many small and large green spaces. The building is designed following “sustainable principles”. The installation of solar panels was included in the original plan, but they have not been installed. The green roof consists of a water drainage and retention system, a special substrate and vegetation

	based on heather, lavender and suitable accompanying plants. The walls of the building need time to become fully green; the first plants have been planted on the basis of the specially structured walls, but they are not overgrown yet.
	**Ahuntsic (Montreal)** The Ahuntsic greenhouse on the roof of an office building in Montreal, has a surface of almost 3000 m2 (31000 square foot) and produces 70 ton of food per year. The farm harvests food every morning and delivers it to the drop-off points in the city, where customers can pick them up. The farm does not work solitarily, but has an alliance with more than 150 local producers which provide other fresh foods for the baskets. The greenhouse in Montreal benefits from its climatic circumstances (cold climate with a short open air growing season) and the interests of the population in organic and local food. The sustainable farming principles focus on water conservation (rainwater capture and recirculation), biological pest control (without pesticides), energy saving, composting green waste, rain water buffering, waste minimization and transport reduction.
	**Greenpoint Brooklyn (New York)** This rooftop greenhouse is designed, built and owned by Gotham Greens, a company specialized in urban agriculture projects which owns also three other rooftop greenhouses in Brooklyn, Queens and Chicago. This one measures about 1400 m2 and produces more than 100 ton of crops per year, supplying an outlet in the building below. Sustainability is translated in system control. The greenhouse is a closed system with intensive control and monitoring by computer systems, aiming to optimize yield and minimize energy and water losses. The plants are grown in a hydroponic system, which means that all nutrients are delivered by water and no soil is used. The unused water is recirculated. The greenhouse is equipped with LED lighting, advanced glazing, passive ventilation and thermal curtains. On the rooftop solar PV panels are installed to reduce the fossil energy consumption.

	**Nieuw Zaailand (Leeuwarden)** “Nieuw Zaailand” is market square that is also used for cultural activities and is surrounded by shops, dwellings, offices, a museum and cinema. Beneath the square, a two-floor parking place has been constructed. In an integrated design the top of the parking is covered by a water retention system, which forms the foundation of the square. The water retention system consists of elevated units of 60 to 80 centimeters of the “Watershell Atlantis” system, which consists of plastic units that can be sewn in the preferred height. Several functions (e.g. the combination of recreation, accessibility and water retention in the square) have been combined on top of the parking.
	**Kruisplein (Rotterdam)** The parking garage at the Kruisplein in Rotterdam is built at a logistic node, between the central station and the Westersingel. In case of heavy rainfall, the Westersingel has a high risk of flooding and thereby hindering the city centre. Since there is little flexibility in the densely built centre of Rotterdam, smart solutions are sought for such space demanding problems. The parking garage is enriched with an extra function: a water retention system is created by means of “water shells”. The parking area is protected from water infiltration by means of a rubber emulsion of several millimetres thick which seals the water retention area.
	**Skyline Plaza (Frankfurt)** Close to the “Frankfurter Messe”, a shopping centre with a large green roof has been realised in 2013. The aim of the rooftop park is to create a recreational area with diverse functions for people of all ages, with e.g. a restaurant, a playground, a terrace with panorama view of the city, an event stage, a special corner for yoga and tai chi. Plants grow all year round. The rooftop garden is irrigated with rain water, which is captured in cisterns with a capacity of 265.000 litres in total. This rainwater capture reduces the water runoff problems in case of heavy rainfall.
	Parkroyal hotel (Singapore) Vegetation was integrated in many aspects of the interior and exterior design. The building has rooftop gardens and gardens on several floor levels, just outside the building. The green surface is about twice as large as the net building area. The vegetation is irrigated with captured rainwater and the irrigation process is fuelled by energy from PV cells on the roof.

	Further: motion-activated lighting, naturally-ventilated hallways, an energy-efficient chiller system, demand-based ventilation systems, daylight maximization, high performance glass to reduce indoor temperature and use of Cobiax technology (which uses “void formers” made of recycled plastic to reduce concrete consumption). The estimated total energy reduction is about 30%.
	**Quartier Luciline (Rouen)** A former industrial area redeveloped into an ecodistrict. High density development with attention for both climate adaptation and mitigation: amongst others warm water from a natural source, integrated water management, tree corridors, good access to public transport and compact building planning. The water course “Luciline” and small canals help to drain the water from buildings and open spaces after heavy rain fall. Green banks with trees form green promenade areas. As a renewable energy source, relatively warm water from the deeper water layers of the Seine River is used. The area is planned and designed to be easy accessible by foot, bike or public transport: it lies only 1.3 km from the city centre and public transport is frequent.
	**Street Trees (Barcelona)** Barcelona aims to enhance the cities’ ecological, environmental, social and economic services by connecting the various parts of the city by an effective ecological infrastructure. Currently the city is completing a Street Tree Management Plan. 10 strategic lines constitute the basis for the Tree Management Plan in order to have trees being appreciated as an urban infrastructure of first order and to favour cooperation between the municipal departments. These strategic lines include heritage and biodiversity, planning and connectivity, plant material, land, water, safety and pruning, health of trees, preservation and protection, knowledge, and communication and participation. These 10 lines will be implemented by 46 actions and a range of associated tasks.

4. Adaptation assignment

4.1 Climate resilience and liveability

The adaptation assignment is the set of - preferably quantified - adaptation targets that is set to make an area climate resilient enough, according to accepted hazard, risk and/or vulnerability standards. For the improvement of the liveability of the project area and for strengthening its climate resilience we first have to find out where the most vulnerable 'hot spots' are for flooding, drought and heat stress and how much adaptation is needed to make the situation acceptable. Greening and blue-ing the area can provide shelter for extreme weather conditions, meanwhile improving the public appreciation of the urban landscape. Another aspect for the adaptation assignment is the protection of vital and vulnerable objects, networks and population groups for extreme weather conditions. Liveability can be improved by strengthening the coping and recovery capacity of a society during and after a weather-related disruption of the urban system. Extra protection for the vital objects and networks is an essential part of these capacities.

4.2 Climate change

Climate change projection for the Netherlands were made by the Royal Netherlands Meteorological Institute (2014). They produced 4 scenario's based on 1 or 2 ^{o}C increase of the average temperature (schemes G and W) in 2050 and with or without change in the circulation pattern on our hemisphere, indicated by subscripts L and H respectively. Figure 4.1 shows estimated changes in 2050 – unfortunately available in Dutch only. Similar figures are available for the 2085 scenarios.

Seizoen[A)]	**Variabele**	**Indicator**	**Klimaat**[B)] **1951-1980**	**Klimaat**[B)] **1981-2010**	**Scenario veranderingen voor het klimaat rond 2050**[c)] **(2036-2065)**			
				= referentie-periode	G_L	G_H	W_L	W_H
Wereldwijde temperatuurstijging:					+1 °C	+1 °C	+2 °C	+2 °C
Verandering van luchtstromingspatroon:					Lage waarde	Hoge waarde	Lage waarde	Hoge waarde
Jaar	Temperatuur	gemiddelde	9,2 °C	10,1 °C	+1,0 °C	+1,4 °C	+2,0 °C	+2,3 °C
	Neerslag	gemiddelde hoeveelheid	774 mm	851 mm	+4%	+2,5%	+5,5%	+5%
	Zonnestraling	zonnestraling	346 kJ/cm2[F)]	354 kJ/cm2	+0,6%	+1,6%	-0,8%	+1,2%
	Verdamping	potentiele verdamping (Makkink)	534 mm[F)]	559 mm	+3%	+5%	+4%	+7%
Winter	Temperatuur	gemiddelde	2,4 °C	3,4 °C	+1,1 °C	+1,6 °C	+2,1 °C	+2,7 °C
	Neerslag	gemiddelde hoeveelheid	188 mm	211 mm	+3%	+8%	+8%	+17%
		10-daagse neerslagsom die eens in de 10 jaar wordt overschreden[I)]	80 mm	89 mm	+6%	+10%	+12%	+17%
		aantal dagen ≥ 10 mm	4,1 dagen	5,3 dagen	+9,5%	+19%	+20%	+35%
Lente	Neerslag	gemiddelde hoeveelheid	148 mm	173 mm	+4,5%	+2,3%	+11%	+9%
Zomer	Temperatuur	gemiddelde	16,1 °C	17,0 °C	+1,0 °C	+1,4 °C	+1,7 °C	+2,3 °C
		aantal zomerse dagen (max temp ≥ 25 °C)	13 dagen	21 dagen	+22%	+35%	+40%	+70%

		aantal tropische nachten (min temp ≥ 20 °C)	< 0,1 dagen	0,1 dagen	+0,5%	+0,6%	+1,4%	+2,2%
	Neerslag	gemiddelde hoeveelheid	224 mm	224 mm	+1,2%	-8%	+1,4%	-13%
		dagelijkse hoeveelheid die eens in de 10 jaar wordt overschredenI)	44 mm	44 mm	+1,7 tot +10%	+2,0 tot +13%	+3 tot +21%	+2,5 tot +22%
		maximum uurneerslag per jaar	14,9 mm/uur	15,1 mm/uur	+5,5 tot +11%	+7 +1		
		aantal dagen ≥ 20 mm	1,6 dagen	1,7 dagen	+4,5 tot +18%	-4,5 +1		
	Droogte	hoogste neerslagtekort dat eens in de 10 jaar wordt overschreden[I)]	-	230 mm	+5%	+1		
Herfst	Neerslag	gemiddelde hoeveelheid	214 mm	245 mm	+7%	+		

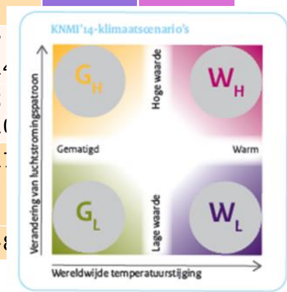


Figure 4.1. Climate scenarios for the Netherlands (excerpt from KNMI, 2014)

Extreme daily rainfall volumes (T = 10 years) are expected to increase by 4-27 % in 2050. Our project area is located in the centre of a larger city and climate change might be exacerbated by its location. Not only will the urban heat island produce higher average and extreme temperatures, also rainfall, evaporation, and other meteorological factors are influenced by the fact that we are working in the city centre. For example Daniels *et al.* (2015) proved that p at the downwind side of cities is nowadays increased by some 7 %. This impact of urbanization on precipitation could not yet be studied more in depth as fundamental research on this topic is very scarce. That is why we will use the 'regular' KNMI climate scenarios 2050 for our further analysis.

4.3 Pluvial flooding

To find out where flooding would occur the project area was modelled with a 3Di hydraulic model. A first estimate could be given by introducing a very extreme uniform design storm of 58 mm/h lasting 4 hours, 232 mm in total; such a storm volume goes beyond every realistic climate scenario, even exceeds the volume of the storm that flooded the city of Copenhagen on 2 July 2011 (155 mm in 3 hours) and would occur in the Netherlands less than once every 1000 years. Moreover, drainage of the storm sewers was neglected and rough land level data from our national digital elevation model AHN2 were used; the design storm was only used to make the drainage system fail, so that the most hazardous places would pop up. A movie was produced showing the response of the area during and after the storm. Figure 4.2 shows a still after 2.5 hours. Water is collecting and ponding in depths over 0.30 m at several places in the area. In particular the low zones behind and below the buildings along the Graadt van Roggenweg seem hit by the flood, but also the large Jaarbeurs parking lot along the Croeselaan and the loading zone between hall 7 and hall 12 suffer from severe flooding.

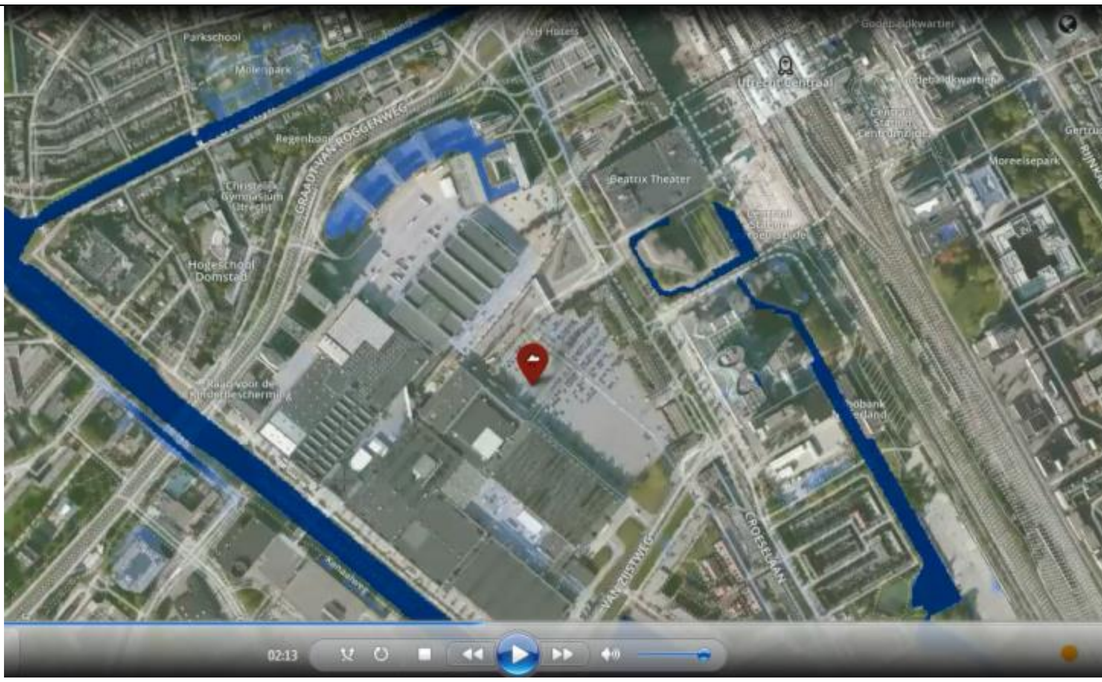


Figure 4.2 Expected flooding in the project area due to 2,5 hours of rainfall with 58 mm/h intensity. Estimates based on quick scan with 3Di hydraulic model

4.4 Water retention

To determine the required storage capacity in the project area – in relation to the accepted discharge capacity from this area - SDF curves for the Utrecht Central Station area are assessed. To this end the total Central Station reconstruction area was taken up into a water balance model, as elaborated on in Appendix II. The balance model is run for the period 1981 – 2010; hourly rainfall and evaporation values of weather station De Bilt are applied. For 15 discharge capacities (from 1 mm/d up to 15 mm/d over the entire area) the required storage in the open water system and other retention facilities is determined. For each of the 15 discharge capacities extreme value statistical analysis is applied on the top 100 storage events in 30 years (1981-2010) to determine (a) the return periods for the different events and (b) the required storage capacity for a list of different return periods. By fitting a logarithmic relation between the required storage capacity and the return time for each of the 15 discharge capacities we can estimate the required storage volume for return times of 1, 2, 5, 10, 20, 50 and 100 year. These estimates can be plotted against discharge capacity of 2 – 15 mm/d to produce Storage Discharge Frequency curves. Figure 4.3 provides an overview of the result.

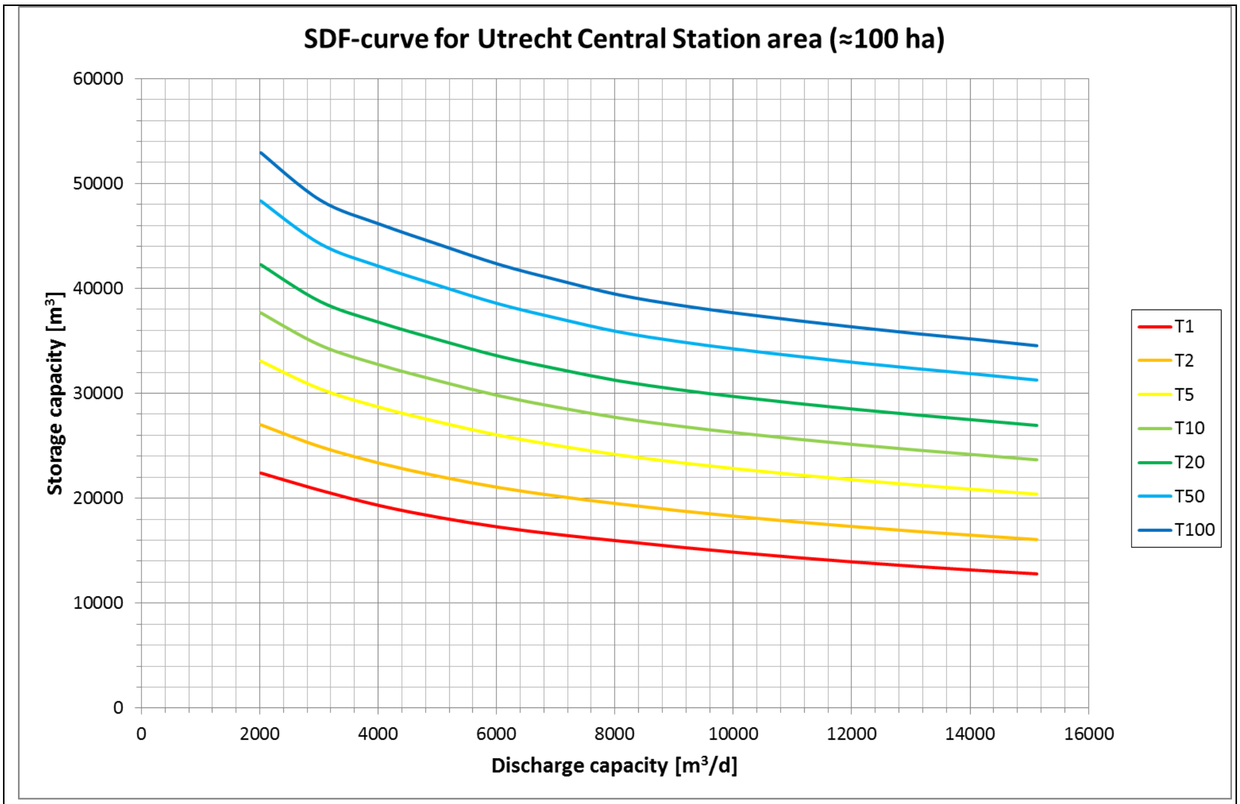


Figure 4.3 Storage-Discharge Frequency curves for Utrecht Central Station area, based on top 100 events over 30 years (1981-2010).

As an example, a water system in the 101 ha Station Area with a discharge capacity of 6000 m^3/d requires a storage capacity of 30.000 m^3 to be able to deal with storm events with return times up to 10 year.

The standard design discharge for drainage of rural areas in the Netherlands is about 1.5 l/s/ha. If we would require that urbanization of a terrain has no influence on neighbouring land – never shift problems, neither in time nor in space – and we apply this same standard to our project area the discharge capacity of the total reconstruction area (101 ha) would not exceed 13,000 m^3/d. In view of the vital economic function of the area we would like to require a return period for pluvial flooding of at least 20, if not 50 years and maybe even more. To be prepared for climate change in this largely covered and paved project area this leads to a required storage capacity of 30,000 – 35,000 m^3 or 300 - 350 m^3/ha.

4.5 Drought

Drought is in general the result of prolonged periods of low precipitation. As a result soil moisture is not replenished while vegetation extracts water from the root zone. Consequently groundwater recharge is reduced or even negligible. Lower groundwater levels and soil moisture availability causes lower transpiration rates of vegetation and consequent wilting. Reduced transpiration and therefore reduced evaporative cooling in its turn enhance the urban heat island effect. Low groundwater levels can enhance land subsidence and rotting of wooden piled foundations. Drought can also influence surface water levels and water quality, but the damages that result from this are much lower than the damages as a consequence of low groundwater levels. Therefore we focus on groundwater levels and reduced evaporation as result of low soil moisture availability.

Figure 4.4 shows the yearly sums of the main water fluxes in the area. The annual precipitation is 887mm per year. Of this precipitation 13% is intercepted by vegetation and by paved land surface from which it evaporates. Due to the high fraction of paved surface large part of the precipitation (49%) drained by the sewer system either toward the surface water or waste water treatment plant. Only 28% of the rainfall infiltrates into the soil of which 42% is taken up by vegetation and transpires and 58 % percolates to the groundwater. This means that only 9% of precipitation is transpired.

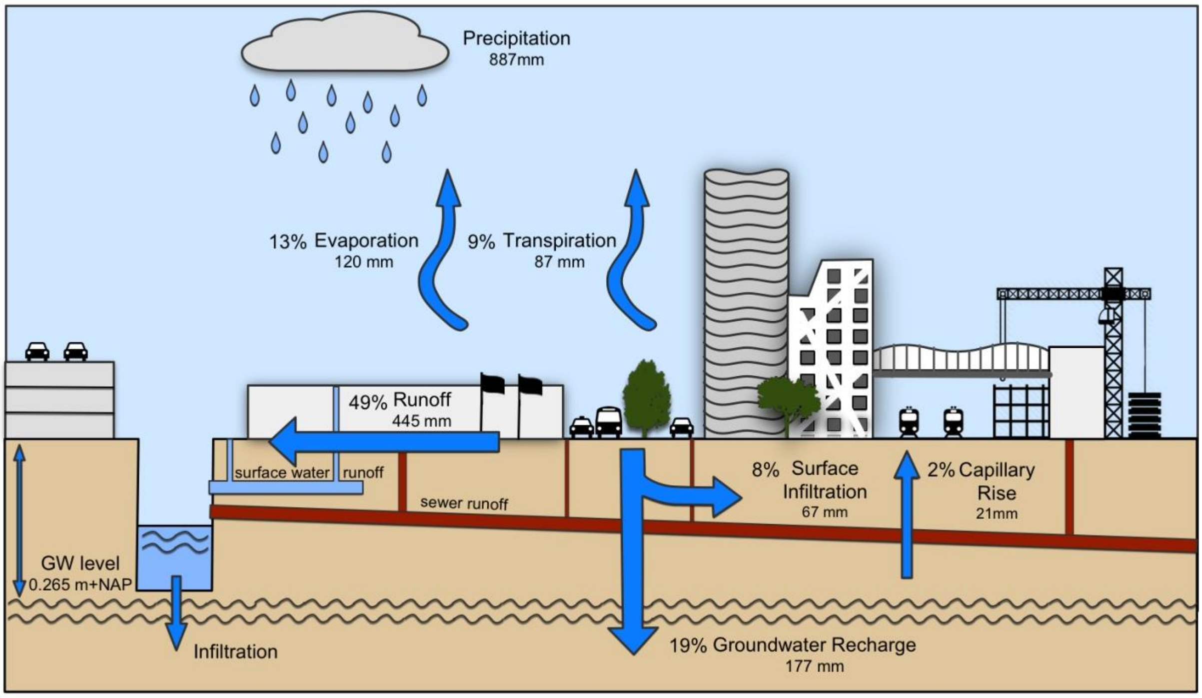


Figure 4.4 Schematization of water system at Utrecht Station area with main water fluxes

The effect of climate change on groundwater is limited to approximately 2 cm, as illustrated in Figure 4.5. In the climate scenario in which changes are most pronounced (WH2050) the groundwater level in winter is 2cm higher, while in summer it is 2cm lower. This change is relatively small and the result of the fact that groundwater recharge in the baseline scenario (current) is only 19% of the rainfall. Therefore more water will be discharged by the sewer system and the effect on groundwater will be relatively small. Next to that, rainfall intensities are expected to increase in all scenarios which will result in a lower fraction of infiltration. Also the fixed lower boundary condition reduces the effect of the climate scenarios on phreatic groundwater level.

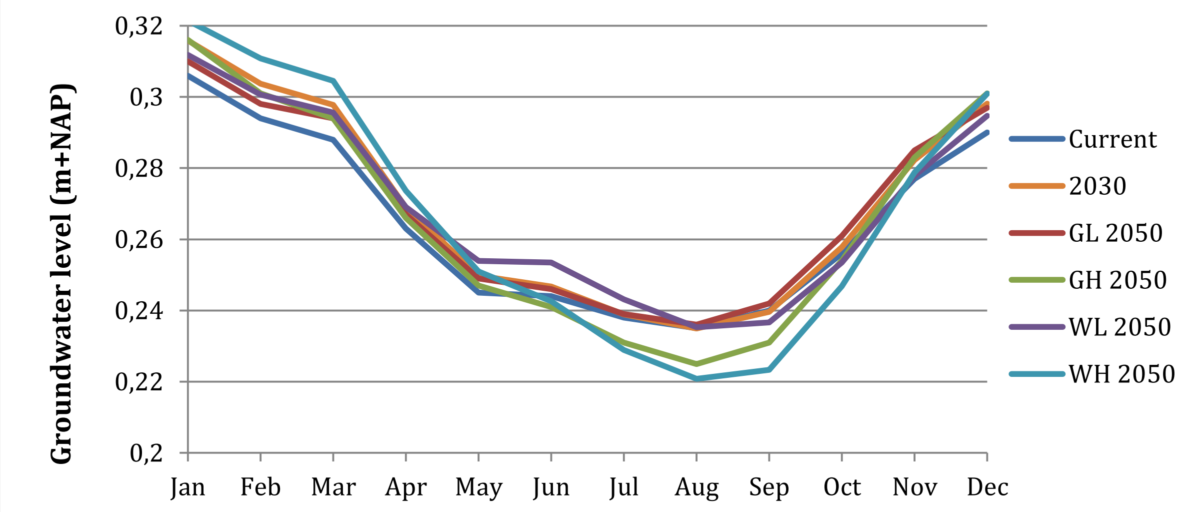
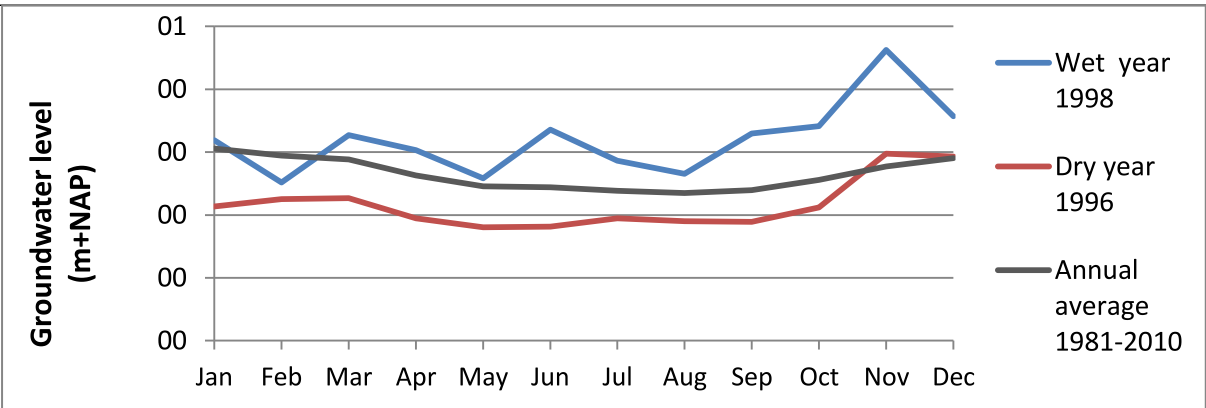


Figure 4.5 Effect of different climate projections on average areal groundwater level.

The inter-annual change is larger than the effect of climate change which provides another way to explore the sensitivity of the area to climate change. Figure 4.6 (top) shows the groundwater levels of the driest year 1996 and wettest year 1998 and the average of the 30 year time series. The difference in yearly average groundwater levels is only -5cm and + 5cm respectively relative to the average of 30 years. The limited effect of the wet year was caused by the fact that most precipitation fell in autumn while the first eight months were about average. The effect of the dry year is limited due to the deep groundwater level that is assumed to be constant that prevented lower groundwater levels by upward seepage. The unsaturated zone was dryer than normal which resulted in lower evapotranspiration rates (Figure 4.6, bottom) and less evaporative cooling.



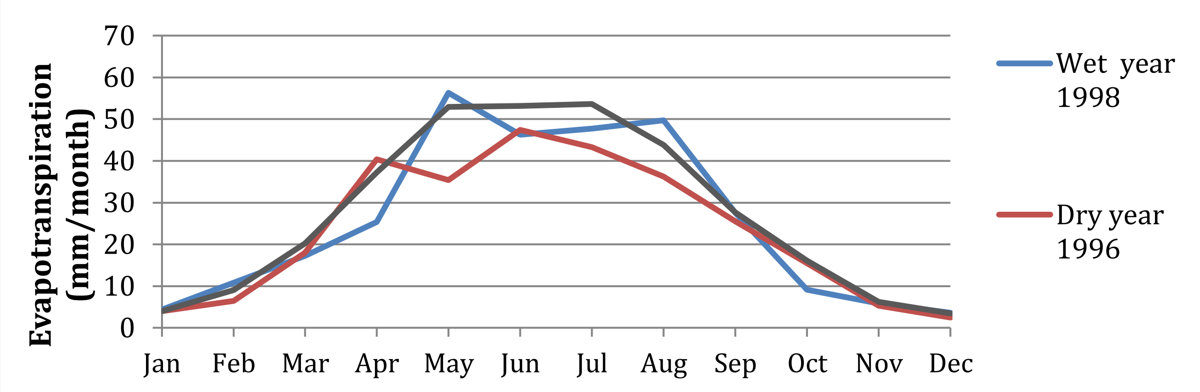


Figure 4.6 Groundwater level (top) and evapotranspiration (bottom) over a year during a wet and a dry and the 30 year average.

Different scenarios of land use change have also been simulated to explore the effectiveness of different interventions to make the area more climate resilient Table 4.1 gives an overview of investigated land use scenarios. In one scenario the paved area was increased to show the effect of building the area even more dense than it is now, without further interventions to make the area water robust.

Table 4.1 Overview of predicted effects of land use changes and of implementation of blue and green roofs on drought flooding and heat (Van der Meulen et al., 2015).

Scenario	Intervention	Effects
Green roofs extensive	Extensive green roofs are implemented on all flat roofs in the area, while the roofs remain connected to sewer system	Extensive green roofs (<15cm) can store a limited amount of water in the growth medium and provide a limited reduction of total runoff from the area and peak discharge: 2% of rainfall is stored during extreme rainfall events and up to 16% for small rainfall intensities. As the roofs discharge towards the sewer system these roofs have no effect on the groundwater level. Evaporative cooling is slightly increased due to increased interception evaporation and transpiration of vegetation.
Green roof intensive	Intensive green roofs are implemented on all flat roofs in the area, while the roofs remain connected to sewer system	Intensive green roofs (>50cm) can store a fair amount of water in the growth medium and provide an effective reduction of total runoff and peak discharge. 14% of rainfall is stored during extreme rainfall events and up to 26% for small rainfall intensities. As the roofs discharge towards the sewer system these roofs have no effect on the groundwater level. Evaporative cooling is increased due to increased interception evaporation and transpiration of vegetation.
Water retention (on blue roofs)	Blue roofs are implemented on all flat roofs in the area	Blue roofs can store water that can be used for cooling or water usage and does not need to be discharged to the sewer system. The total roof surface allows storage of 165,000 m^3/y. As the roofs discharge towards the sewer system these roofs have no effect on the groundwater level. Evaporative cooling can be increased if water is stored on the roof instead of slowly drained.
All pavement permeable	All impermeable and semi-permeable paved surface is replaced by highly permeable pavement	Permeable pavement allows for infiltration of precipitation into the soil. It increases groundwater recharge resulting in 10 cm higher groundwater levels in summer. Transpiration increases by up to 18% due to a higher soil moisture content, which enhances

		evaporative cooling.
Semi-permeable pavement to permeable	Semi-permeable paved surface is replaced by semi-permeable pavement systems. Impermeable paved remains impermeable.	Permeable pavement allows for infiltration of precipitation into the soil. It increases groundwater recharge resulting in 4cm higher groundwater levels in summer. Transpiration increases by 8% due to a higher soil moisture content, which enhances evaporative cooling.
More vegetation (from 33% to 40%)	Create 40% surface area of vegetation instead of 33% by reducing paved area	More green enhances transpiration in summer up to 17%. The effect on groundwater in summer is negligible.
Disconnection roofs	All flat roofs are disconnected	Roofs are disconnected from the sewer system towards groundwater. Less stormwater runoff to the sewer system occurs and groundwater levels in summer increase. This will increase transpiration in summer up to 44%.
Increased paved surface	114% extra paved surface by reducing unpaved area	Closed paved surfaces reduce infiltration, groundwater recharge and transpiration and enhance stormwater runoff. This results in lower groundwater levels all year round (2-6cm) and less transpiration in summer (-54%).
More surface water (x2)	100% more surface water by reducing paved area	A larger area of surface water can store more stormwater runoff. Groundwater levels increase all year round (8-10 cm) as the surface water levels are higher than groundwater levels. The effect on transpiration is negligible.

For investigating the effects of changes in land use we focus on groundwater (Figure 4.7) levels and transpiration (Figure 4.8). All scenarios intended to make the system more climate robust cause an increase in groundwater level up to 13 cm higher than in the current situation. This means that implementing one or more of these measures can compensate for the drop of groundwater level in summer.

Groundwater is lowest during summer when potential evapotranspiration is highest and could have a significant cooling effect on ambient air temperatures. However, groundwater levels are critical in relation to water availability to vegetation’s evaporation. Most scenarios, except more vegetation and more pavements, have a positive effect on the groundwater level and cause an increase of the lowest monthly average groundwater level of up to 12 cm. Hence we may conclude that land use changes can compensate for the expected drop of groundwater levels in summer in the different climate projections.

More vegetation in the area increases transpiration which results in a slight drop of the groundwater levels in summer. In winter more vegetation has a positive effect on groundwater levels, as vegetation was added in combination with open soil allowing for infiltration of precipitation and groundwater recharge in periods of low evaporation . More paved surfaces cause more runoff and less infiltration and therefore less recharge to phreatic groundwater.

For the adaptation assignment we can conclude that it is not so much climate change but rather land use change that will influence drought conditions. Groundwater level changes will be significant where areas are greened, blue-ed or provided with permeable pavement. And transpiration will change accordingly. As transpiration plays an important role in heat stress prevention, the availability of water for transpiration could become critical during long dry and hot spells in summer. Irrigation of the vegetation could become necessary during extreme drought and to avoid heat stress.

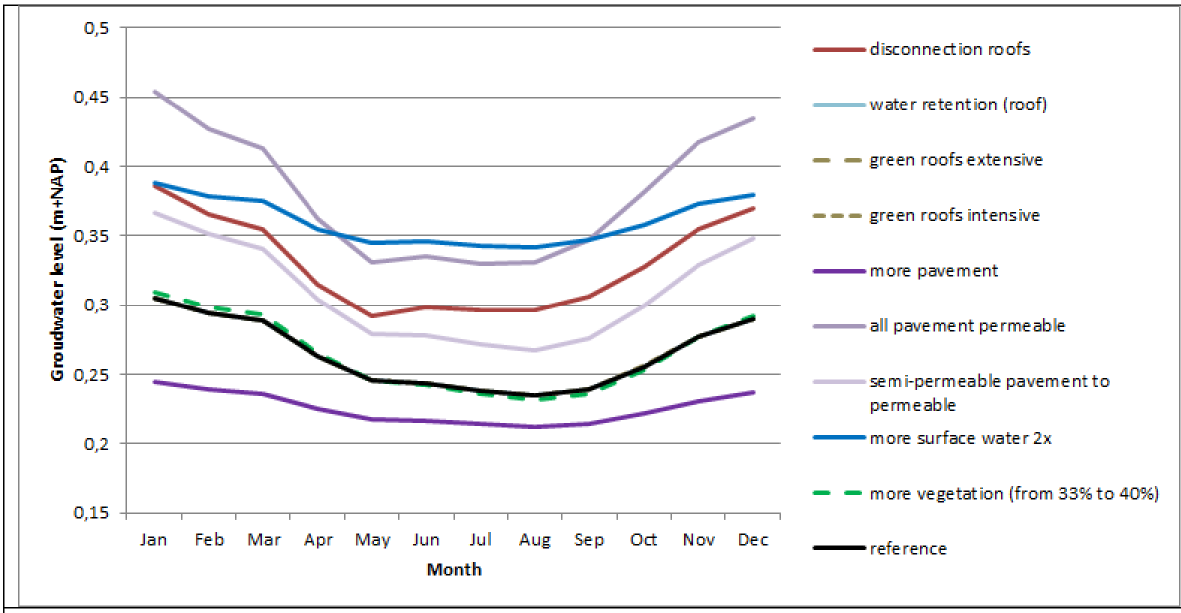


Figure 4.7 Effect of different land use interventions on groundwater level. Green roofs extensive, green roofs intensive and water retention coincide with the reference scenario. (Van der Meulen et al., 2015)

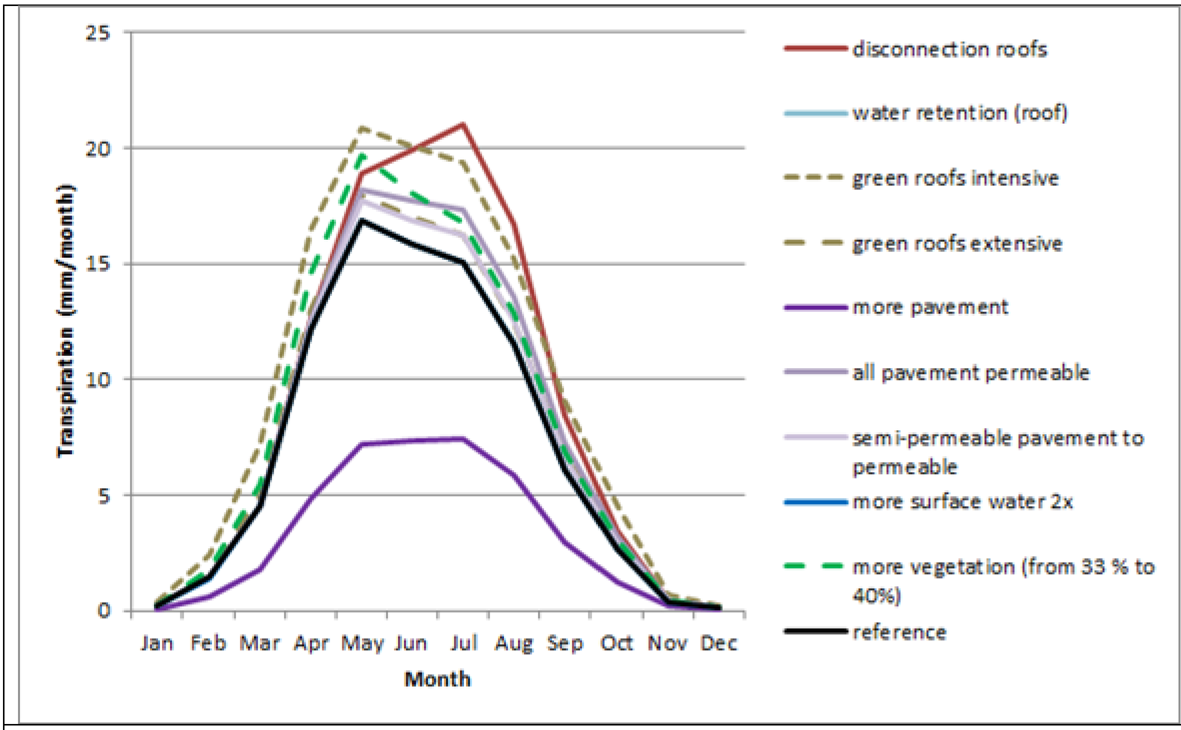


Figure 4.8 Effect of different interventions on transpiration. Surface water coincides with reference scenario. (Van der Meulen et al., 2015)

4.6 Heat stress

Basic information on heat stress was made available by the municipality of Utrecht. Heat stress maps were produced by TAUW (2015). Figure 4.9 shows the heat stress map for the project area with the current layout of buildings and infrastructure.

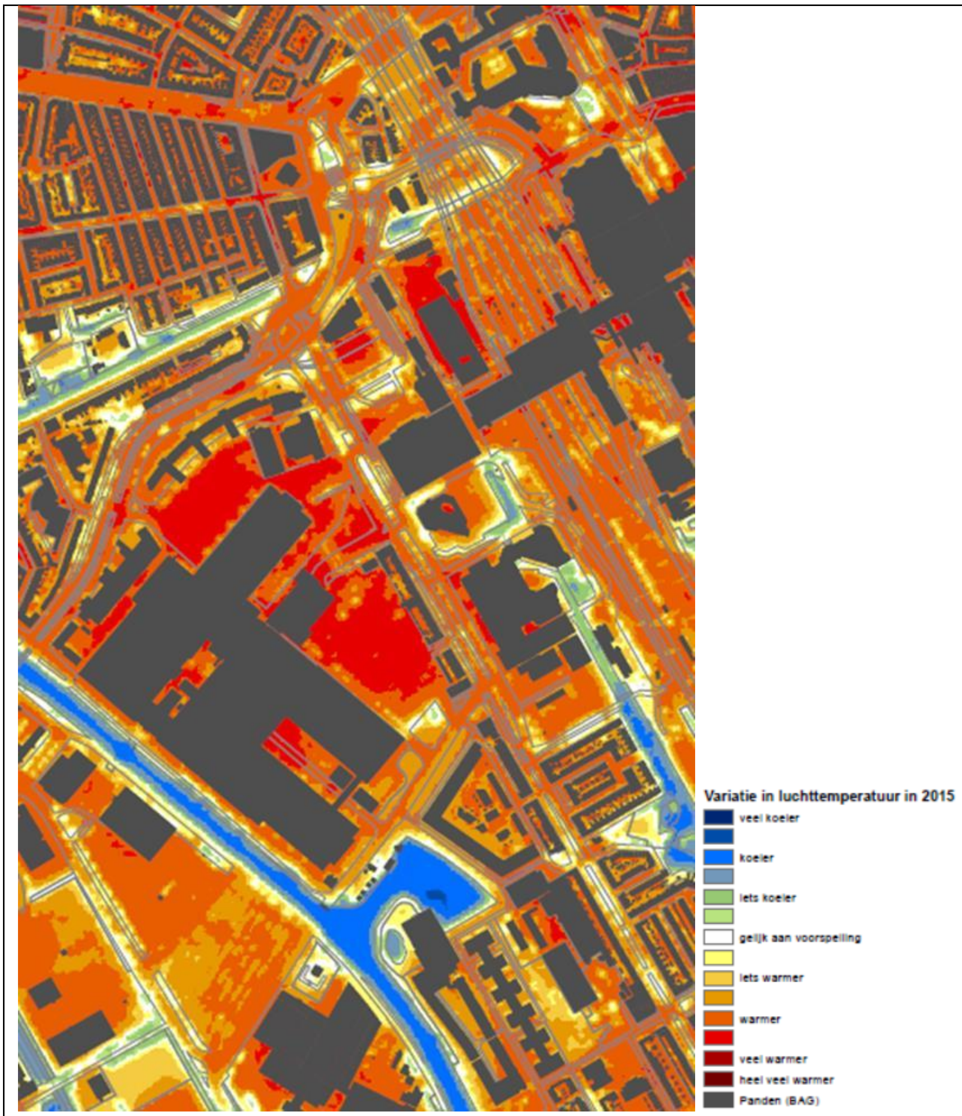


Figure 4.9 Heat stress map of Utrecht Centre area for current climate. (TAUW, 2015)

When the reconstruction plans for Jaarbeurs and Phase 2 the Utrecht Centre-West area will have been realized the distribution of heat stress in the area will change. Currently, the parking areas around the Jaarbeurs (black asphalt, covered soil) and hot spots between buildings experience the highest temperatures during a hot period.

In order to avoid excessive heat in the area we ought to reduce the average maximum temperatures at street level on a hot summer day with at least 2-3 ^{o}C; in particular pedestrian zones, bicycle paths and open air recreational areas would benefit from greening and blue-ing to reduce ambient air temperatures.

Future exposure to heat will depend on the share of green areas and open soil, and especially the availability of trees, on the orientation and height of the new buildings. Vegetation can reduce urban heat by providing shade and evaporative cooling. Besides cooling effects, green elements have a positive influence on the perception of temperature (Gehrels et al., 2016). For the Utrecht Centre West district, adding more green elements to the area transpiration, and thereby evaporative cooling, increases (see Figure 4.8). Increasing the percentage of green space from 33% to 40% is expected to cause a cooling effect of 0.24 °C decrease in average air temperature and 0.48°C in maximum UHI reduction (Van der Meulen et al., 2015). In reality, the current percentage of green space in the study area is lower than the 33% which is assumed in the model calculations so the cooling effect of an increase to 40% vegetation cover will be somewhat higher in reality. The total cooling effect of adding vegetation will be complemented by the shading effect, depending on the size and positioning of trees.

Important to note is that the cooling effect of greening occurs only if the vegetation can evaporate well. Sufficient amounts of water should be available in the root zone. In Van der Meulen et al. (2015) the availability of water for vegetation in relation to evapotranspiration has been assessed for the Jaarbeurs/Station district. In general, drought stress is identified in Utrecht in areas where impervious pavement is surrounding the vegetation and where the topsoil constitutes of a layer of filling sand. Hence this soil has a limited water retention capacity in the unsaturated zone and negligible capillary rise (recharge) from the saturated zone. This may also occur in the Utrecht Centre West area.

4.7 Vital and vulnerable objects, networks and groups

Extra protection against extreme weather conditions is recommended for the vital infrastructural objects and networks in the area as well as for the most vulnerable population groups. Power and telecom outages, blocked evacuation routes, children, elderly and many more objects networks and people deserve extra protection for flooding, drought and heat stress. That is why an attempt was made to make an inventory of all these objects and groups in the project area.

The Jaarbeurs organization was able to provide us with detailed information on vital objects and networks on their properties in relation to flood risk and heat stress. For confidentiality and safety reasons this information however cannot be shared in this report.

The other part of the project area is mainly public land, maintained by the municipality. They however have no overview of vital infrastructural objects and networks (except for the evident ones). Information seems to be available for each issue, but is distributed over many desks and different parts of the organization. Within the boundaries of the current project it was impossible to collect this information and synthesize this into one map for a comprehensive overview.

Fire fighting

The Utrecht fire department reported a request when contacted about vital infrastructure. In view of the future developments in the area and due to the fact that the drinking water company is no longer capable to meet the increasing water demand for fire fighting. They are searching for a large water reservoir in the area, preferably in the (north)western side of the area. The alternative to provide water for fire fighting from wells is not attractive as this would influence both the Aquifer Thermal Energy Systems and the polluted groundwater fields in the vicinity. Harvested rain- and stormwater could provide a welcome water source close to the buildings.

5. Opportunities of blue-green adaptation

5.1 Ecosystem services

Retrofitting of blue-green measures not only contributes to the attractiveness of an urban area or to its resilience to extreme weather conditions. The adaptation measures potentially bring many other positive effects. But water availability should be sufficient and water quality should meet minimum requirements. Table 5.1 provides an overview of potential services and the requirements this sets for water quantity and water quality. More background information on the water needs for functional green spaces can be found in Van der Meulen *et al.* (2015). Also, Gehrels et al. (2016) provides an extensive overview of the effectiveness of green spaces for several ecosystem services and design principles that should be taken into account when designing green spaces. In Broers and Lijzen (2014) and Vermooten and Lijzen (2014), available knowledge on ecosystem services related to groundwater is provided in compact factsheets.

Table 5.1 Ecosystem services of blue-green infrastructure and its relation to the availability of sufficient amounts of water, water quality and the timing of service delivery

Effectiveness limited by **Ecosystem services**	**Quantity**	**Quality**	**Timing**	**Remarks**
Green spaces (groundwater and soil moisture attributes)				
Temperature regulation (cooling) through: - shadow - evapotranspiration - heat exchange	 - no - yes - yes	 - no - no - no	Water needed for evapotranspiration in summer, in particular during hot & dry spells	Shadow function only affected when tree loses leaves due to severe drought or raising groundwater*. Drought limits evapotranspiration; especially grass susceptible to drought.
Storm water runoff mitigation through: - interception - infiltration - surface storage in green spaces with low surface level	 -no - yes;	 - no - no - yes, indirect	Slowdown of discharge desirable during heavy rain (intensity and duration) to prevent sewer overflow and flooding	Interception only affected when tree loses leaves due to severe drought or raising groundwater*. In dry situation (summer): hydrophobic soil hampers infiltration Under very wet conditions (high groundwater table) : limited or no storage capacity Quality of the storm water could make direct infiltration undesirable although treatment by soil filtration is generally sufficient
Air quality regulation through - influence on air circulation - filtering air pollutants	 - no - yes	 - no - no	Services by deciduous vegetation altered by season (presence of leaves)	Influence on air circulation (either positive or negative) and particulate matter capture altered when tree loses leaves due to severe drought or raising groundwater*.

				Drought or very wet conditions may reduce the vegetation's effectiveness for absorption of gasses through the stomata of vegetation (they close).
Noise reduction through - noise reduction - reduced perception when noise source visually camouflaged	- no - no	- no - no	Services by deciduous vegetation only delivered during spring and summer	Noise reduction only affected when tree loses leaves due to severe drought or raising groundwater*.
General wellbeing and recovery through: - green environment	- no	- no	Services by deciduous vegetation only delivered during spring and summer	Uncertain: Only directly affected when tree loses leaves due to severe drought? Indirectly, this service may be limited by ponding (reduced storm water runoff mitigation)
Recreation in green environment	- no	- yes/no		Uncertain: Only directly affected when tree loses leaves due to severe drought? Indirectly, this service may be limited by ponding (reduced storm water runoff mitigation)
Water quality regulation via: - uptake of pollutants from soil (eg h. metals) - capture of pollutants from air+surface runoff	- yes	- yes/no	Services by deciduous vegetation altered by season (presence of leaves)	Toxicity may harm the vegetation
Food production	- yes	- yes		Food security is an issue (soil/groundwater quality).
Biomass production (eg wood)	- yes	- yes		Groundwater quality may limit use options.
Surface water				
Recreation: - swimming - boating - fishing - walking, biking etc - skating	 - yes - yes - yes - no - yes	 - yes - yes - yes - no - no	 - summer - spring-summer - all year - all year - winter	 Minimum depth required Certain quality required (swimming water standards, ecological parameters for fishing, transparency and smell) Skating requires constant water level In times of drought, recreation is latest (4th)priority in water distribution policy.
Water purification, pollution retention	- yes	- yes	- service provision influenced by season	Natural purification processes depend on oxic/anoxic conditions, light, flow velocity, retention time (size of water body), bed sediment conditions, macrophytes growth, etc.
Water for industrial extraction	- yes	- yes	- service provision may be influenced by season (freezing)	Resource limited by quantity and quality of the water, freezing In times of drought, industrial

				water is 3rd priority in water distribution policy.
Water for drinking water extraction	- yes	- yes		The closer the water quality to drinking water standards, the better. In times of drought, drinking water is 2nd priority in water distribution policy.
Space (e.g for shipping, housing)	- yes	- yes (for housing)		Depth, size and quality of water can limit functionality
Temperature buffering (for cooling water discharge)	- yes	- yes	Allowed discharge limited during dry and warm periods	Max. Temp is limited to increase surface water 3 ºC, max 28 °C.
Thermal energy (for harvesting)	- yes	- yes		Harvesting heat and cold is possible if size of surface water body is sufficient. Circulation of surface water should be sufficient; In times of drought, energy provision is 2nd priority in water distribution policy.
Irrigation water	- yes	- yes		
Water storage and discharge water surplus	- yes	- no		Quality of discharge water make storage undesirable
Groundwater (phreatic and first aquifer)				
Drinking water	- yes	- yes	Currently from deep groundwater, potentially 1st aquifer in future	The closer the water quality to drinking water standards, the better. In times of drought, drinking water is 2nd priority in water distribution policy.
Irrigation water	- yes	- yes		Quality requirements: mainly chloride and iron and bacteria important. In times of drought, energy provision is 3rd or 4th (depending on crop value) priority in water distribution policy.
Water for industrial extraction	- yes	- yes		Resource limited by quantity and quality of the water. In times of drought, industrial water is 3rd priority in water distribution policy.
Temperature buffering, for Aquifer Thermal Energy Storage	- no	- yes		Water quantity is more important than quality. Changes in redox conditions (e.g. as result of groundwater remediation or extractions) can result in clogging of the well.
Water quality regulation	- no	- yes		Filtration and hydro(geo, bio)chemical reactions improve groundwater quality.
Prevention of land subsidence and peat oxidation	- yes	- yes		High groundwater levels reduce subsidence; Anoxic conditions to prevent peat oxidation

Water storage	- yes	- no		Capacity depends on groundwater table/volume unsaturated zone and pore size.

5.2 Economic and social benefits

Another way of looking at blue-green adaptation is to look at the opportunities and services from the perspective of the stakeholders and to investigate what the projected benefits and co-benefits might include:

STAKEHOLDERS

In the area there are several stakeholders that may benefit from adaptation measures. A distinction is made between *direct stakeholders*, who are directly affected by the project, and *indirect stakeholders*. These have only indirect benefits and hardly any direct costs – hence there is less direct need of including them in the decision making process, but they need to be informed.

Direct stakeholders

Municipality Utrecht: The municipality has several responsibilities and ambitions in the project area. Among others, they want the quality of the environment to be good in order to increase the liveability for inhabitants. The area also serves as showcase for Utrecht, as it is the first part of Utrecht that most visitors will see. The municipality faces the challenge of dealing with an increasing numbers of travellers, as well as an increasing number of residents living in the area. They are also aiming for a healthy environment and they are responsible for the management and maintenance of the sewer system.

Water managers: Rijkswaterstaat is responsible for the Merwedekanaal, the regional water authority Hoogheemraadschap De Stichtse Rijnlanden (HDSR) for the local surface waters and a division of the Utrecht municipality for the sewers and drainage system. The major concern of the water managers is flood protection and water quality management.

Jaarbeurs: This large conference centre is an important actor in the project. They own a large part of the project area, and are directly involved in the redevelopment of the area. Jaarbeurs aspires sustainable development of their grounds, with increased quality of the nearby environment.

Inhabitants: Currently there are only few inhabitants in the project area, but in future scenario's much more housing opportunities will be provided. Several thousand new residents will be housed in the Jaarbeurs East development. They will be strongly affected by the spatial and environmental quality in the neighbourhood.

Indirect stakeholders

Travellers and visitors: The Utrecht CS area is one of the most important railway transport hubs in the Netherlands: within 10 years 360.000 travellers a day are expected to use Utrecht CS as a hub. Jaarbeurs receives over 600.000 visitors annually for meetings, expositions, trade shows and similar events and this number is growing.

Leisure companies: Three large leisure companies will be established in the project area in the coming years: Wolff Cinema Group; Holland Casino and Amrath Hotel group. Thousands

of visitors may benefit from an increased spatial quality in the area. Currently, there are two large hotels in the (adjacent) area: NH Hotel and Park-Plaza.
Other companies: There are various large offices in the area (e.g. Rabobank), and more are anticipated in the future. They too will benefit from a healthy and high-quality working environment, and good accessibility.

Types of benefits

The various services that are delivered by adaptation measures can be specified further in benefits. This gives a better overview of who may gain from the measures, which in turn helps in defining the stakeholders that are affected by the measure or service. In this study, four types of benefits are regarded:

- *Financial:* Actual profit or loss can be gained, e.g. avoided damage or decreased costs for certain activities)
- *Health:* Benefits to the physical or psychological health of humans. In some cases this can be translated in financial costs, but as this is an indirect effect and in some cases disputed, health benefits are regarded separately here.
- *Environmental:* Benefits to the environment, without direct effect on humans or business. This may encompass increased biodiversity, decreased pollution, improved connectivity, etc.
- *Other*: Benefits that do not directly fit in the benefit types above, for example reputational benefits.

The magnitude of these benefits depends on the size of the adaptation measures and context in which these are applied. Since the project is still in an explorative phase, the benefits are not yet monetized.

Benefits of services for stakeholders

The ecosystem services that may be provided by the adaptation measures can lead to specific benefits for specific stakeholders. In this section we give an overview of which type of benefits may expected by various stakeholders.

Decreased pluvial flooding
Decreased risk of pluvial flooding is one of the most important goals of this project. There are *financial benefits*, mostly in the shape of reduced damage to property and infrastructure, and *other benefits*, such as meeting safety obligations:

- Municipality Utrecht is responsible for the maintenance and management of the urban drainage system, and for any damage in the public domain (*financial benefits*). The municipality may have reputational damage if nuisance and damage from flooding occurs often (*other benefits*).
- Water manager HDSR and Rijkswaterstaat are responsible for ensuring a low flooding probability. By decreasing the flood probability/ robustness of the area future requirements and investments in drainage and pumping infrastructure may be decreased, as well as current pumping costs during storm events (*financial benefits*).

Reputational damage in case of flooding or water pollution incidents plays a role here as well (*other benefits*).

- Jaarbeurs/ Other companies/ Leisure companies: Owners of buildings are often responsible for damage caused by local flooding, unless it can be proved to be caused by negligence by water manager or municipality – this is not often the case. These parties all have a stake in decreasing flooding, as they are responsible for damage themselves (*financial benefits*). This damage can be direct, but also indirect in the form of foregone income during temporary closure or inaccessibility of the building.

Other beneficiaries include inhabitants and travellers. Damage from flooding may be direct for home owners, but also indirect due to inaccessibility of houses and increased travel time (*financial benefits*).

Improved air quality
It is not expected that the air quality will be improved as a result of most proposed measures. Traffic reduction is much more effective. Improved air quality leads to *health benefits*: decreased health costs, increased length of life and increased quality of life. This is especially relevant for residents and in lesser degree also to others staying in the area: visitors, (frequent) travellers and employees of companies. *Other benefits* are derived by the Utrecht municipality that has the obligation to ensure a healthy living environment and meet regulations. If air quality improves significantly, health insurance companies could also be expected to benefit from increased air quality, as this leads to less claims for health costs related to respiratory and vascular diseases.

Urban climate
In the context of this project, ‘Urban climate’ relates mostly to the urban heat island effect. This is especially relevant for inhabitants and visitors – providing *health benefits* mostly for elderly. The municipality has a responsibility for providing inhabitants with a high quality living environment (*other benefits*). Other beneficiaries may include visitors to the area, and companies – a pleasant environment will increase attractiveness of the area for clients and increase their length of stay (*other benefits*).

Increasing water quality and quantity
Although water quality and low groundwater levels are not considered problematic in the area, many adaptation measures have a positive effect. E.g. in this case green shores may improve the quality of the surface water, whereas parks and trees add to replenishment of groundwater. Improvements of water quality and -quantity in the area potentially leads to the following benefits and beneficiaries: Improved water quality will benefit water managers responsible for surface water quality (*financial benefit*) as well as water recreants (*health benefits*), and improves habitats (*environmental benefits*).

Energy use
Energy use is decreased due to green roofs providing better insulation, and trees in the streetscape causing decrease cooling demands in summer (they provide shade) and decreased heating demands in winter (by decreasing the cooling effect of the wind). Though

this could be seen either as a financial or environmental benefits, it is primarily a *financial benefit*, mostly for the Jaarbeurs, which has many buildings in the area and will have most green roofs. As the ambition of the Utrecht municipality is to develop the area in an energy-neutral way, the decreased energy demand also adds to reaching this goal (*other benefit*).

CO_2- reduction

Storage of CO_2 in biomass can be seen as either a financial, environmental or other benefit. Some stakeholders, like companies, may have reduced taxes, less costs for emission rights or advantages with respect to customers or clients when they operate in a sustainable way (*financial benefits*). It could also be less tangible: more beneficial in a marketing context, and in meeting their own sustainability goals: such as the Jaarbeurs and the Utrecht Municipality (*other benefits*). Additionally, CO_2 reduction has benefits for the *environment*.

Increase recreation opportunities

Increasing the recreation opportunities in the area, through parks, intensive green roofs and water squares, green shores and increased size of surface water as well, has various benefits. The attractiveness and multifunctional use of the area increases, which is an ambition of Municipality of Utrecht (*other benefits*). For inhabitants the quality of the area increases, with more relaxing activities in green areas nearby: this has various *health benefits*, though the exact effects and enabling variables need to be further investigated (Hunter e.a., 2015; Lee & Maheswaran, 2010). Especially for leisure companies, including the Jaarbeurs, the increased recreation opportunities attract more visitors to the area and/ or make the area more attractive for clients (*financial benefit*).

Increase landscape quality

An increased landscape quality in the area is the specific ambition of the Municipality of Utrecht and Jaarbeurs. This improves the entrance of both the city and Jaarbeurs, serving as an attractive showcase. This will improve the image of the municipality and the Jaarbeurs (*other benefits*), and may attract more tourists and visitors to the region (*financial benefits*). Other important beneficiaries are people who often visit the area: inhabitants, travellers and visitors. They will be happier during their stay in the area (*health benefits*). Leisure companies, and to some degree other companies will also benefit from the improved quality of the neighbourhood, as this may attract more customers or increase their length of stay. It is also known that the property value of buildings (especially houses) is larger when there is green-blue space nearby (*financial benefit*).

Increase social cohesion

If green roofs, parks and water squares are designed in such a way that they can serve as community centre/ community activity or meeting place, they increase social cohesion in the area. This is one of the ambitions of Utrecht Municipality (*other benefits*). Residents directly benefit from increased social cohesion: they are the main target group (*other benefits*).

Increase physical activity

Parks, intensive green roofs where gardening or walking is possible, and green shores can encourage participation in physical activity of children, and in lesser extent adults (Hunter e.a., 2015). This has *health benefits* for residents and possibly also attracts visitors. The health of residents- and decreasing health costs – is an ambition for the city's Healty Urban Living programme (*other benefits*).

Decrease noise pollution
Though strongly dependent on the configuration of the green measures, especially parks and trees in de streetscape can decrease noise pollution. Noise pollution in the area originates from traffic and occasionally from the Jaarbeurs (music events). Currently, noise pollution may especially harass employees from regular companies, but when in the future the area will house more inhabitants, noise pollution problem may increase. Keeping noise pollution and nuisance to a minimum is a responsibility of the municipality (*other benefits*). Jaarbeurs may suffer from complaints, reputation damage and possibly even fines if the area is used more intensively in the future (*financial* and *other benefits* from decreasing pollution). The third party benefiting from decreased noise pollution are residents: noise pollution leads to increased stress and sleeplessness (*health benefits*).

Improve habitat function and biodiversity
Most blue-green adaptation measures positively affect biodiversity by providing habitats for flora and fauna (*environmental benefit*). This even holds for subsurface life. This is a benefit for residents, as the attractiveness of the area increases, and for the Municipality Utrecht, who aim to increase biodiversity in the city (*other benefits*).

We will use this overview to evaluate planned adaptation measures for our project area Utrecht Centre-West. Although it is impossible to quantify the benefits this early stage of planning we can use first draft plans in combination with this overview to give a first qualitative overview of the potential benefits for each of the stakeholders. This overview is made up in section 7.3.

6. Potential of Rooftop Greenhouses

6.1 'Vergroenting' / urban agriculture

In the Toekomstvisie Utrecht Centrum 'a Healthy Urban Boost', the use of roofs for urban farming (so called 'vergroenting') and more specifically a large greenhouse on the roof of a car park building are suggested as contributors to local food production serving the nearby office-canteens. Although multi-functional use of roofs is certainly a good aspiration, the question arises whether a rooftop greenhouse in the Netherlands would lead to a profitable business. If not, a next question would be whether there could be additional services that lead to a solid business case for a rooftop greenhouse.

In this study we have made an inventory of the various functions and services that a rooftop greenhouse could deliver and we have scanned the costs and benefits of each of these functions[3]. This analysis serves as an inspiration for new buildings in the Utrecht station area and the Jaarbeurs. For that reason, small greenhouse projects in roof gardens of individuals have not been included in this study.

6.2 Overview: rooftop greenhouses

The installation of greenhouses on roofs is not yet widespread. Especially large-scale projects are rare, but several of them have been developed in the past years. Interestingly, there are many different forms of rooftop greenhouses:

- as public gardens
- for local retail
- for educational purposes
- in the hospitality sector
- as showcases

First of all, there is the "public garden" concept. The rooftop is used as a recreation, education or meeting area for residents. Sometimes there is a "city farmer" who coordinates the farming work; in other cases, there is a neighbourhood community who uses the park and greenhouse as a meeting place. In all cases, the social aspect of the rooftop garden is the main driver for its realisation. Examples of such rooftop gardens are the Bigshops Dakpark in Rotterdam (NL), the Tuinfabriek in Utrecht (NL) and the Food Roof Farm in St. Louis (USA).

Secondly, rooftop farming for supermarkets and local clients has emerged in recent years. In these cases, greenhouses are used to ensure production all year long. The products are

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[3] Researched cases include: Bigshops Dakpark in Rotterdam (NL), Tuinfabriek in Utrecht (NL), Food Roof Farm in St. Louis (USA), Comcorp inc, a Singapore based start-up (SG), Gotham Greens, a Chicago based company (USA). Lufa farms, Montreal (CA), Paradijsvogelschool in Utrecht (NL), Hotel Amstelkwartier, Amsterdam (NL), Vida Verde in Honselersdijk (NL), Restaurant de Kas, Amsterdam (NL), Greennest Hotel in Amsterdam (NL), ONZE volkstuin in Almere (NL), Start-up GrownDownTown in Amsterdam (NL), the ICTA-ICP building of the University of Barcelona (ESP), neighbourhood Hoogeland-Oost in Naaldwijk (NL), Startup Versafarms (NL), Startup Homegrown (NL).

sold to close-by clients (individuals or restaurants) or delivered to a supermarket in the neighbourhood or in the same building. In North-America, several rooftop greenhouses have been developed in this form, such as 3 farms of Gotham Greens in New York (USA) and Lufa Farms in Montreal (CAN).

A third form of rooftop greenhouses is built on schools. Schools often have large (flat) roof surfaces, and can combine the greenhouse with educational programs. The Paradijsvogelschool in Den Haag (NL) and the ICTA-ICP building of the University of Barcelona (ESP) are examples of this type of greenhouse.
Fourthly, rooftops greenhouses can be combined with hotels or restaurants. On a high building, it is impossible to create sufficient food production to feed all users; in this variant, the rooftop greenhouse delivers specialized products (e.g. herbs and spices) and forms a recreation or inspiring place. The added value of such greenhouse should result in added value for the hotel or restaurant in the form of more customers and/or a product of higher value. An example is the new built Hotel Amstelkwartier in Amsterdam (NL). “Restaurant De Kas” in Amsterdam (NL) is an example of how a greenhouse can be an premium location for restaurants, though it is not built on a rooftop.

Last, several forms of rooftop greenhouses functioning solely as “inspiration location” or showcase area exist. An example of such a location is the greenhouse of the horticulture store Vida Verde in Honselersdijk (NL). The greenhouse is even called “House of Inspiration” and is mainly a showroom and meeting place, where only few plants are cultivated.

6.3 Methodology

People representing several of these concepts have been interviewed for this study, in order to get more detailed information on the benefits and drawbacks of the concept. They have been asked about their production system, organization, clients (if any), (additional) functions, energy and water system, business model and financing, technical issues and general challenges and advantages. Information from digital sources and public literature has been used to complement the overview.

6.4 Added values and greenhouse functions

An overview of greenhouse functions and their added values is shown in Table 4.1. But first added values are briefly explained.

Community building: A greenhouse can function as a community building in a rooftop park or garden. If the rooftop is not publically accessible, this function is less relevant.

Food production for individuals: The greenhouse can be used in a public garden or school. The applicability of this value depends on the available surface per person and on the way the greenhouse is organized (public, private or community-owned).

Food production for commercial selling: Food production for commercial purposes is only possible if the scale (i.e. the greenhouse surface) is large enough, if there is a profitable business model and by focussing on high-value crops (e.g. fast growing crops or crops with a strong branding) and upmarket clients (willing to pay a bit more for locally produced food). For the Netherlands, it will be difficult to get enough revenues from this function, mostly due to the fact that prices for crops in the Netherlands are relatively low in comparison to neighbouring countries (see Figure 6.1) and other regions, such as North America and Russia.

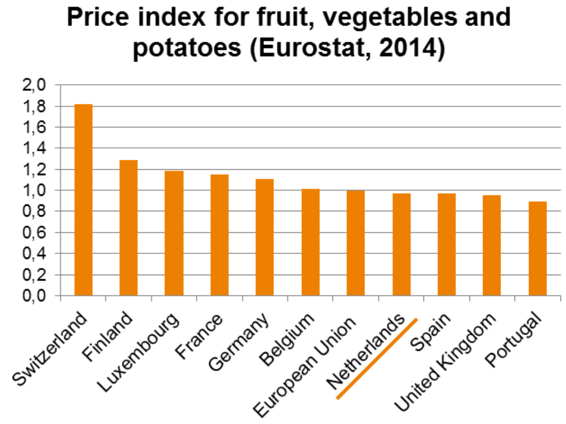


Figure 6.1 Price index for crops in the Netherlands as compared to other European countries.

(Social) Employment: In some cases, the creation of a rooftop greenhouse can create new jobs. This is especially appealing for local governments when jobs are created for the long-term unemployed or workers with disabilities, which is feasible in a greenhouse. Note that this is mostly dependent on the scale of the greenhouse, and not per se on the type of greenhouse; however, in some cases the scale is more likely to be larger (farming for supermarkets) than others (schools).

Education: Rooftop greenhouses can be accompanied by an educative programme or service. The applicability of the educative programmes depends however also on the other goals of the greenhouse, especially commercial goals (e.g. an exclusive hotel area).

Inspiration: To offer an inspiring location, a rooftop greenhouse is often associated with commercial services which use the greenhouse for branding or a meeting place for customers and business partners.

Recreation: Greenhouses can offer a warm and sheltered space in a (rooftop) park or otherwise exposed rooftop area. However, when used for recreation, less space remains for growing food crops.

GHG mitigation: Greenhouse gas emissions mitigation can be achieved by reducing transport distances (in case of food production) or by smart energy systems. However, locally produced food does not automatically lead to a decrease of ‘food kilometres’, and transport results in only a small contribution to the total CO2-emission of food production (see Nunes et al., 2015 for the results of a literature review on this matter). Smart energy systems may have higher potential, for example using heat and cold storage or exploiting synergies with local energy consumers with a different profile. Using heat and cold storage to minimize energy use for greenhouses is already common in the Netherlands, and the first pilots where excess heat from greenhouses is used for heating of neighbourhoods through such storage facilities are currently implemented, such as the newly build neighbourhood Hoogeland-Oost in Naaldwijk.

Water retention: Water storage is often associated with greenhouses because it allows to make efficient use of resources. Especially on rooftops, water retention and reuse in the greenhouse can be a valuable function in view of the impacts of climate change. This value is largely independent on the type of greenhouse; it can be useful in all occurrences. For example, a greenhouse water storage spill has been developed that can temporarily store excess rain water on the greenhouse roof, which can be subsequently drained towards a long-term water storage tank for use within the greenhouse.

Table 4.1 Overview of added values of several types of rooftop greenhouse functions.
Scores range from ++ (very applicable value) to -- (not applicable at all) and are based on expert judgement by the interviewed researchers

Added value → Rooftop greenhouse function type ↓	Community building	Food production for individuals	Food production for commercial selling	Production of high-value herbs	Employment	Education	Inspiration	Branding	Recreation	GHG mitigation	Water retention
1. Public garden	++	++	0	++	0	+	+	--	++	-	+
2. Local retail	--	-	++	++	++	-	0	+	--	+	+
3. Schools	0	0	-	+	0	++	+	+	0	0	+
4. Hospitality	--	-	-	++	0	-	++	++	+	0	+
5. Showcase	+	--	0	+	+	++	++	++	0	+	+

6.5 Cases of rooftop greenhouse functions

TYPE 1: PUBLIC GARDEN

Greenhouses can be valuable additions to rooftop gardens or public parks. In such a situation, the greenhouse has more functions than only growing crops more quickly. For example, the residents of the surrounding area of the Bigshops Dakpark in Rotterdam, the largest rooftop garden in Europe, asked for a greenhouse in the park because they wanted a sheltered community building and a greenhouse reflects both the idea of a public park and a community centre. The neighbours wanted to use it partly for farming, though the surface is not sufficiently large to produce substantial amounts of food. They would also use the greenhouse for small educative projects and maybe to rent the location occasionally to small parties, for business or club meetings, against a small financial compensation which could then be used to support local initiatives. The financial organization of the park's greenhouse was thus mainly based on subsidies.

In case of the Dakpark Rotterdam, the greenhouse was not taken into service as a community centre in the end, because the municipality couldn't find sufficient funding and rented the whole greenhouse to a local entrepreneur. The entrepreneur does not use the greenhouse for any other purpose than serving food as no plants or crops are grown, nor is the energy services a greenhouse could provide, exploited actively. This illustrates the importance of sufficient funding and a well-thought business plan in case of public gardens and rooftop greenhouses.

Type 2: Local retail

There exist several business models for rooftop greenhouses in relation to customers, as reflected by the current businesses of the American and the Canadian greenhouse companies Gotham Greens and Lufa Farms: some of the greenhouses produce directly for the supermarket underneath the greenhouse; while others produce food and deliver it to near-by restaurants and individuals. In principle, they can grow all kinds of fruits and vegetables, but currently they focus on fast growing vegetables and herbs which are high-value crops due to the emotional value of these products for premium customers. The main greenhouse of Gotham Greens produces 200-300 tons of crops annually on a production area of 185 m^2. COMCROP's facility in Singapore has a larger scale of 550 m2 and produces 1 ton of herbs per month.

The benefit of the rooftop greenhouse is that it reduces transportation distances of food and that it does not require occupation of agricultural land, but uses otherwise unused space. However, experts have noted that they do not expect these benefits to balance the added costs for extra construction costs for the supporting structure and the operating costs for producing crops above ground level. Most rooftop greenhouses used for commercial production of crops are built highly energy and water efficient, by recirculating (hot or cold) air from the building below and by recirculation of rainwater in an innovative aquaponics system. Heat and cold storage is not included in the above mentioned cases, as the greenhouses were build atop of existing infrastructure with no heat and cold storage facilities (an old building was upgraded, not a new building was built). This could be a valuable addition for new built greenhouses in the Netherlands, where these facilities are more common.

The higher investment costs require a good marketing or crowd funding campaign for the start-up phase and premium prices for products. Nevertheless, urban rooftop greenhouses are growing in number and Gotham Greens considers rooftop greenhouses as a necessary form of agriculture in the future to ensure sufficient food for the world population against the lowest environmental cost. In the Netherlands, this situation might be different because the current crop prices are very low due to the high production greenhouses in the Westland area.

Type 3: Schools

Rooftop greenhouses can be a valuable addition to the conventional educational programmes of urban schools which often have little public space around them and no green areas nearby. Constructing a rooftop greenhouse can improve the education system in a number of ways, for example through classes on nature, arts and technical workshops. However, constructing a greenhouse on a school in a densely built urban area is challenging in many ways as well, for example legally and financially.

The basic requirement for making a rooftop greenhouse on a school a success is to bring the necessary stakeholders together and take the time to develop a successful business case. The aforementioned school in Den Haag (NL) already had a focus on sustainability when they came up with the idea of a school garden. It was then a logical next step to include a greenhouse, because it provides an additional educational space in a rainy climate and it accelerates the growing process.

Although it was an aim of the greenhouse project that kids could grow their own vegetables, the school was realistic about the potential of a rooftop greenhouse. They expected the kids to learn from it, not to produce large amounts of food. Teachers were not specifically trained for it; this was also a learning experience for them.
It wasn't a goal either to do something with the heat and cold system of the greenhouse; incorporation in the school's energy system was too difficult. The greenhouse is built in such a way that it requires little maintenance; this was a financial prerequisite, because the school managed to find funding for the construction but not for the whole service life of the greenhouse.

The school faced more challenges to build the greenhouse than they imagined on beforehand, amongst others in obtaining building permissions, altering the emergency pathways and other minor issues. The main reason for success, in the opinion of the school itself, is the optimism and ambition of the school board and the parents, the financial support from diverse funds and the practical (non-financial) help from parents and companies. Nevertheless, this case illustrates how a school can realize a rooftop greenhouse which will last for years.

Type 4: Hospitality

Small rooftop greenhouse will not be able to provide a good return on the investment costs by selling the herbs or vegetables, nor can you produce a substantial part of the hotel's demand for food. This is demonstrated in the case of the Hotel Amstelkwartier in Amsterdam, in which the rooftop surface is simply too small in comparison to the total floor surface of the hotel.

However, that does not mean that the greenhouse has no added value. It provides added value to the hotel because it contributes to the sustainability goals of the hotel (e.g. by growing a part of its own vegetables and closing water loops), by creating more "green space" and by offering a comfortable lounge area. The main values are thus in branding, recreation and an inspirational setting for guests. In the end, the rooftop greenhouse provides the hotel a competitive advantage and unique selling point.

Several Dutch start-ups are targeting the hospitality sector with small-scale crop-growing facilities that can be integrated into a greenhouse and/or the building's structure, such as Versafarm and the high-tech "Homegrown" design. In any case, cooperation with the creative sector to create visually attractive settings including crop production is recommendable.

Type 5: Show case

The horticulture centre Vida Verde is an example of how a rooftop greenhouse can provide an inspirational meeting place. The company uses the rooftop greenhouse as a showroom for new products, concepts and trends. In such a way, the construction costs of the greenhouse will not deliver a direct return on investment and the added value is materialized through branding and customer contact. When a rooftop greenhouse is incorporated in a company building, it depends on how the company is organized whether the greenhouse can be used for social employment projects, recreation, production and education. For example, if the company profile supports the support of school projects, educational services can be more easily realized than in the case where the company has special confidential information and a strict door policy.

6.6 Rooftop greenhouses potential

The analysis of potential added values provides a broad overview of the advantages and disadvantages of rooftop greenhouses. Several conclusions can be drawn from this analysis:

First, the production of food in rooftop greenhouses is only economically feasible if the project scale is large enough and the business case is focussed on the production of premium crops. Examples of such business models include partnerships with local restaurants or hotels, offering a "local food box" system with contracted clients who are prepared to pay for a premium product. When considering this type of business model, it is important to take into account that food prices in the Netherlands are low due to the highly efficient greenhouses in the Westland area, which makes the business case less profitable than in America.

Secondly, the investment costs of the construction of a rooftop greenhouse are higher than those of conventional ground level greenhouses. However, the investment might be justified by added benefits from branding (e.g. a "green image" and higher hotel room prices) or offering inspirational meeting places (e.g. conference rooms in a greenhouse can provide a premium compared to "standard" conference rooms).

Thirdly, the practical drawbacks and challenges of a rooftop greenhouse are multiple, and a clear vision, ambition and optimism are prerequisites for a successful project. When building on top of an existing building, it can be difficult to organise heat and cold storage, to realise the necessary supporting structure or to integrate the water and energy system of the greenhouse with the rest of the building. Greenhouses on top of new buildings can be easier to implement if they are included in the designs in an early stage.

Lastly, the energy benefits of rooftop greenhouses are often overestimated; it requires a sophisticated design to decrease energy use substantially. It is true that a greenhouse produces heat in summer and is (partly) protected from cold in winter, but to exchange these temperature gradients requires a heat and cold storage system which is often not available. Some projects “reuse” office heat (or cold) in the greenhouse, but when the hot office air is brought to the greenhouse, the office itself needs “new” heat, thereby not always reducing the total building’s energy demand. Greenhouses are also sometimes mentioned as “an extra insulation layer” on top of an office (or other function) building; this is however dependent on the specific design and cannot be claimed for all rooftops.

Summarizing for the Utrecht station area, it is clear that rooftop greenhouses for food production can only be financially viable if the rooftop surface is sufficiently large (e.g. the commercial food producing greenhouses in America range from 1300 to 5500 m^2) and if the right crops (e.g. high value herbs) and business model are developed (e.g. a “local food box” system, or contracts with Jaarbeurs restaurants).

It might be a more valuable option for the station area to focus on indirect added values of rooftop greenhouses like branding and providing a premium hospitality experience, eventually combined with education or social employment functions. The value of the Jaarbeurs conference centres can be enhanced by this special form of branding and offering a relatively unique conferencing atmosphere. The investment costs have to be earned back by the added revenues for the conference centre.

7. Spatial planning with adaptation measures

7.1 Collaborative design sessions

Within the SSD project two workshops have been organised to co-create a climate resilient desing for the project area. The aim was to reduce pluvial flooding and heatstress in the project area. The focus was on implementation of sustainable climate adaptation interventions to meet the ambition of the municipality.

The first workshop consisted of two rounds to which the different stakeholders from the municipality, the Jaarbeurs and external urban designers were invited. They were asked to implement blue-green measures in the project area and discuss which would be the best options. This resulted in some good interventions. However there was not enough time for discussion, and not all relevant stakeholders were present at the workshop or during both rounds. Therefore the results can be seen as a first exploration of adaptation options.

Based on these results a second workshop was organised with three stakeholders from the municipality to implement additional interventions, especially in public space. The background of the stakeholders were public health, water management and urban green. Additionally experts on watermanagement and urban climate adaptation from Deltares and TNO were present.In this second session the municipality opted for twoalternatives, one **green alternative** and one **high density urban alternative**. In this workshop more detailed plans for a climate resilient project area were developed. Appendix I gives an overview of projected adaptation measures.

To maximize potential benefits of adaptation, to better meet the adaptation targets for flooding and heatstress and based on suggestions made during the sessions, several additional measures were added to the two alternatives. Green roofs were added to most of the buildings in the green alternative. In the urban alternative a storage tank was added for stormwater harvested by the Jaarbeurs and a park area was converted to a square with porous pavement. This **maximized benefits alternative** aims at creating added value to stimulate liveability and spatial quality of the project area.

7.2 Blue-green adaptation alternatives

Alternatives

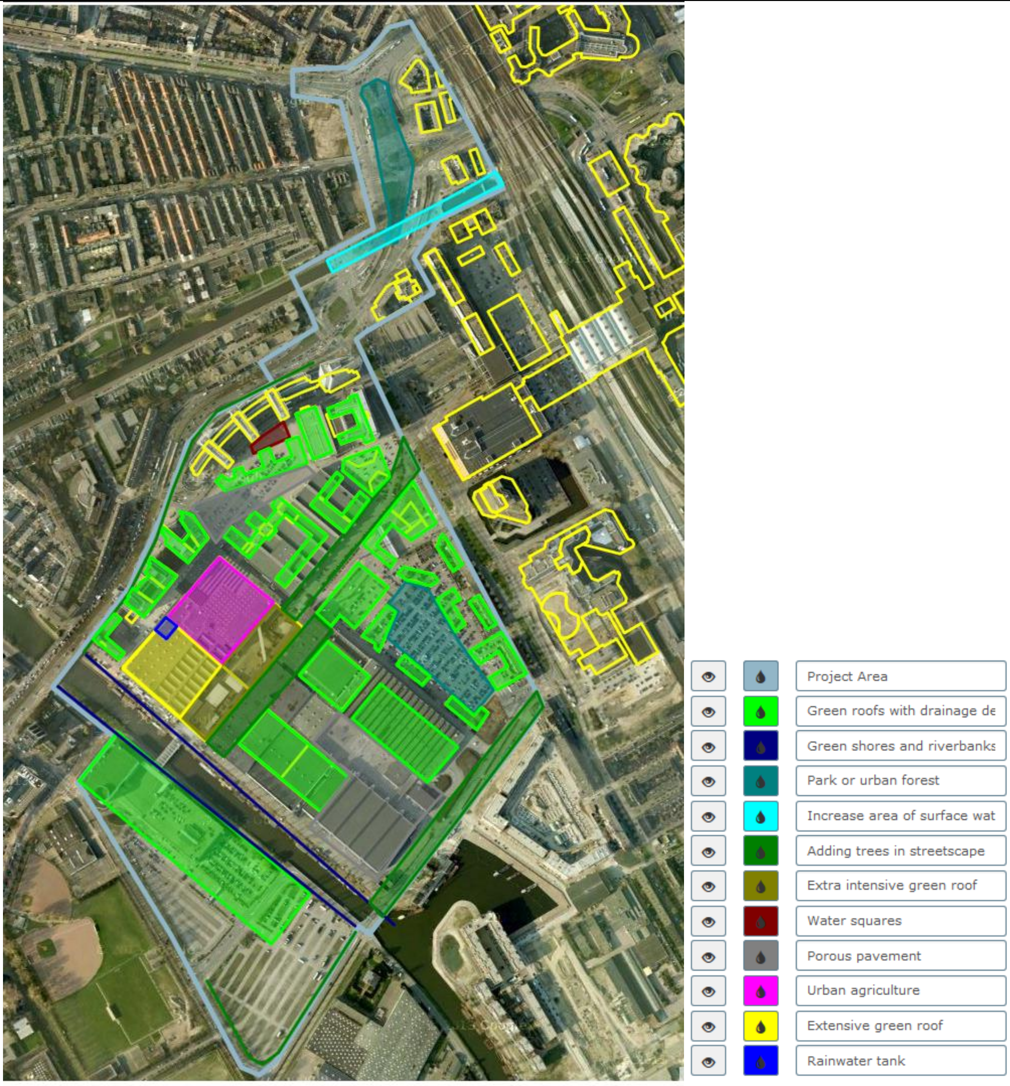
Figures of the three alternatives are shown below, in Figures 7.1 – 7.3, including the estimated performance of each of the interventions. The project area – see also Figure 1.2 - covers 52 hectare, which sets the design storage capacity to 15,600 – 18,200 m^3 according to the assignment formulated in paragraph 4.4.
Peak flow reduction is quantified as the new return time for what is now the once per two years peak flow; this reduction is the result of the increase in available storage capacity.
Heat stress reduction as the result of greening the environment is expressed as the expected decrease in average maximum ambient air temperature.

Intervention	Storage capacity (m3)	Return time (y)	Heat reduction (C)
Adding trees in streetscape	1345	21.4	-0.06
Extra intensive green roof	2142	4.0	-0.02
Green roofs with drainage delay	5416	23.6	-0.11
Green shores and riverbanks	2888	12.5	-0.01
Increase area of surface water	1052	11.5	0.00
Park or urban forest	1040	16.9	-0.04
Porous pavement	931	5.3	0.00
Water squares	540	4.2	-0.01
Grand Total	**15354**	**85.3**	**-0.25**

Figure 7.1 Green development alternative for blue-greening Utrecht Centre-West area.

Intervention	Storage capacity (m3)	Return time (y)	Heat reduction (C)
Adding trees in streetscape	1281	21.4	-0.06
Extra intensive green roof	2141	4.0	-0.02
Green roofs with drainage delay	1679	8.1	-0.03
Green shores and riverbanks	2887	12.5	-0.01
Increase area of surface water	1162	12.4	0.00
Park or urban forest	405	16.7	-0.02
Porous pavement	1107	14.7	0.00
Rainwater tank	989	2.1	0.00
Water squares	540	4.0	-0.01
Grand Total	**12194**	**79.9**	**-0.14**

Figure 7.2 High urban density alternative for blue-greening Utrecht Centre-West area



Intervention	Storage capacity (m3)	Return time (y)	Heat reduction (C)
Adding trees in streetscape	2178	23.1	-0.08
Porous pavement	2989	20.4	0.00
Water squares	540	4.2	-0.01
Urban agriculture	1201	4.4	-0.01
Extra intensive green roof	2142	4.0	-0.02
Extensive green roof	417	2.1	-0.01
Green shores and riverbanks	2888	12.5	-0.01
Increase area of surface water	1052	11.5	0.00
Park or urban forest	1040	16.9	-0.04
Rainwater tank	494	4.0	0.00
Green roofs with drainage delay	4588	22.2	-0.10
Grand Total	**19528**	**105.0**	**-0.28**

Figure 7.3 Maximizing benefits - alternative for blue-greening Utrecht Centre-West area

HEAT STRESS REDUCTION

Projected land use changes in the Jaarbeursplein East area will particularly change heat stress in that area. To give a more detailed impression of the possible effect of the alternatives, the trial allotment for the Jaarbeurs East area – see section 1.4 for more details- and an assumed future layout of Jaarbeurs buildings has been taken as a starting point for sketching a new heat stress map. Figure 7.4 shows the result if there would be no green areas included. Figure 7.5 displays the heat stress using the indicative distribution of trees and green according to the Maximizing benefits alternative and expert judgment.

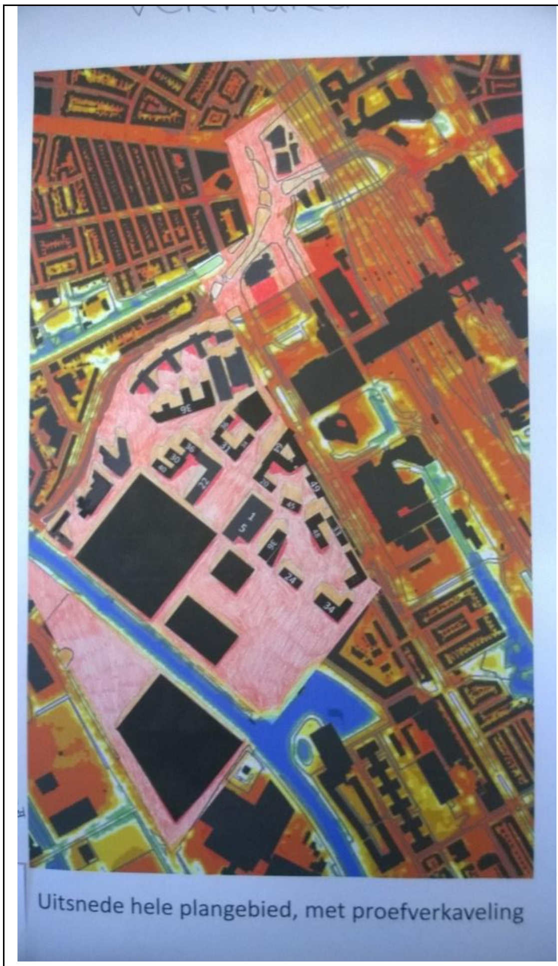


Figure 7.4: Sketch of heat stress map: no green areas

Figure 7.5 Sketch of heat stress map: area with grass areas and trees

Figure 7.4 shows a predominantly “hot” urban area, whereby the shadow of the planned high-rise buildings creates areas that will be slightly cooler than the surroundings. South-facing facades especially between buildings create new hotspots.
In Figure 7.5 tree lines create cool areas. Their precise location can be crucial for their effect: the map shows in the center a hot stretch between the Beatrix gebouw and the Jaarbeurs (the entry avenue) because a tree line at the north side was assumed that cools the buildings behind it, but not the walking area in front of it. This shows that in particular pedestrian zones, bicycle paths and open air recreational areas would benefit from well-placed greening and blue-ing to reduce ambient air temperatures.

Important to note is that the cooling effect of greening occurs *optima forma* only if the vegetation can evaporate well. Sufficient amounts of water should be available in the root zone. This could require irrigation and creates a water demand during hot and dry summer periods.

7.3 First evaluation of alternatives

As can be seen from the figures above, not all alternatives perform similar; the high density urban scenario does, in its current form, not even meet the design storage capacity for the area. Also the estimated average heat stress reduction over the total area is limited. But due to the greening of transit zones and accommodation areas for pedestrians and bicyclists the *perceived* heat stress is reduced substantially on sites that matter. Peak flow reduction is also substantial, due to the stormwater retention volume that is created.

It is considered too early to compare the three alternatives as a whole, as the presented plans are only first drafts. Their total performance can further be improved by an analysis of the performance, benefits and effectiveness of individual adaptation measures. A first overview:

- '**Green roofs with drainage delay**' were planned to reduce the runoff from the large area of flat roofs in the Jaarbeurs area. These are roofs that are covered with vegetation and a growth medium. Underneath the growth medium is a waterproofing membrane and drainage *and irrigation* systems. The drainage delay facility is added to delay runoff from the roof by using the drainage layer as a retention reservoir. The advantage of these roofs is that a relatively large storage capacity can be reached with a relatively thin growth medium and a thin layer of water, hence having a limited weight. Due to evaporative cooling the temperature above a green roof can be lower than above a traditional roof if sufficient soil moisture is available to the plants on the roof. The irrigation system is used to sustain evaporation during hot and dry spells. Such green roofs also produce ecological services and could be used for urban horticulture. See also Hendriks *et al.* (2015).
- '**Extra intensive green roofs**' were implemented to create a roof top park on top of the Jaarbeurs, where also cafés and restaurants could be located. These roofs have a thickness over 50 cm and can support a wide variety of plants. Underneath the growth medium is a waterproofing membrane. Water can be stored within growth medium of the green roofs. Annually the runoff reduction equals the evapotranspiration rate. During extreme events the peak flow is reduced by temporal storage of stormwater. Due to evaporative cooling intensive green roofs have a cooling effect, however not at street level. Such roofs have no irrigation system and their weight is considerable.
- '**Adding green (trees) in streetscape**' was implemented to improve thermal comfort and stormwater retention along the main entrance boulevard to the Jaarbeurs and along the roads around the Jaarbeurs. Trees reduce the air air-temperature by evaporative cooling and providing shade. Next to improving thermal comfort it reduces runoff through interception and infiltration underneath the tree (tree-pit bioretention).
- '**Green shores and riverbanks**' were implemented along the Merwedekanaal to make them more attractive, increase ecological value and create extra water storage. A green

shore is the low-lying vegetated terrain alongside the bed of a lake or river. The grade of these banks or shorelines can vary from steep to a shallow slope. In this case we suggested a lower gradient to make the water body wider such that more water can be stored within the channel. Local temperatures are lowered due to evaporative cooling of vegetation and the shade of trees.

- A '**park or urban forest**' is suggested between the apartment buildings offering recreation and green space to residents and Jaarbeurs visitors. This park can be used to store stormwater in local depressions and ponds. This stored water can infiltrate or be released slowly to another part of the water system. Due to evaporative cooling and shade effects air temperature can be 1-4^{o}C cooler than the surrounding urban area, thereby improving the thermal comfort in this area.
- '**Surface water area**' was increased not only to create storage but also to allow larger tourist boats to pass through the area. By increasing the width and thereby the surface area of water bodies and/or by accepting a higher water level the storage capacity is increased. Next to that, surface water buffers the air temperature in comparison the surrounding urban area. During the day it is cooler and during the night warmer than the air above.
- '**Porous pavements**' or permeable pavements are implemented at locations where large squares are planned. These systems can be implemented on all roads with low to medium traffic load and in pedestrian zones. These pavement systems include a range of pavement systems that allow the movement of stormwater runoff through the surface. Infiltration will results in higher groundwater levels of approximately 11 cm in summer (see Figure 4.7). This may increase available soil moisture in summer and lead to higher evapotranspiration rates. In addition to reducing runoff, these systems can trap suspended solids and filter pollutants from the water. Effect on air temperature is negligible. Where reducing soil sealing is not possible, infiltration measures in which runoff water is collected, harvested and/or infiltrated into the soil can be applied.
- '**Water squares**' were implemented in a square in the western part where the exposure to pluvial flooding is severe and on the Stationsplein where it would be highly visible. A water square is a (public) square that can temporarily store water and is often combined with improvement of the quality of urban public space. The water square can be understood as a twofold strategy. It makes money invested in water storage facilities visible and enjoyable. It also generates opportunities to create environmental quality and identity to central spaces in neighbourhoods. Water squares can reduce air temperature by green elements they contain and by evaporation of stored water.
- '**Urban agriculture**' is implemented at one of the rooftops of the Jaarbeurs to reduce the distance between food production and consumption. See also chapter 6. The roof could also be used by people from around the Jaarbeurs area. Next to that it can contribute to reduction of pluvial flooding by infiltration and water storage within the soil and reducing the air temperature by evaporative cooling. It can also contribute to social interacting awareness for healthy food.
- A **rainwater storage tank** was designed next to the Jaarbeurs to collect water from the roof for usage within the Jaarbeurs. A rainwater tank is a water tank used to collect and temporarily store rain water runoff, typically from rooftops via rain gutters. The water can

be used for e.g. irrigation, toilet flushing or domestic usage. Alternatively, water could also be infiltrated or slowly discharged toward the sewer system of surface water.

Application of each of these solutions does not depend on application of another one. But measures that contribute to retaining water for dry periods need special attention as we would like to provide sufficient amounts of water for evaporative cooling in periods of heat waves.

POTENTIAL SERVICES DELIVERED BY BLUE-GREEN MEASURES

The primary focus of Opportunity 3 is on reducing pluvial flooding and heat stress and improving the liveability in the area. The latter is a combination of multiple factors, such as landscape quality, social cohesion, level of noise and air pollution and recreational and physical activities. Various other services can be delivered by spatial green-blue interventions, as we have seen in section 5.2. In Table 7.1 the effect of each of the proposed measures is estimated qualitatively based on literature (e.g. Centre for Neighborhood Technology, 2010; De Lange e.a., *2016, in prep.*) results of the AST as shown in figures 7.1 – 7.3 and expert judgement: for further elaboration of the method, see (Ellen e.a., *2016, in prep.*) It is important to note that this table only provides an indication of the presence of these services, but nothing about the order of magnitude of the effect. Additionally, whether or not these services will actually be delivered depends strongly on the future development of the region, related local circumstances and the specific design of the measures.
As can be seen in Table 7.1, the measures have numerous potential services: especially the intensive green roofs, green roofs with drainage delay and parks provide a wide range of services. The most frequently delivered services of the green-blue measures are:

- Decreased pluvial flooding
- Improved urban climate / reduced heat stress
- Increased landscape quality
- Improved habitats and biodiversity
- Increased recreation options.

BENEFITS & STAKEHOLDERS

Table 7.2 shows which stakeholders –and to what degree- are expected to potentially benefit from each service that is delivered by the adaptation measures.

Services/ Measures	Green roofs drainage delay	Extra intensive green roofs	Green shores	Park	Increase surface water area	Trees in streetscape	Water square	Permeable pavement	Rainwater tank
Climate adaptation									
Decrease pluvial flooding	2	2	2	2	2	2	2	2	2
Increase air quality	1	1	1	2	0	1	0	0	0
Reduce heat stress	1	1	1	2	1	2	0	0	0
Increase water quality	-1	-1	1	0	1	1	0	1	1
Replenish ground water	0	0	1	2	1	1	1	2	0
Climate mitigation									
Decreased energy use	1	1	0	1	0	1	0	0	0
Decreased CO2 emission	1	2	1	2	0	1	0	0	0
Circular economy									
Increase lifetime of infrastructure	1	1	0	0	0	0	0	0	0
Add to closing water cycle	0	0	0	1	1	1	0	1	2
Add to closing energy cycle	1	1	0	0	0	1	0	0	0
Add to closing nutrient cycle	-1	-1	1	1	0	1	0	0	0
Other services									
Increase recreation opportunities	1	2	1	2	1	1	2	0	0
Increase landscape quality	2	2	2	2	2	2	2	0	0
Increase social cohesion	0	2	1	2	0	1	2	0	0
Increase physical activity	0	2	1	2	1	1	1	0	0
Decrease noise pollution	0	0	0	2	0	1	0	0	0
Improve habitat function and biodiversity	2	2	2	2	1	1	0	0	0
Increase food production	0	1	0	1	0	0	0	0	0
Decrease criminality	0	0	0	1	0	1	0	0	0
Decrease management & maintenance	-1	-1	0	0	0	0	0	0	0

-1	Negative effect
0	No effect
1	Small effect
2	Large effect

Table 7.1 Overview of potential services provided by planned adaptation measures in the Utrecht Centre-West area[4]

[4] Green roofs may deliver a negative effect on water quality, the nutrient cycle and management and maintenance. As fertilization is needed to maintain the vegetation on the roof, the water is enriched with nutrients. Green roofs also require more management and maintenance effort (and costs) than regular roofs.

Services/ Stakeholders	Municipality Utrecht	Water manager	Jaarbeurs	Residents	Travelers	Visitors	Other companies	Leisure companies
Climate adaptation								
Decrease pluvial flooding	+++	+++	++	++	+	+	++	++
Increase air quality	++		+	+++	+	+	+	+
Decrease heat stress	++		+	+++	+	++	+	+
Increase water quality*	+	+++		+		?		?
Replenish ground water**		++						
Climate mitigation								
Decreased energy use	+++		+++	+			++	++
Decreased CO2 emission	++		++					
Circular economy								
Increase lifetime of infrastructure***	+++							
Add to closing water cycle		++	+				+	+
Add to closing energy cycle****	+++		+++	+			++	++
Add to closing nutrient/resources cycle		??						
Other services								
Increase recreation opportunities	++		+++	+++	+	+++	+	+++
Increase landscape quality	+++		+++	+++	++	+++	++	+++
Increase social cohesion	+++			+++				
Increase physical activity	++			+++		++		
Decrease noise pollution	++		+++	+++		+		
Improve habitat function and biodiversity	++			++				
Increase food production								
Decrease criminality								
Decrease management & maintenance	+		+				+	+
?: only if water recreation is part of the new developments - in this case water recreationst and - companies will benefit								
??: Financial benefits may be derived by the waste water treatment plants as costs are lower when water quality is higher								
*: Only if there is demand for improved water quality and a substantial improvement is realized, this is a benefit								
**: Only if there is currently a problem with the ground water level - unknown at the time of writing								
***: Undertain effect, and not likely very strong								
****: There is double counting here with 'decreased energy use'								

Table 7.2 Potential benefits for stakeholders from ecosystem services that are delivered by planned adaptation measures in the Utrecht Centre-West area.

As can be seen, the municipality, the residents and the Jaarbeurs are the main beneficiaries of implementing the proposed adaptation measures. Visitors and local companies may also expect significant benefits. The water managers (HDSR water authority, Rijkswaterstaat) benefit only in their respective fields of activity – in flood protection, closing water cycles and in water quality.

COSTS

To make a realistic estimate of the cost of construction and maintenance of the blue-green adaptation measures is impossible at this stage. But the key unit cost figures included in the Adaptation Support Tool show interesting differences between the costs of measures. It is estimated that the largest construction and maintenance costs are to be expected for the green roofs with drainage delay and the extra intensive green roofs. This is because current roof construction standards do not allow such a heavy load on top. Strengthening the construction of the building is quite costly – even though the benefits are substantial too. The high maintenance costs could be compensated by the benefits of the active use of the green roof space, either for food production or for social activities.

8. Link adaptation measures with energy and mobility

8.1 Integration with other DDU- opportunities

Several adaptation measures were selected to obtain a green, comfortable and attractive area, meanwhile increasing resilience against the impacts of climate change, reducing noise nuisance, decreasing the concentrations of air pollutants, increasing biodiversity and strengthening the use functions of the area. Table 8.1 gives an overview of the measures and their main effects. A more extensive explanation is found in Appendix 1.

Table 8.1 Overview of proposed adaptation measures and their potential contribution to energy neutrality, climate resilience and attractiveness.

Integrated solutions	Opportunity 1 & 2: Energy-neutral	Opportunity 3: Climate resilient	Opportunity 3: Attractive	Potential icon?
Green roofs with inhibited discharge	Insulating effect	Water retention; limited heat stress reduction effect	In combination with roof terrace attractive for visitors	Could become attractive for public
Water retention tank	Heat buffer?	Water retention and detention for toilet flushing and irrigation; water reservoir for fire fighting	Subsurface structure; hardly or not visible	For experts only
Greening the facilities: ○ Corridor to main entrance ○ Riparian zone along Merwede canal ○ Stretch along Van Zijstweg ○ Park on Westplein	Heat stress reduction in and around the buildings	Reduces heat stress; can be combined with stormwater retention	Can be turned into accommodation area for visitors	If properly designed; e.g. Gardens by the Bay project in Singapore
Greenhouse on the roof	Insulating and heat producing	Could be combined with water retention	If combined with restaurant, tea parlor or market	If properly designed and developed
Infiltration fields	n.a.	Water retention; drainage water could be collected in retention tank	Combination of urban green and permeable pavement could be landscaped	Not unique
Water square	n.a.	Water retention	Nice accommodation area when combined with recreational facilities	See e.g.Benthemplein, Rotterdam
Put vital infra in elevated position	n.a.	Reduce risk of flood damage	? (could we turn this into something beautiful?)	Unlikely

Bioswales	Heat stress reduction around the buildings	Water retention	Nice, biodiverse accommodation area	Not unique
Visible (surface) water	n.a.	Water retention	Very attractive if well landscaped	Not unique

Question is however in how far these proposed measures can be combined with the measures proposed in the DDU-opportunities 1, 2 and 4.

8.2 Combination with measures proposed by Opportunities 1, 2 and 4

Opportunity 1: Hybrid integrated systems for heating and cooling

No spatial conflicts are foreseen with the measures proposed by opportunity 1. Points of attention could include the use of the aquifer thermal energy systems (ATES) in relation to stormwater infiltration. Groundwater levels in the vicinity of the ATES wells are increased when infiltrating water there. In case of a stormwater infiltration facility at the same site this could result in nuisance by high groundwater levels.

The greening of the project area will result in a reduction of extreme outdoor air temperatures and consequently a reduced cooling demand of the buildings. On the other hand, green roofs, green walls and trees can reduce the heat demand of the buildings during cold periods.

Opportunity 2: Local use of locally produced renewable (PV) power

A potential dilemma can occur in the choice between the use of green roofs and the use of roof area for installing PV or PVT – solar panels or solar-thermal panels. Panels can be placed in low density on a green roof; but intensive use of the roof for panes cannot be combined with a green roof. However, panels could be combined with a so called blue roof, a roof with substantial water retention capacity and reduced discharge capacity. PV-elements can also be placed in low density in the roof of a greenhouse – on top of the roof – or in pavement material.

Opportunity 4: Clean and safe personal mobility

Green infrastructure and infrastructure for mobility are to be matched closely. Substantial road reconstruction activities are foreseen in our project area, as shown in Chapter 1.3. Traffic load reduction of roads and spatial concentration of parking in multi-story garages makes space available for green and blue surface; surfaces that are badly needed in the area to provide storage and infiltration capacity for excessive storm water and for providing evapotranspiration (= cooling!) in times of heat. Green infrastructure, if properly designed, can also contribute to air quality improvement, noise reduction and mental health and stimulate healthy living. Practical design principles for optimization of these functions are provided in Gehrels et al. (2016). The reconstruction of the Graadt van Roggenweg / Westplein, Croeselaan and Van Zijstweg will also provide ample opportunity to visualize water flows in the urban landscape.

Reconstruction of the banks along the Merwedekanaal for ‘Rondje Utrecht’ and other bicycle routes are to be integrated with the plans for greening these embankments and creating extra water storage. And the central corridor for people to move from the new parking garage in the south-west of the project area to Utrecht Central station and historic city centre provides opportunity for greening and for visualizing the water flow. People tend to appreciate seeing flowing water (if clean) and this could be used to make the corridor attractive for public.

8.3 Manageability of proposed adaptations

The proposed blue-green adaptation measures do not only require another way of construction; also maintenance, operation and exploitation differ from traditional techniques such as regular brick pavements or regular tar roofs. In most cases maintenance costs will increase. So do the benefits and co-benefits of these solutions. However, the social, ecological and economic benefits are only sustainable on the long run if sufficient investments in operation and maintenance are being made. Knowledge and skills to manage the blue-green facilities have to be available, both on the side of the municipality as on the side of the Jaarbeurs. Utrecht municipality has collected wide experience with most of the solutions in e.g. the Leidsche Rijn area over the past decades. This knowledge and these skills are now to be shared with Jaarbeurs and other private organizations in order to safeguard operation of the blue-green facilities on the long run.

9. Conclusions & recommendations

9.1 General conclusions

- The Utrecht Centre-West project area – in its existing form - suffers a significant and increasing risk of flooding due to extreme rainfall and of heat stress. Economic development conditions, public health, social well-being and liveability in the area are at stake.
- Greening and 'blue-ing' the Utrecht Centre-West project area, both on public terrain as well as on private land, will make the area much more climate resilient, attractive and comfortable. More green and water can be created outdoors, but also indoors green and blue would help create a pleasant climate and atmosphere for residents and visitors. Green and blue facilities can help to turn the area in an accommodation area with increased and permanent social and economic activities.
- Space to create green and blue surfaces is abundantly available, in particular in view of the projected reconstruction activities. Underground space and space at rooftops provide a valuable space resource in addition to space at ground level.
- The water system of the project area – in particular the components surface water, groundwater and stormwater runoff – provides ample opportunities for water/ecosystem system services, including e.g.:
  - Rainwater and stormwater harvesting to reduce water imports; harvested water can for example be used for toilet flushing, irrigation, evaporative cooling and fire fighting. The retention tank(s) for harvested water can also be used for peak flow reduction and as thermal energy balancing system.
  - Surface water areas allows for temporary floating functions such as temporary parking capacity and temporary warehouses, housing, shops, et cetera.
  - The high permeability of the sandy subsoil and the relatively deep groundwater levels in the area make stormwater infiltration an attractive way of stormwater disposal. Soils can also be used for filtering and degrading stormwater pollutants.
  - Surface facilities for stormwater retention and infiltration can be designed in such a way that they offer other functionalities during dry periods, such as playgrounds, accommodation areas or logistic service areas.
  - The Merwedekanaal in the project area provides substantial storage and discharge capacity for stormwater drainage. Excessive use of this capacity however can shift drainage problems from the project area to areas further downstream ("afwentelen").
  - Evaporative cooling of the area can be enhanced by irrigating the vegetation during dry spells and by wetting pavement surfaces during the day.
- People value visible water. Except when noticeably polluted, they perceive it as relaxing, cooling and pleasant.
- Interesting opportunities exist to use the area for local food production. A greenhouse on the roof of the Jaarbeurs, in combination with a product outlet (market), a coffee/tea parlour, meeting facilities and/or a restaurant could produce an interesting business case for using the empty space on top of the halls, meanwhile producing liveliness in the area.

- Vital and vulnerable objects, networks and population groups require extra protection against flooding and heat stress. Flood damage can be prevented by putting facilities ‘high and dry’; e.g. higher land or floor levels can prevent flood damage of susceptible objects.
- Heat stress reduction is important in view of the increasing and aging population that is living in and visiting the area. Evapotranspiration by trees and by other green and blue infrastructure plays an essential role in cooling the area. Water availability in the unsaturated zone is however limited in hot and dry summer periods, leading to a significant reduction of the cooling effect. Water supply (irrigation) could reduce this limitation.

9.2 Climate resilience

With regard to climate resilience we may conclude that (1) the adaptation assignment for the project area for both pluvial flood prevention and heat stress reduction is substantial.
Due to the high percentage of paved and impermeable surfaces the required storage capacity (water assignment) is in the order of 300 – 350 m^3/ha if we accept a natural drainage capacity of such an area of 1.5 l/s/ha – a standard value often used in the Netherlands to avoid that urban areas produce a flood peak that exceeds the peak capacity of rural areas. As can be seen in the alternative plans (scenarios) that were produced, this storage requirement can be met with an intensive programme of interventions.
Fending for oneself (“eigen broek ophouden”; “ niet afwentelen”) is a golden rule in Dutch water management that leads to strict limitation of the drainage capacity of an area such as the 1.5 l/s/ha standard. However, it can be questioned whether such a strict standard is wise in the project area. The Merwedekanaal is a main interregional drain that could provide both storage and discharge capacity for the project area. But in an equitable approach riparian terrains have to comply with the same standards as terrains further away from a main drain. It would at least be fair to investigate the feasibility of the strict drainage standard.

Heat stress assessments indicate that the existing land use in the area leads to an aggravation of the urban heat island effect of approximately 6-7 ^{o}C during the hottest time of the day. This has a negative impact on health, on productivity, and on economic and social activities. In practice, people will try to avoid such hot places. Moreover, high outdoor temperatures will also influence indoor temperatures and therefore cooling demand of the buildings. Although it is very hard to quantify these effects it would be fair to reduce extreme temperatures in the area by about 2 ^{o}C. As can be seen from the proposed scenarios, it will be almost impossible to achieve this objective over the total project area; however, this objective is met in most of the plans on places that are meant to accommodate many people.

In order to provide better protection for vital and vulnerable objects, networks and population groups, a thorough inventory is to be made. Mapping them proved infeasible in this project, as information is to be given by a large number of people from different organisations and is sometimes confidential. This lack of information makes it impossible to plan extra protection measures for such facilities.

Three scenarios are provided showing alternative (conceptual) designs for making the area more attractive, pleasant and climate resilient. The three scenarios show that the water and heat assignment can be met only with an extra-intensive package of adaptation measures. The other scenarios show significant beneficial effect in the places that are most in need for extra water retention capacity and heat stress reduction.

From the perspective of water robustness it is not recommended to use the complete roof of the Jaarbeurs for PV solar panels. An intensive green roof with reduced runoff can effectively help reduce runoff volumes and peak flows from urban areas.

9.3 Recommendations

So far, this SSD-DDU project quantified the hazards of flooding, drought and heat stress in the project area, some of its damage sensitivity, the adaptation assignment and an estimate of the effectiveness of three alternative packages of adaptation measures. First efforts should now be oriented to communicating the project results and their backgrounds to all stakeholders involved in the detailed planning and design for this area. The project results provide a basis for first choices in spatial design of the Jaarbeurs / Utrecht Central Station area. In the next step these first choices can be made and elaborated in more detail.

Further elaboration is also required in the assessment of the degree of sustainability, health protection, resiliency and attractiveness that is achieved. More detailed evaluation criteria can be defined to quantify the expected achievements of proposed adaptation measures, e.g. in relation to healthy urban living – one of the key-policy-themes of the municipality of Utrecht.

It is recommended to involve the regional water authority Hoogheemraadschap der Stichtse Rijnlanden (HDSR) in the continued planning process, as they have several responsibilities regarding the water management in the project area. Moreover, they have the legal obligation to give their advice on the development of the water system according to the Water Assessment procedure (Watertoets). Also Rijkswaterstaat, as owner and manager of the Merwedekanaal, could be invited to assist the more detailed spatial planning of this district.

Specific problems that are to be addressed in more detail in the near future include:

- The ‘translation’ of the Netherlands’ climate scenarios to the conditions in the centre of a large urban area like Utrecht. The expected effect of the urban heat island is an increase in local heat stress and in the probability of extreme rainfall and drought.
- The local impact of ATES-groundwater wells on phreatic groundwater levels. This, in order to assess the applicability of stormwater infiltration in the vicinity of these wells and in relation to groundwater pollution sites in the vicinity of the project area.
- A further elaboration and analysis of the sustainability, benefits and disadvantages of specific adaptation measures including a financing and business model Utrecht Municipality and Jaarbeurs.

- A detailed analysis of the effectiveness, flexibility and adaptability of the final draft of the adaptation plan.
- Availability of underground water and space for large trees. And an investigation on whether there is enough water available for such trees for maximum evaporation during hot and dry spells. Maximum evaporation helps reduce heat stress in the vicinity of the tree.
- What is the water demand of the (extra) vegetation that is projected in the project area during dry and hot spells? Is this water available, could it be harvested from the stormwater runoff or from the local groundwater?

Finally, we recommend sharing the approach, the results and the lessons learned in the first phase of SSD Deep Dive Utrecht– opportunity 3 in particular – with the other SSD project areas in Europe, in order to stimulate mutual learning on how to design a sustainable, resilient, healthy, attractive and intensively used urban environment.

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Appendix I: Overview of proposed adaptation measures

GREEN ROOFS WITH DRAINAGE DELAY

A green roof is a roof that is partially or completely covered with vegetation and a growth medium. Underneath the growth medium is a waterproofing membrane and often additional root barriers and drainage and irrigation systems. The drainage delay is added to retard runoff from the roof. Due to evaporative cooling the temperature above a green roof can be lower can above a traditional roof. To provide this cooling effect sufficient water needs to be available to the plants on the roof.

GREEN SHORES AND RIVERBANKS

A green shore or river bank is the vegetated terrain alongside the bed of a lake (or pond, swamp, estuaries, reservoirs) or river (or reek, or stream). The grade of these banks or shorelines can vary from vertical to a shallow slope. If a shore or bank with a lower gradient is implemented by making the water body wider more water can be stored within the bed. Due to evaporative cooling and shade in case of planted trees local temperatures can be 1-4 degrees lower.

PARKS AND URBAN FORESTS

An urban park or a public park offers recreation and green space to residents of, and visitors to, the municipality. Parks can be used to store stormwater in depressions, ponds and canals. From this water can infiltrate of be released slowly to another part of the water system. Due to evaporative cooling park van be 1-4^{o}C cooler than the urban area around it. Next to that trees provide shade.

INCREASE STORAGE OR DISCHARGE CAPACITY OF SURFACE WATER

Increasing storage or discharge capacity of surface water can be achieved by increasing the width, surface area or depth of water bodies or by accepting a higher water level. The discharge of a river can be improved by removing obstacles. Surface water buffers the air temperature in comparison the surrounding urban area. During the day it is cooler and during the night warmer than the air above.

ADDING GREEN IN STREETSCAPE: TREES

Adding trees along the street as part of the streetscape (public space). Runoff is reduced through stem flow that infiltrates into the tree pit next to the stem. Infiltration can be enhanced by increasing the area of open soil or using permeable pavements around the tree. Next to that, trees have a small rainfall interception capacity (1-3mm) that reduces runoff during small rainfall events. The main cooling effect of trees is through the shadow they provide, thereby lowering the temperature locally at street level up to 4^{o}C. Also evapotranspiration provides cooling. This effect occurs at canopy level.

EXTRA INTENSIVE GREEN ROOF

A green roof is a roof that is partially or completely covered with vegetation and a growth medium. Extra intensive roofs, are thicker than intensive green roofs (minimum depth of 50 cm) that can support a wide variety of plants. Underneath the growth medium is a waterproofing membrane and often additional root barriers and drainage and irrigation systems. These roofs are heavier than intensive green roofs. More water can be stored in extra extensive green roofs. Annually the runoff reduction equals the evapotranspiration rate. Due to the thick growth medium they will hardly get saturated and the conductivity is small enough to reduce peak flow also during extreme events and long wet periods. Due to evaporative cooling extra intensive green roofs can be 1-4 C cooler than the urban area around it. Next to that these roofs can carry small trees that provide shade.

WATER SQUARES

The water square is a (public) square that can temporarily store water and is often combined with improvement of the quality of urban public space. The water square can be understood as a twofold strategy. It makes money invested in water storage facilities visible and enjoyable. It also generates opportunities to create environmental quality and identity to central spaces in neighbourhoods. Most of the time the water square will be dry and in use as a recreational space. Water squares can reduce air temperature by green elements they contain and by evaporation of water that can be present.

RAINWATER RETENTION TANK

A rainwater tank is a water tank used to collect and temporarily store rain water runoff, typically from rooftops via rain gutters. The water can be used for e.g. irrigation or domestic usage. Alternatively water can be infiltrated or slowly discharged toward the sewer system of surface water.

POROUS/PERMEABLE PAVEMENTS

Porous or permeable pavements include a range of pavement systems that allow the movement of stormwater runoff through the surface. In addition to reducing runoff, this effectively traps suspended solids and filters pollutants from the water. Effect of temperature is negligible.

Appendix II Storage-Discharge-Frequency (SDF) curves

A.II Required storage assessment

To determine the retention capacity that is required in the project area SDF curves were calculated for the total Utrecht Central Station area. The total Central Station reconstruction area was taken up into the water balance model based on the data from the report District Data Repository Smart Sustainable Districts, Opportunity 3.0: Data collection for "Green, comfortable and attractive areas" (Deltares report 1220357-000, 2015).

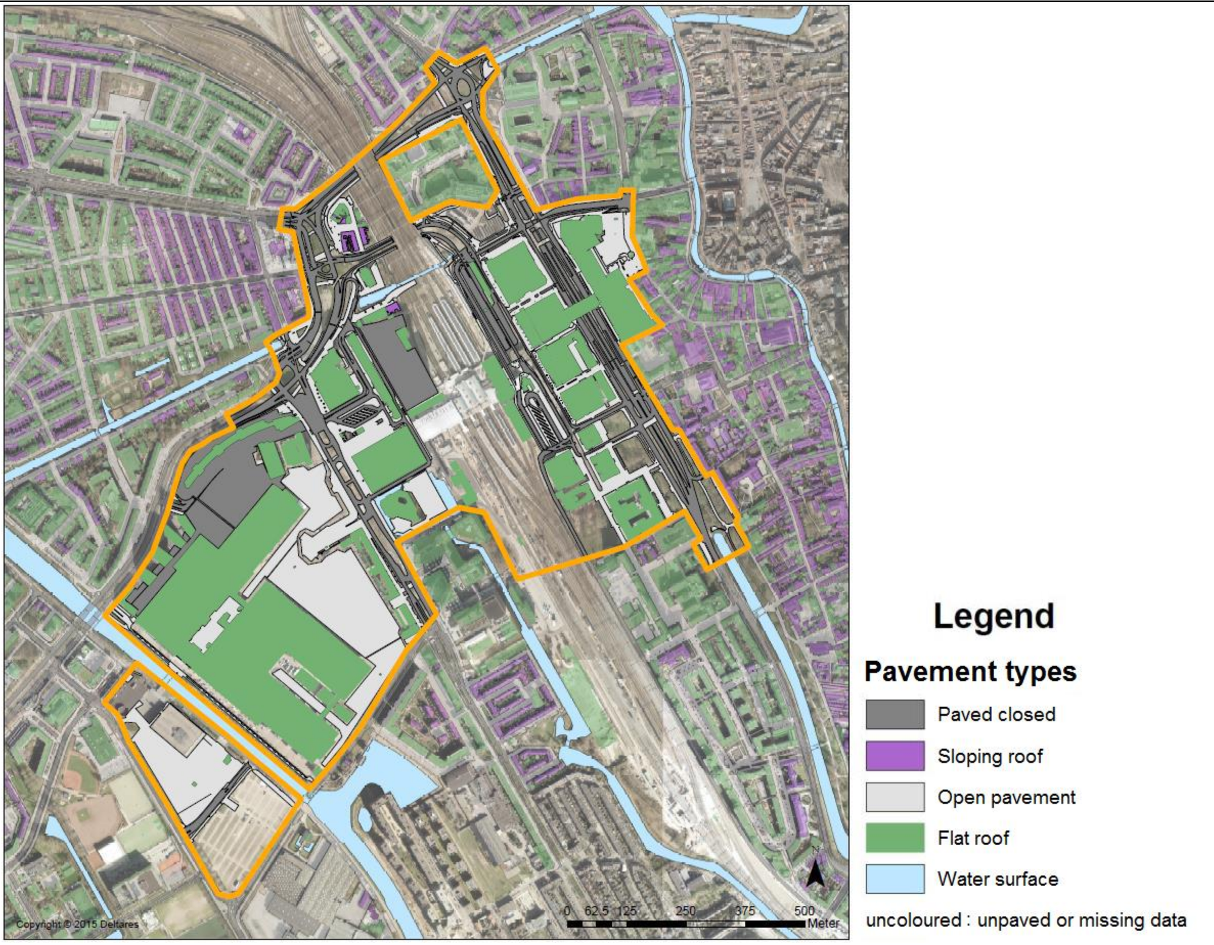

Figure A.II.1 Overview of the paved areas in the Central Station reconstruction area.

Figure A.II.1, taken from this report, provides an overview of the different paved areas. Table A.II.1 shows how the areas are applied in the water balance model.

Table A.II.1 Total Central Station reconstruction area applied in the water balance model

Area type	**Area size [m²]**
Roof area	241.507
Closed paved area	174.668
Open paved area	227.000
Unpaved area	345.144
Open water area (2%)	20.170
Total area	**1.008.489**
Connected to storm water drainage system (storage cap. 2 mm)	55%
Connected to combined sewer system (storage cap. 9 mm)	45%

The open water target level is defined at 1.92 m below surface level. Other variables are assumed based on expert judgement and some area information. These assumptions are: unpaved areas have a grass cover on top, soil type is podzol (fine sand, low on loamy contents), root zone depth is 0.40 m, seepage is zero and drainage resistance against groundwater flow to open water is 100 days.

The model is run for the period 1981 – 2010; hourly rainfall and evaporation values of weather station De Bilt are applied. For 15 discharge capacities (from 1 mm/d up to 15 mm/d over the entire area) the required storage in the open water system is determined. For that purpose storage events are defined as continuous periods in which the surface water level is above target water level. For each of the 15 discharge capacities statistical analysis (trend lines in EXCEL) and extreme value statistical analysis are applied on the top 100 storage events in 30 years (1981-2010) to determine (a) the return periods for the different events and (b) the required storage capacity for a rate of different return periods. Only the maximum water level per storage event is applied in the statistical analysis. The highest storage event is ranked 1 and results in a 30 / 1 = 30 year return time; the lowest storage event is ranked 100 and results in a 30 / 100 = 0.3 year return time.

Figure A.II.2 provides an overview of the resulting hundred largest storage events for discharge capacities varying from 1 mm/d to 15 mm/d over the entire area, i.e. 2017 – 15128 m^3/d. The 1 mm/d line clearly differs from the rest. The discharge capacity of 1 mm/d is so small that the storage hardly ever empties and hence storage events last from several months up to more than a year. This fact influences the statistical calculations so strong that this discharge capacity is left out.

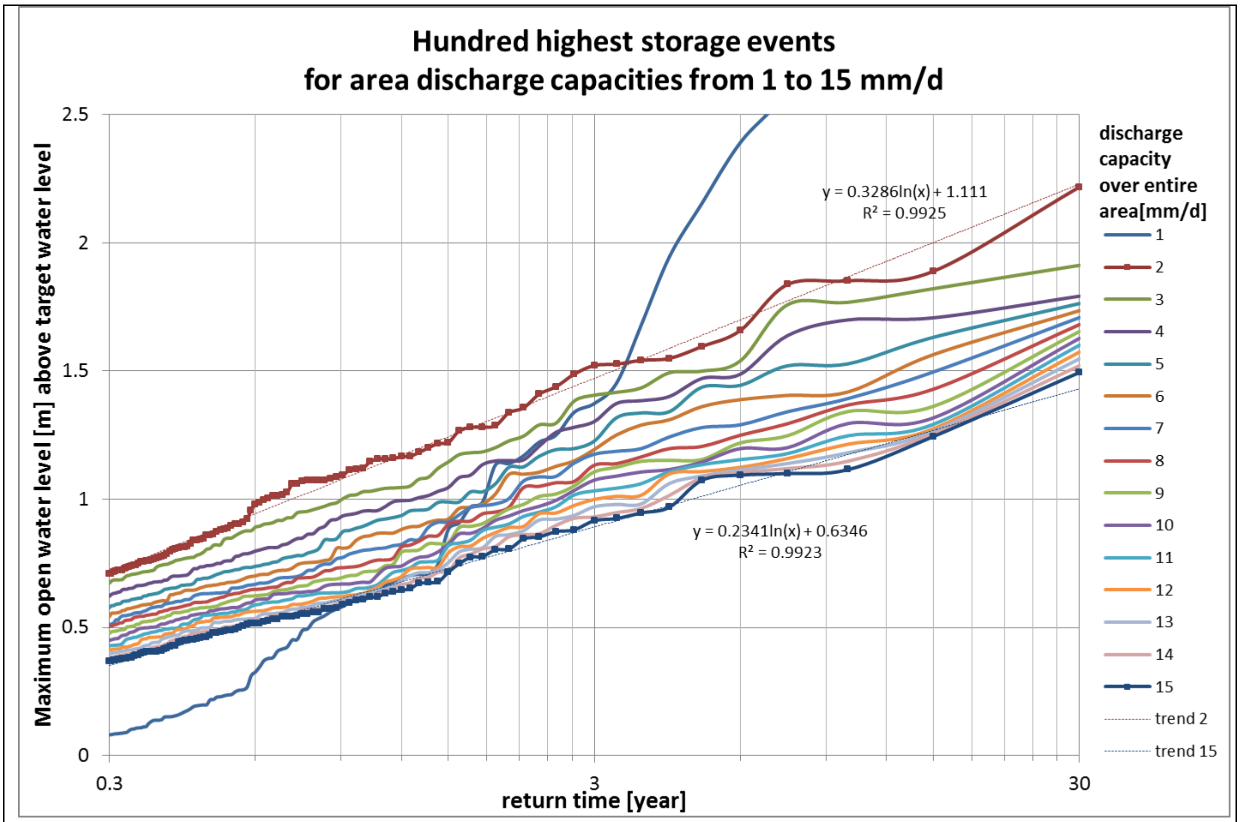

Figure A.II.2 Resulting Storage-Discharge Frequency curves (top 100 events) based on log-trend lines.

For all other discharge capacities the logarithmic trend lines are determined as is shown for the discharge capacities of 2 and 15 mm/d. Based on these trend-lines the required storage capacities for each discharge capacity can be determined for every desirable return time. The required storage capacities in m^3 given a certain discharge capacity are combined per return time - for the return times of 1, 2, 5, 10, 20, 50 and 100 year - to Storage Discharge Frequency curves. Figure A.II.3 provides an overview of the result.

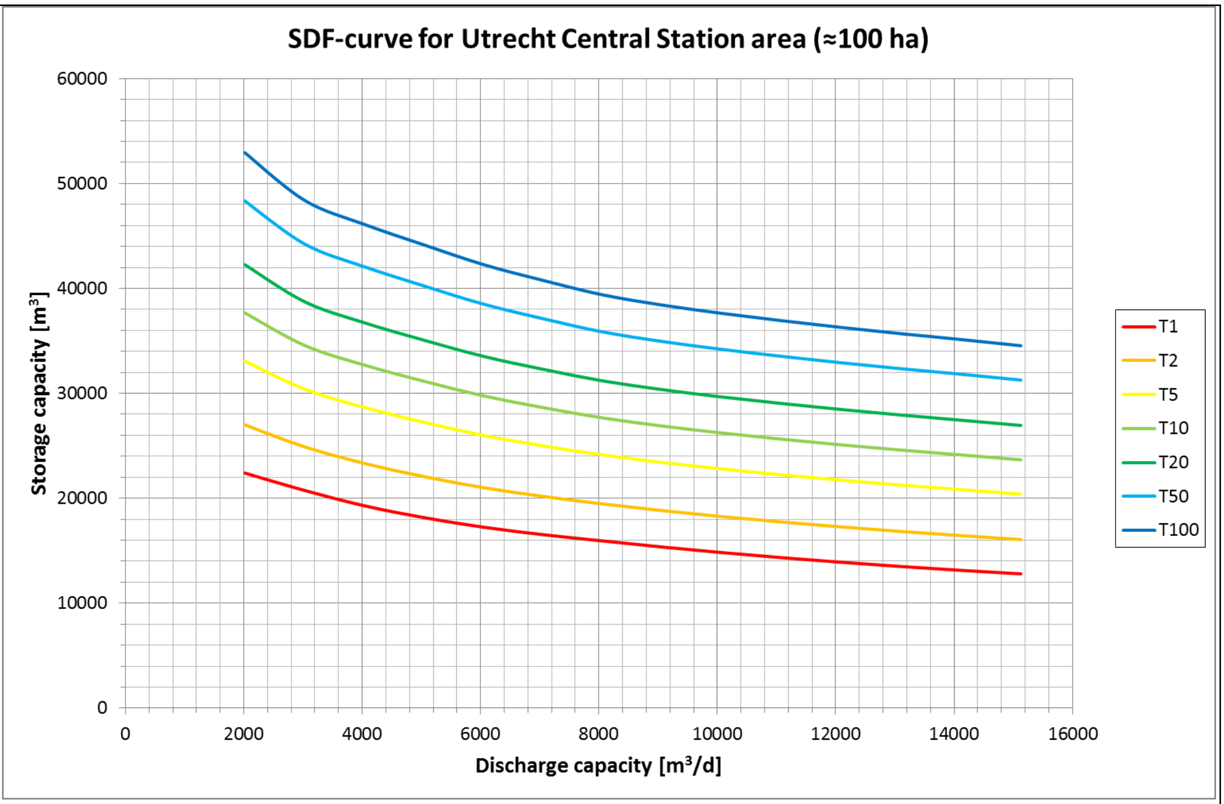

Figure A.II.3 Resulting Storage-Discharge-Frequency curves based log-trend lines (top 100 events over 30 years).