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Solutions for a resilient urban water system: the case study of Hoofddorp park

Master Thesis

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Abstract

Most urban water systems are poorly adapted to challenges as climate change and population growth. A resilient urban water system contributes to a sustainable environment and provides urban ecosystem serves for the city's inhabitants. The current water management of Hoofddorp park, divided in a wander forest and fruit nursery, is an example of an urban water system which does not contribute to a sustainable environment. The aim of this research was to define how the water system of Hoofddorp park could cost effectively be improved to reach a resilient water system for the future up to 2050. The most resilient and cost effective measurement was selected using a Multiple Criteria Decision Analysis (MCDA), that includes a current state analysis and scenario analysis.

The current state analysis showed that the soil at the fruit nursery is compact and the soil in the wander forest is partly contaminated. The chemical and ecological water quality is low. The scenario analysis showed that besides the increasing pressure from climate change, developments around Hoofddorp park are expected to increase the use of the park.

The criteria used for analyzing the measurements were: water flow, soil infiltration capacity, potential water storage, water quality, habitat quality, pollution stability, costs, and risk. Two weighing methods were used for assessing the measurements: the equal weight method and the SIMOS method. The weights assigned through application of the SIMOS method emphasized the importance of water quality and soil contamination and the low importance of cost and risk.

The best scoring measurements were the implementation of natural banks, changing water courses to increase flow, remove a weir that is not in use, and change the management of the fruit nursery so that the soil can improve. The most resilient water system is reached by implementing additional measurements such as equalizing the target water level in the area, applying drainage by sand columns in the fruit nursery, and changing the petting zoo water management. The additional analyzed measurements including the implementation of drainage ditches, debris funded paths, increasing maintenance of the water courses, tree removal, and implementing a fountain did either not score well or lower than another measurement for the same purpose and are therefore not advised for implementation.

The results of the MCDA are not sensitive to a bias of the specialists to low importance of costs because both weighing methods show similar results.

Contents

Abbreviations

EQR Ecological Quality Ratio. 20

IPCC Intergovernmental Panel on Climate Change. 12

MCDA Multiple Criteria Decision Analysis. 4, 9, 13, 35, 36

NAP Nieuw Amsterdams Peil. 25, 59

WFD Water Framework Directive. 20

Glossary

boezem means a canal supplying freshwater to a polder and facilitate drainage from the polder. 7, 8, 19

ecosystem is an ecological complex functional system of interacting plant, animal and microorganism communities and their nonliving environment. 1, 26

ecosystem service mean a benefit provided by the natural capital of an ecosystem including goods and services. 1, 2, 6, 10, 22

municipality Haarlemmermeer means the municipality of Haarlemmermeer. 2, 3, 10, 12, 13, 17, 18, 24, 36

polder is a low-lying area of land enclosed by a dyke forming an artificial hydrological entity only connected with outside water through inlets and pumps. 1, 5–8, 13, 20–23, 26, 36

target water level means a by the water board specified surface water level. 2, 10, 19, 25, 29, 31, 35, 37

water board is a democratic institute arranging water levels, flood protection measurements and clean water. 2, 3, 7, 8, 10, 12, 18, 39, 49

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1. Introduction

1.1. Problem description

1.1.1. General

Urbanization is a global and profound process during the 21st century (McDonald et al., 2014). Consequently, cities provide an important aspect of our daily lives, yet continuing urbanization as during the last century already leads to problematic situations (Wu, 2014). By enabling global economic growth and increasing human well-being, cities contributed to increased consumption of water and energy among other natural resources (McDonald et al., 2014; Wu, 2014).

Depending on design and management, green areas and water bodies forming the urban water system could provide urban ecosystem services improving the sustainability of a city (Wu, 2014). Bolund and Hunhammar (1999) defined 7 types of urban ecosystems: street trees, lawns and parks, urban forests, cultivated land, lakes and sea, wetlands and streams. The services they can provide are eg. air filtration, climate regulation, rainwater drainage, habitat for plants and animals, sewage treatment, reduced soil erosion, alleviated noise pollution, recreational and cultural values, increased real estate values and enhanced human psychological well-being (Bolund and Hunhammar, 1999; Wu, 2014).

At this moment, most urban water systems are poorly adapted to worldwide challenges as climate change, population growth, sustainability issues, and other socio-economic problems (Marlow et al., 2013; Wu, 2014). Constructions and pavement create an almost impermeable surface for water in cities. Furthermore, straightened streams increase discharge velocity and decrease storage capacity (Booth and Fischenich, 2015). Improving the urban water system, by focusing on decentralized techniques simulating natural behavior of water bodies, can enhance sustainability (Wu, 2014; Zhou, 2014).

Research into urban ecosystems and the role of hydrology for sustainability in cities has only started recently (Wu, 2014; Booth and Fischenich, 2015). Technical advances in sustainable urban water management are available, however implementation by governments proceed rather slowly since they are not well informed (Van de Meene et al., 2011). Practical case studies on sustainable urban water management are not widely available (Van de Meene et al., 2011). Moreover, resilience in urban water systems is hard to define causing higher risk for implementation of measurements (Blackmore and Plant, 2008).

The technical water management of the Netherlands from the past century is not prepared to meet the challenges caused by climate change. A polder dyke in Wilnis, the Netherlands, breached after a long period of drought in 2003 (Van der Brugge et al., 2005) and fresh water demand for flushing the polders is increasing whereas the supply is decreasing due to climate change (Aydin et al., 2016). Research by van Leeuwen et al. (2012) shows that the urban water management in three cities in the Netherlands, Rotterdam, Maastricht and Venlo, cannot meet the challenges of the future. These dutch cities do not score well on biodiversity, groundwater and surface water quality because of high nutrient loads, trouble water and little green spaces (van Leeuwen et al., 2012). Therefore, the technical water management strategy is not sustainable.

1.1.2. The Hoofddorp park case

Hoofddorp is a town located in the Haarlemmermeer polder in the west of the Netherlands (see figure 1.1). Because the town is located in a polder, it has a more complex urban water management system than the cities of Rotterdam, Maastricht and Venlo, which are situated along rivers.

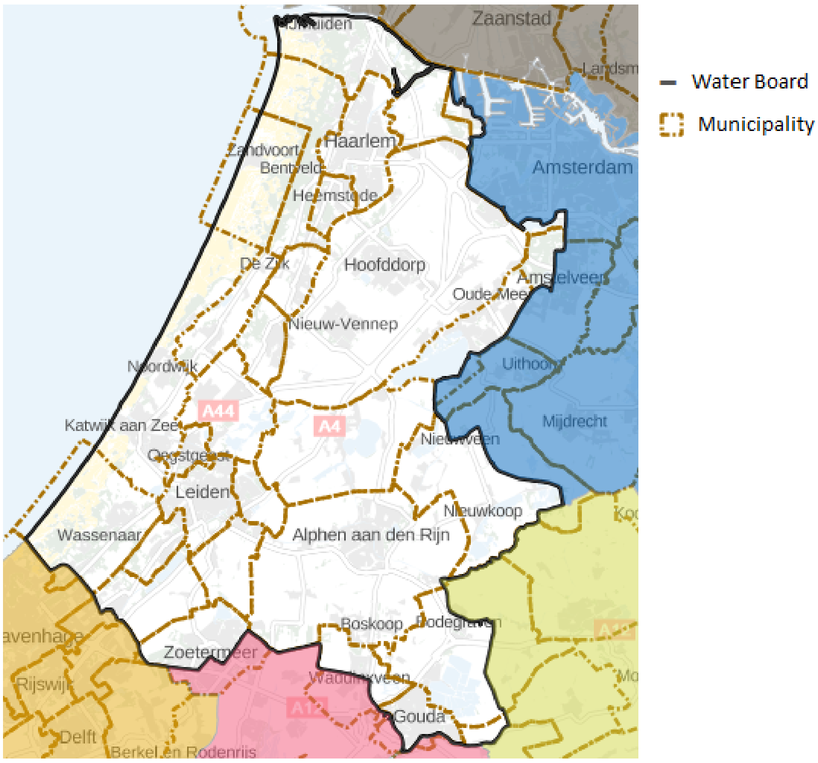

Figure 1.1.: The location of Hoofddorp within the area of water board Rijnland (Hoogheemraadschap Rijnland, nd)

Hoofddorp park is a green area including a wander forest, fruit nursery and tennis course, used for recreational purposes along the route from the train station to the city center (S. van der Laan, personal communication, 13 November, 2017). The park is surrounded by office and residential area, which are mostly paved and drain water via spillways to the park.

The problems encountered in Hoofddorp are an example of unsustainable urban water management. This includes different target water level decisions on a small spatial scale, deferred maintenance of the water courses and infrastructure, and waterlogging (S. van der Laan, personal communication, 13 November, 2017). In this way, urban ecosystem services cannot be provided and the urban water system is not resilient to challenges as demographic changes and climate change.

The municipality Haarlemmermeer, is increasingly focusing on sustainability (Gemeente Haarlemmermeer, 2014). They identified Hoofddorp park (see figure 1.2) as a place where they can improve the urban water system along with the developments around the park. Improvement is required for very practical reasons as smelly water and enhancing recreation but also for climate adaptation and sustainability (Gemeente Haarlemmermeer, 2016).

By improving the area of Hoofddorp-Centraal, urban ecosystem services including air purification, climate regulation, habitat provision for plants and animals can be provided by the Hoofddorp park. The route passing through Hoofddorp park will be more attractive for commuting and will thereby contribute to a higher human well-being. This case study contributes as an example for reaching a more resilient city using of green spaces and water bodies to provide urban ecosystem services.

Figure 1.2.: A detailed map of Hoofddorp park (Gemeente Haarlemmermeer, 2016)

1.2. Objectives

The objective of this research is to provide measurements for the integral water related questions of municipality Haarlemmermeer and water board Rijnland on Hoofddorp park to create a future proof and climate resilient water system. The aim of the measurements is to improve surface water flow and quality in the wander forest and fruit nursery. The research question to be answered is

"How can the water system of Hoofddorp park cost effectively be improved to reach a resilient water system for the future up to 2050?"

This means Hoofddorp park could deal with all sorts of possible, unknown disturbances in the future without changing its state.

The main research question is divided in the following sub questions:

1. What is the current state of the water system?
2. What are possible measurements for system improvement?
3. Which measurements fit the situation best according to the defined criteria?

1.3. Outline

The starting point of this study is that the water system of Hoofddorp Central can become resilient by multiple small solutions rather than one large solution in the system in order to reach a sustainable situation. These small adjustments are measurements to increase water quality, flow and decrease waterlogging in the future.

To assess various measurements for creating a resilient water system in Hoofddorp park, a Multiple Criteria Decision Analysis (MCDA) was performed. A MCDA is used to deal with uncertainty, including both risk and ignorance, in the process of finding sustainable and resilient solutions for the water management of Hoofddorp park. The terms sustainability and resilience will be further defined and discussed in Backgrounds concepts and context. In MCDA theory, measurements are referred to as alternatives (Wang et al., 2009; Comes et al., 2011), in the remainder of this thesis measurements are used instead of alternatives. In this MCDA, the current state and future challenges were determined first so the measurements for system improvement could be based on them. Thereafter, the criteria were weighed and evaluated on which the conclusion was based.

2. Background concepts and context

2.1. Concepts

2.1.1. General

This study focuses on a resilient water system. The broad term of resilience needs to be defined as well as its relation to sustainability and the polder system. The relation between resilience and sustainability is still subject of debate in science (Olsson et al., 2014; Meerow and Newell, 2015). For this study, resilience is defined as a prerequisite for sustainability because resilience explains the state stability of a system in a natural environment (Holling, 1996), whereas sustainability only refers to sustaining a certain state within the system (Costanza and Patten, 1995). The polder system of Haarlemmermeer is an artificially managed system. Since resilience refers to ecological systems without human intervention, the polder system can only be partly resilient. However, within the boundaries of the polder system, Hoofddorp park is supposed to move to a self-sustaining state. The red arrow in figure 2.1 shows the desired move of Hoofddorp park within the concepts. The relations between the concepts is also shown by figure 2.1.

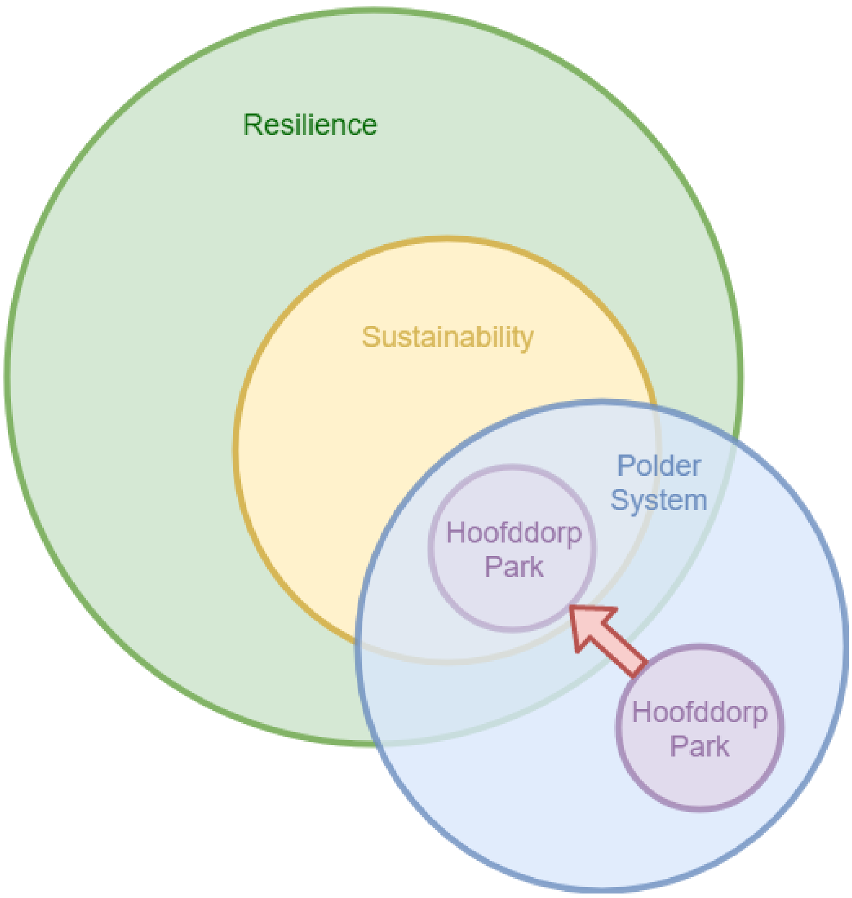

Figure 2.1.: Conceptual framework

2.1.2. Resilience

Resilience describes dynamic system stability (see figure 2.2). It can be defined as the amount of disruption a system can absorb without changing state. The time to return to the stable point is one way to measure this, the steeper the slopes of the valley the earlier a system will return to the stable state. On the other hand, the width of the valley represents the magnitude of a disruption that a system could absorb before it changes states. An example of changing states is a clear stream turning into a turbid one (Holling, 1996; Gunderson, 2000). These situations are shown in figure 2.2: the ball represents the state and the line on which it is projected the stability of the system. The stability is dynamic and changes usually slowly (without human intervention). The arrows illustrate disruptions; the larger the disruption the more likely a system will change of state and from high to low state needs less effort than the other way around Gunderson (2000).

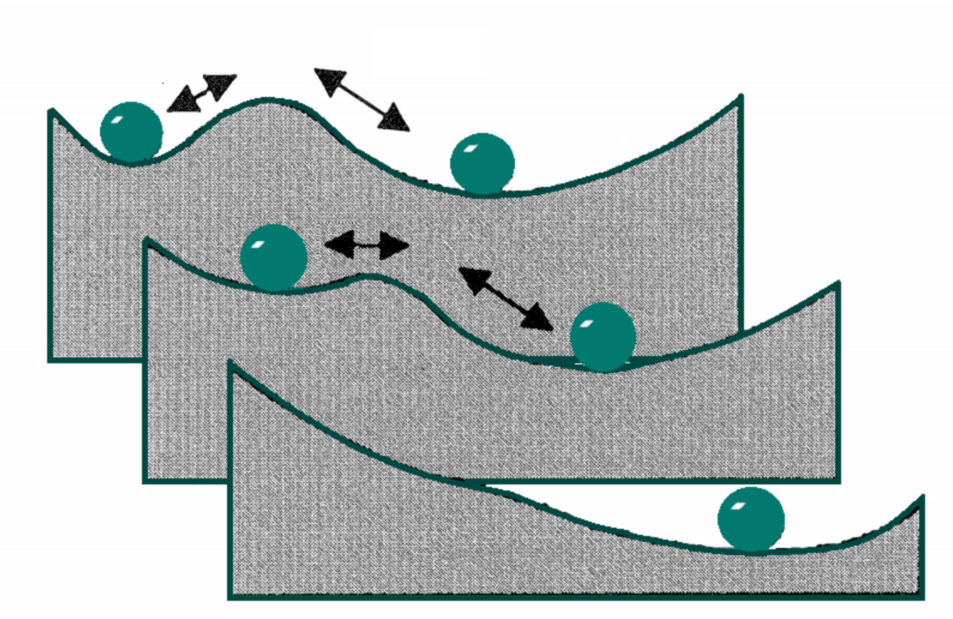

Figure 2.2.: System stability: the ball represents the state of the system, the line on which it projected the stability boundary conditions, which could change over time. The arrows represents disruptions, which could push a system into a new state. Adjusted from (Gunderson, 2000)

2.1.3. Sustainability

The most used and encompassing definition of sustainability comes from Brundtland et al. (1987): *"sustainability is meeting the needs of the present without compromising the ability of future generations to meet their own needs"*. This definition is too vague to apply on the researched question formed for this study, it however gives a direction for the definition used here. In the case of sustainable urban water management in Hoofddorp park, sustainability entails a system that can sustain itself in water quality and biodiversity so it provides urban ecosystem services to the community.

2.2. Polder system

A polder is a low-lying area of land enclosed by a dyke forming an artificial hydrological entity only connected with outside water through inlets and pumps (van Andel et al., 2008; Schuetze and

Chelleri, 2011). Management of water in Dutch polders is the responsibility of water boards. In the case of polder Haarlemmermeer, the water board of Rijnland is responsible for water levels and quality (van Andel et al., 2008). The polder Haarlemmermeer was formed after the pumping of lake Haarlemmermeer, after many changes of the landscape caused by land and water management (Toen Haarlemmermeer, nd).

The water management system changed to what it is nowadays in five different phases (see figure 2.3). The natural landscape represents the initial phase of water management. The initial phase adjusted to natural water management which used the protection of relief and dealt with water with minimal interventions up until the 10th century. The defensive water management period lasted until the 15th century and used man made structures to protect houses, villages, and towns from flooding. The offensive water management is signified by peat mining facilitated by windmills for drainage. This period ended during the mid-19th century. Thereafter, the manipulative water management period started, representing the techniques still used nowadays. Effective pumping technologies contributed to the drainage of the by mining formed large lakes, of which some are pumped dry for land reclamation (Schuetze and Chelleri, 2011).

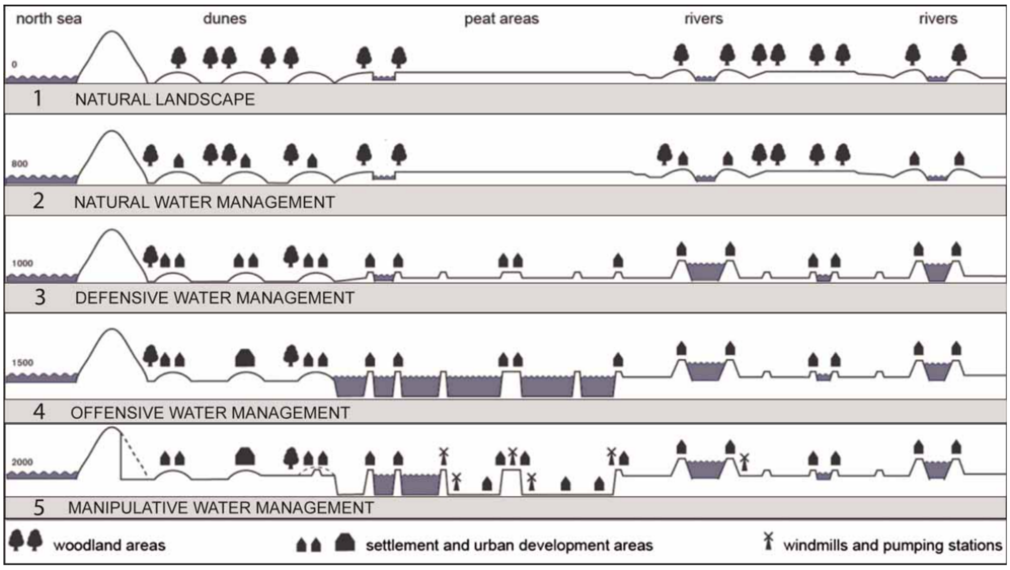

Figure 2.3.: The phases of water management in Dutch polders (Schuetze and Chelleri, 2011)

Polder management of the manipulative water management phase is shown in figure 2.4. The system has artificially managed constant water levels with fresh water supply and drainage systems. Groundwater and surface water levels are maintained at target levels to facilitate agriculture and urban areas in their needs. The dikes around the polder protect the area from flooding. The canals around the polder area (in Dutch called boezems) supply freshwater to the polder and allow pumping stations to pump surplus drainage water out of the polder (Schuetze and Chelleri, 2011).

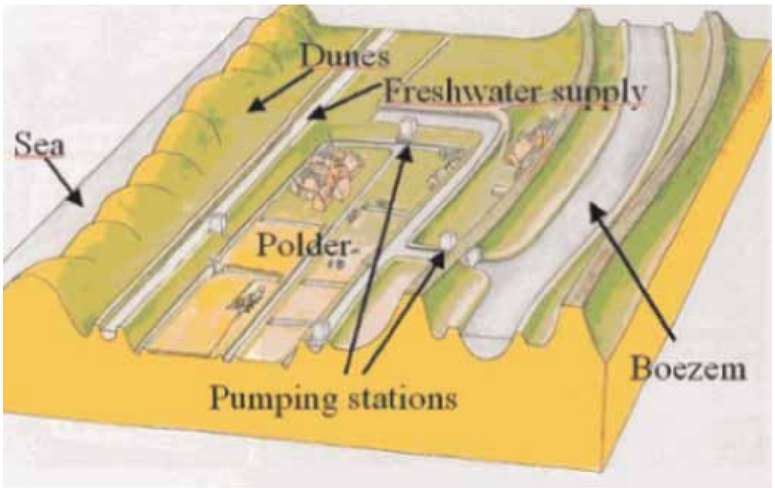

Figure 2.4.: Water management in Dutch polders (Schuetze and Chelleri, 2011)

Climatic factors, such as precipitation and evapotranspiration, influence the water balance and available water in a polder. During the cold season, there is a surplus of fresh water and during the warm season a shortage. Freshwater supply by boezems can be affected by river water quality of the supplying river as well as salt water intrusion at the river inlet for all the polders in the area of water board Rijnland during high tides. Another significant factor in the polder water balance is upward seepage from fresh or brackish water. In the case of brackish water, it also affects the water quality via seepage in the polder. The rate of upward seepage depends on soil type and water pressure. Built-up areas in polders change the standard polder system by requiring different water levels, reducing evapotranspiration and potential storage areas for rainwater (Schuetze and Chelleri, 2011).

3. Methods

The research was set up in five separate but interrelated blocks: Current state analysis, Measurement analysis, Scenario definition, Criteria definition, and Evaluation. These blocks are all part of the MCDA. The MCDA is used to compare measurements with respect to multiple objectives or criteria (Wang et al., 2009). Figure 3.1 gives an overview of the relations between the blocks. The dark blue diamonds are the subjects addressed within the block, the light blue boxes visualize the process performed in that specific block. The yellow arrows show the input of the processes, which can be either subjects or the results of processes.

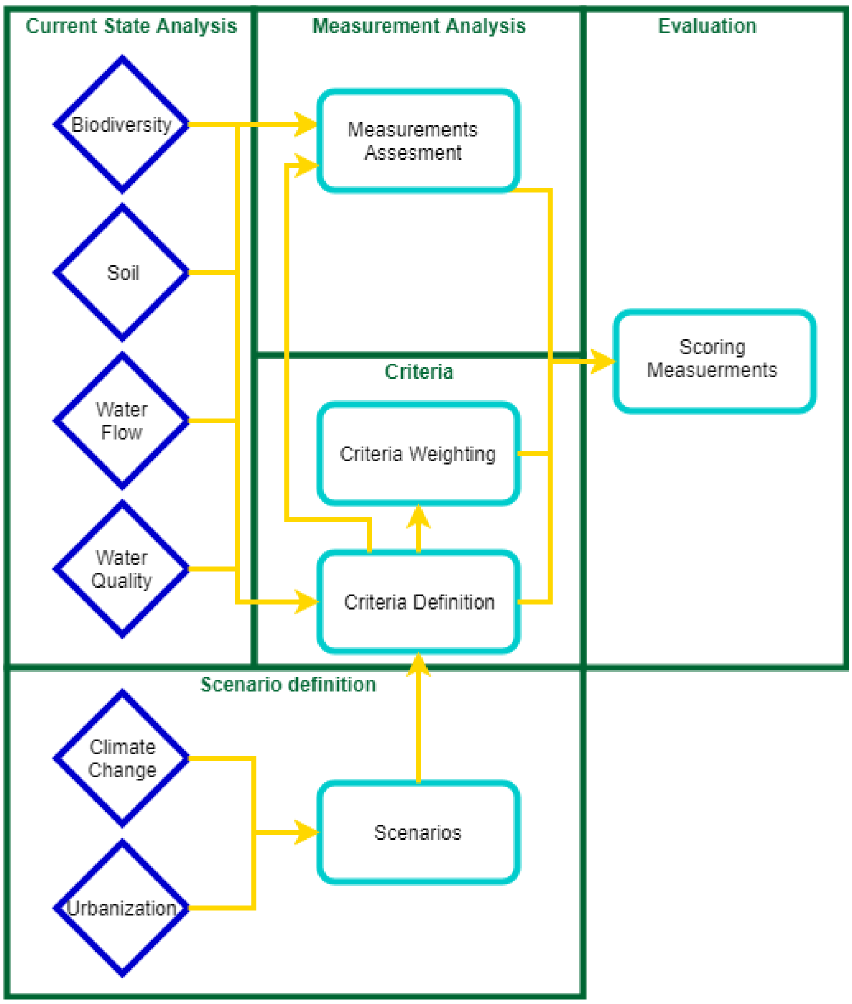

Figure 3.1.: Flowchart of methods, an applied MCDA according to Wang et al. (2009)

3.1. Current state analysis

An overview of the current state was created by analyzing soil properties, biodiversity, water flow, water quality, and developments. The surrounding area is subject to developments in the near future which can influence the demand on the ecosystem services of Hoofddorp park according to the development strategy of Gemeente Haarlemmermeer (2016).

The soil analysis was performed by fieldwork of which the locations are shown by figure 3.2. At these locations, a soil profile was determined as well as the ground water depth. The archives of the municipality Haarlemmermeer were consulted to identify previous soil quality issues. A dumping ground is present in the wander forest and was analyzed in 1997 by Oranjewoud (1997).

The biodiversity of the area was determined with a fieldwork tool, called IPC Groene Ruimte (2015). This tool indicates the quality of different types of habitat as a prerequisite for the settlement of organisms belonging to that type of habitat. That is easier to determine than biodiversity itself (Noss, 1990). The maximum score on habitat quality using this tool is 280 points, however there are not any areas scoring 100% on each aspect. A score of 200 represents a very good habitat quality whereas a score of 100 points represents a low habitat quality (IPC Groene Ruimte, 2015). For this study the sea clay and low peat habitat is used.

The water flow analysis was performed with infield validation of surface water flow, depth of water courses and bank conditions (for the locations see figure 3.2). It also included the groundwater depth measurements with the soil profiles. The water board Rijnland provides open access information on culverts, weirs, target water levels and pumping stations (Hoogheemraadschap Rijnland, nd). Locations of combined sewage spillways were provided by the municipality Haarlemmermeer. All this information was combined in a geographical database using the Microstation software (Bentley Systems, 2013). The water flow analysis included calculations on the water content in water courses at target level, potential water storage in the soil, and a standard extreme rain event of the municipality Haarlemmermeer.

The total water content in the water (Cw) courses at target level of Hoofddorp park was determined with a calculation method of water board Rijnland and the municipality Haarlemmermeer (see equation 3.1), using an interactive map on the water courses, provided by Hoogheemraadschap Rijnland (nd). This map provides length (L), depth (D) and width on surface level (Ws) and at the bottom (Wb) for each water body (i) of all water bodies (n).

$$Cw = \sum_{i=1}^{n} L_i * D_i * (\frac{1}{2}Wb_i + \frac{1}{2}Ws_i) \quad \text{with} \quad i = 1, 2, ..., n \tag{3.1}$$

The water storage (Sw) and potential water storage (pSw) in the soil were calculated using the equations 3.2 and 3.3.

$$Sw = \frac{\sum_{j=1}^{m} \delta h_j * w_j * l_j * \eta_j}{A} \quad \text{with} \quad j = 1, 2, ..., m \tag{3.2}$$

$$pSw = \frac{\sum_{j=1}^{m} \delta h_j * w_j * l_j * \eta_j}{A} \quad \text{with} \quad j = 1, 2, ..., m \tag{3.3}$$

For the water storage, delta height (δh) was taken as the height difference between the target water level and the groundwater depth measurements for all subareas (j as index for subareas m) taken during field work in winter. For the potential water storage, delta height was taken as the maximum height difference between the water surface level and ground surface level. The width (w) and length (l) of the areas are determined with geographical data provided by municipality Haarlemmermeer. The porosity (η) of clay ranges from 0,35 to 0,70 (Kutílek et al., 1994), this range was used for the calculation.

Municipality Haarlemmermeer used a precipitation event of 100 mm rain in 2 hours for climate stress testing (Van Paridon et al., 2012). This is not a standard rain event, but was used here because Hoofddorp park is located within this municipality. Equation 3.4 shows the potential height increase (Hp) of the watercourses after after such a rain event (with precipitation (R) in

m) (with area (A in m^2)) when the total amount of water ends up in the water courses (with water surface area (WsA in m^2)) immediately.

$$Hp = \frac{R * A}{WsA} \tag{3.4}$$

When the soil storage space was used up first, the calculation of the surface water height increase was calculated with equation 3.5

$$Hp = \frac{(R * A) - pSw}{WsA} \tag{3.5}$$

The water quality was analyzed on pH, EC, arsenic, cadmium, chrome, copper, mercury, lead, nickel, zinc, chloride (salt), total nitrogen, total phosphate, and total cyanide by Eurofins on 9/2/2018. Most of the elements are analyzed according to the NEN-EN-ISO 17294-2 and NEN-EN-ISO 15587-1 or similar methods (see Appendix D). The sample locations are shown by figure 3.2. These results are compared with the European standards and the monitored quality of the water in Haarlemmermeer.

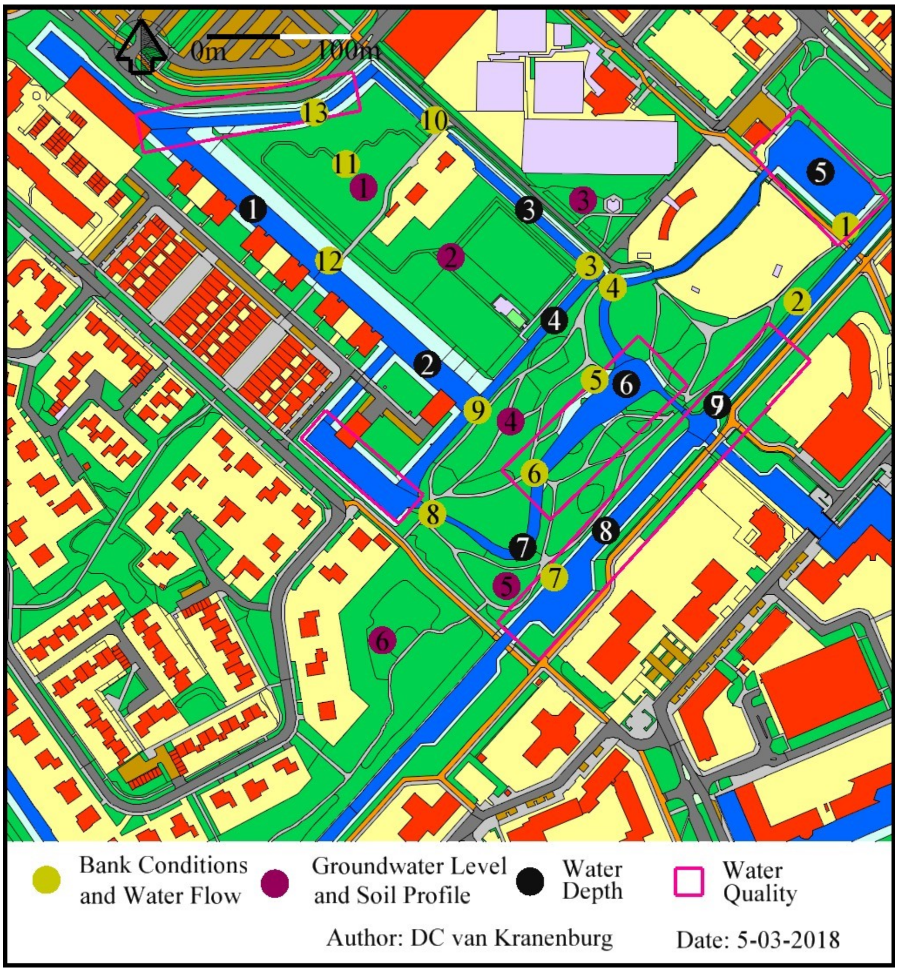

Figure 3.2.: Fieldwork observations

3.2. Scenario definition

The current state of the functions of Hoofddorp park and the surrounding developments are projected into the future up to the year 2050. Plausible, consistent, and coherent scenarios allow dealing with uncertainties and help overcoming cognitive biases (Comes et al., 2011). Scenarios are also a unifying factor for all disciplines and allow a trans-disciplinary approach which is essential to understand the broad scope of sustainable urban water management. Especially for urban water management, a look into the future of climate change and sustainable or unsustainable development is necessary (Zhou, 2014).

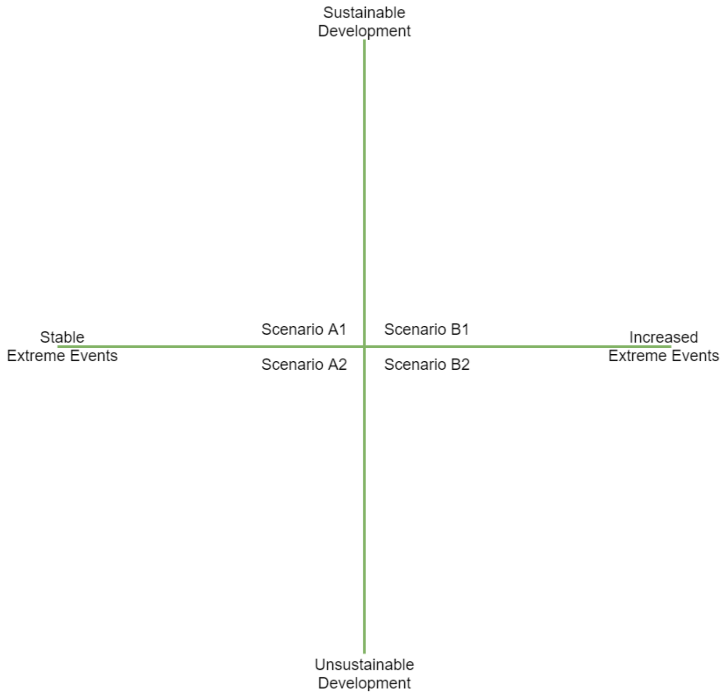

Figure 3.3.: Scenario trend method with climate change and development trends

With climate change and developments, four different scenarios are formulated. The effects on the water system vary in each scenario. To reach a sustainable situation, the system has to be resilient to preferably all possible disturbances. A scenario trend analysis, with two trends creating four different scenarios, was performed. Figure 3.3 shows the scenarios. The scenarios were developed using literature on trends in urbanization and climate change.

For climate change specifically, the scenario assessment of Klein Tank et al. (2014) based on the Intergovernmental Panel on Climate Change (IPCC) report of 2013 was used. All four scenarios were used for the prediction up to 2050.

3.3. Criteria

The criteria include environmental, economic, technical and institutional aspects (Hellström et al., 2000; Makropoulos et al., 2008). Based on literature review (Noss, 1990; Arshad and Coen, 1992; Beeson and Doyle, 1995; Oranjewoud, 1997; Lobbrecht et al., 1999; van Well Stam, 2004; Wang et al., 2009; Van Paridon et al., 2012; Hoogheemraadschap Rijnland, 2017) and interviews with experts of the municipality Haarlemmermeer and the water board Rijnland, the criteria are selected for hydrological, quality and general aspects. The expert input consisted of information obtained from semi-structured interviews of which the structure is shown in Appendix A.

The hydrological criteria are divided into: water flow, soil infiltration capacity, and water storage. Water flow and water quality are related to each other as water flow contributes to the flushing of salt, nutrients and pesticides and thereby improves the water quality (Lobbrecht et al., 1999). A high water flow, especially after extreme rain events, might cause additional problems as bank erosion (Beeson and Doyle, 1995), since the polder is only artificially flushed this should not occur in Hoofddorp park. Stagnant water maintains the current problems which is undesirable. Soil infiltration capacity is used as criterion because a low infiltration capacity can cause waterlogging. The soil has a much higher hydraulic conductivity when the soil infiltration capacity is low (Arshad and Coen, 1992). Potential water storage is included as criterion because it represents adaptation and resilience to climate change. The municipality Haarlemmermeer guideline for climate adaptation includes the capacity of the area to receive 100 mm precipitation in a 2 hour rain event without disrupting public life (Van Paridon et al., 2012). This means that the main paths through the wander forest and fruit nursery have to be accessible and the water should be stored in soil and water courses.

The quality criteria consist of water quality, habitat quality and pollution stability. Water quality in the whole system is one of the main issues in the area (S. van der Laan, personal communication, 13 November, 2017). This results in too little flora and fauna in the water in the whole of Haarlemmermeer (Hoogheemraadschap Rijnland, 2017), but can also result in algae blooms (Janse and Van Puijenbroek, 1998). Habitat quality forms a major prerequisite for biodiversity. Habitat quality is easier to determine than biodiversity as a whole because it depends on environmental aspects as heterogeneity of the landscape only (Noss, 1990). The pollution stability of the dumping ground in the wander forest is included since this dumping ground is partially to heavily contaminated and it is not supposed to move in the environment (Oranjewoud, 1997).

The general criteria are costs and risk. Cost is used as a criterion since it is an important aspect in decision making. It is used often in MCDA (Wang et al., 2009). Cost involves the implementation and yearly maintenance costs for the 100 years after implementation. The costs are compared with each other by dividing by the least costly measurement. The last criterion is the risk involved with the implementation. Risks have to be defined so they can be controlled to a certain level, high risks are preferably avoided in projects (van Well Stam, 2004). The uncertainty of the above-mentioned criteria are scored by this criterion.

The scoring of the criteria was divided in three categories: green, orange or red. In the scoring process green scores 1 point, orange scores 0 points and red scores -1 point. The prerequisites for these scores per criterion are shown by 3.1

Table 3.1.: Criteria scoring requirements

	1 point	0 points	-1 point
Water flow	improves flow	no influence	no flow
Soil infiltration capacity	increases	remains stable	decreases
Potential water storage	increases	remains stable	decreases
Water quality	improves	remains stable	decreases
Habitat quality	improves	remains stable	decreases
Pollution stability	remains stable		becomes unstable
Costs	33% least expensive measurements	33% middle expensive measurements	33% most expensive measurements
Risk	low	middle	high

The formed criteria were weighed to be able to compare the different criteria among each other for each measurement. To evaluate the robustness of the conclusions on the best measurements, two weighting methods were used: the equal weight method and the SIMOS method.

The equal weight method gives all the criteria the same weight (Wang et al., 2009). The other method has been developed by Simos (1990). Criteria were ranked by eleven experts with backgrounds in landscape, water management, sustainability or project management of municipality Haarlemmermeer. During a workshop, cards with criteria were ranked from low importance to high importance. Equally important criteria were put alongside each other and are thereby assigned the same rank. Thereafter, white cards are introduced and are put between the criteria according to the relative importance between them. Criteria weights are calculated by the position they had in the first ranking divided by the total amount of cards (see equation 3.6) and then standardized to a sum of 1 by dividing the weights by the sum of all weights (Wang et al., 2009). The weights given by the different experts were averaged by taking the arithmetic mean of the weights to obtain an average weight for each criterion.

$$w_j = \frac{r_j}{\sum_{j=1}^{n} r} \tag{3.6}$$

3.4. Measurement analysis

Measurements for the problems with water management in Hoofddorp park were based on a literature study (Boyd, 1998; Coops, 2002; Hamza and Anderson, 2005; Gerke, 2006; Needelman et al., 2007; Najjar et al., 2010; Schuetze and Chelleri, 2011; Sollie et al., 2011; van Heukelum, 2012; Evans and Wilcox, 2014; Hoogvliet et al., 2014; IPC Groene Ruimte, 2015; Lõhmus et al., 2015; Whelan et al., 2015; Mellor et al., 2017). This study was complemented with semi-structured interviews. The measurements were assessed and scored for each criterion. The habitat quality was defined with the biodiversity meter of IPC Groene Ruimte (2015). The risk of implementing each measurement is determined with the RISMAN method (van Well Stam, 2004). This method is widely used for construction project risk management in the Netherlands (van Staveren, 2014). It is based on a risk table with frequency and consequence of the particular risk (see figure 3.4). The costs of each measurement are defined with the 'Standaardsystematiek voor Kostenraming' (Standard system for cost estimation) method.

Frequency / Consequence	Weekly	Monthly	Yearly	Less than once per year
Small	Low	Very low	Very low	Very low
Moderate	High	Low	Low	Very low
Large	Very high	High	Low	Very low
Catastrophic	Very high	Very high	High	Low

Figure 3.4.: Risman risk table, adjusted from (van Well Stam, 2004)

3.5. Evaluation

The evaluation for each criterion was performed by calculating the final scores of the measurements for both the SIMOS and the equal weight method. The final score was calculated using equation

3.7(Wang et al., 2009).

$$Measurement_i = \sum_{j=1}^{n} weight_j score_{ij} \quad \text{with} \quad i = 1, 2, ..., m \quad \text{and} \quad j = 1, 2, ..., n \tag{3.7}$$

In equation 3.7 represents i the different measurements and j the criteria. The $score_{ij}$ means the scoring of measurement i for criterion j. The measurement with the maximum score was selected as the best measurement (Wang et al., 2009)

4. Results

4.1. Current state analysis

4.1.1. Biodiversity

Hoofddorp park is separated in the fruit nursery and wander forest since these areas are very different in vegetation. The fruit nursery scores low on habitat quality with a score of 87. The low score is caused by absence of herbs, dead wood, and leaves. The trees in the fruit nursery are all of similar height. There are no banks with a low gradient which would allow a diversity in flora and fauna. Also, leaves and branches are cleaned up at the end of autumn, leaving no organic material for soil life and hiding places behind. The wander forest scores relatively high with a 171 points because of layered vegetation, dead wood, herbs, and gradients in the landscape. However, the wander forest does not provide no low gradient banks. Water plants are almost absent, water is turbid and connectivity within the water system is low.

4.1.2. Soil

The geological history in Haarlemmermeer defined the current landscape and soil characteristics. The sea has left a salt aquifer behind which is confined with a clay and peat layer. This layer is very thin and salt water seepage occurs through the clay layer (Van Paridon et al., 2012; Schuetze and Chelleri, 2011; Wesselingh, nd).

The geological history also defines the soil in Hoofddorp park as it consists of clay. The clay is alternating in oxidized or reduced condition. At the fruit nursery the soil is compact and the upper 15 cm of the soil is in reduced conditions (see Appendix B). This indicates that precipitation in the recent past closes off the pores completely from oxygen and that water cannot infiltrate easily (IUSS Working Group WRB, 2015), which causes waterlogging. Between the groundwater level and this upper layer, an oxidized layer is present.

In the wander forest, the soil has a granular structure at the top (see Appendix B), indicating active soil organisms. This structure allows water infiltrate in the soil easily via preferential flow through macro pores (Gerke, 2006; IUSS Working Group WRB, 2015). The soil in the wander forest is oxidized to the groundwater level.

Based on the groundwater levels from fieldwork, the storage of water in the soil ranges from 138 mm to 276 mm with respect to surface water levels. The potential storage of water in the soil is much larger and ranges from 482 mm to 964 mm with a porosity of 0,35 to 0,70 (see Appendix C). The total potential water storage is much larger than the 100 mm precipitation during the standard rain event for climate adaptation of municipality Haarlemmermeer. Accordingly, the area should be able to handle such a rain event when the infiltration capacity of the soil allows the necessary infiltration and a part of the storage space is already filled with water.

Underneath the petting zoo in the wander forest, an old dumping ground is present. The dumping ground is highlighted by red cross hatching in figure 4.1. The soil contamination analysis performed by Oranjewoud (1997) found that the dump material consists of coal and debris in the first 3 meters below ground surface. As a result, the soil is partially to heavily contaminated by heavy metals as arsenic, cadmium, copper, mercury, lead, nickel, zinc, and cyanide. The center of the dumping ground is also contaminated with mineral oil, poly-cyclic aromatic carbons, and tar. Analyses of groundwater samples did not show any contamination (Oranjewoud, 1997).

The heavy metals found at the sites are all, except for mercury, stable in an environment with pH above 6. Yet, a high pH increases the mobility of arsenic (Wuana and Okieimen, 2011). Polycyclic aromatic carbons are more mobile in the environment. Fortunately, the groundwater samples did not show any contamination, which suggests that the polycyclic aromatic carbons in this area are heavy and therefore less mobile (Oranjewoud, 1997; Wenzl et al., 2006). Tar and mineral oil also have a low mobility in the environment (Angehrn et al., 1998)

According to the standards from 1997, there was no actual risk for public health and spreading of the contamination. However, for the environment, an actual risk was involved. The contamination was reported as heavy and cleaning of the ground with respect to the environment was advised. Instead, a coating layer of ground was applied on top of the contamination before the petting zoo settled there (Oranjewoud, 1997).

4.1.3. Water flow

The total water content in the water courses in Hoofddorp park (the wander forest and around the fruit nursery) amounts to 17,7 * 10^3 m^3 (see calculation of equation 3.1 in Appendix C). The actual amount of water is likely higher because most of the water courses are deeper than the defined 0.75 m (see table B.1 in Appendix C). Since the watercourses are mostly straight, water discharge of rain events happens rather quickly (Gore and Banning, 2017). A 100 mm in 2 hours rain event in Hoofddorp park (ca 11 ha) gives ca 11,0*10^3 m^3 of extra water. If that ends up in the watercourses immediately, it would lead to an increase of 0,76 m in the water courses as calculated in equation 4.1 with data of table 4.1.

Table 4.1.: Data for equations 3.4 and 3.5 calculated in 4.1 and 4.3

Rain	0,1 [m]
Area	110,0*10^3[m^2]
Lower limit potential water storage	50,7*10^3[m^3]
Upper limit potential water storage	101,5*10^3[m^3]
Surface Water Area	14,5*10^3[m^2]

$$Hp = \frac{R * A}{WsA} = \frac{0,1 * 110.000}{14,5 * 10^3} = 0,76m \tag{4.1}$$

The surplus water can only discharge via culverts to the 'Kagertocht'. However, these culverts are not maintained regularly; only incidentally. The capacity of the culvert (see dark red lines in figure 4.1) at the end of Hoofddorp park is unknown as it is not registered in the municipality Haarlemmermeer or water board Rijnland database. The diameter of this culvert is either 0,30, 0,80 or 1,00 m. The flow velocity preferably does not exceed 1 m/s (S van Zonneveld, Personal communication, 6 February 2018). For the largest diameter, this rain event would lead to a flow velocity of 1.9 m/s (see equation 4.2). This rain event can therefore not instantly be discharged via this route.

$$V_{flow} = \frac{R}{A_{culvert} * Time} = \frac{11.000}{\pi 0,5^2 * 7200} = 1,9m/s \tag{4.2}$$

However, the precipitation will not enter the watercourses immediately since it has to pass the soil first. Even, mid-winter groundwater levels give space to store water in the soil. The summer usually has a precipitation shortage in contrary to the winter, therefore it is likely that the soil can store water the whole year (see equation 4.3 with data of table 4.1). The highest groundwater level in Hoofddorp park is in the fruit nursery at 0,60 m below ground surface. In the wander forest, groundwater levels are lower and around 1,35 m below ground surface (see Appendix B).

$$\begin{aligned} Hp_{lowerlimit} &= \frac{(R * A) - pSw}{WsA} = \frac{(0,1 * 110,0 * 10^3) - 50,7 * 10^3}{14,5 * 10^3} < 0 \\ Hp_{upperlimit} &= \frac{(R * A) - pSw}{WsA} = \frac{(0,1 * 110,0 * 10^3) - 101,5 * 10^3}{14,5 * 10^3} < 0 \end{aligned} \tag{4.3}$$

The separated sewage system adds water to the system via precipitation water discharge. The current sewage system is mostly separated or improved separated (Wittenveen+Bos, 2014). This means that precipitation is discharged directly or that the first flush of precipitation is pumped into the sewage system before all precipitation is discharged via spillways (see red dots in figure 4.1)(Wittenveen+Bos, 2014). The total amount of discharged precipitation and sewage via spillways is only determined for a larger area than Hoofddorp park.

Other water input in Hoofddorp park comes from a pumping system water to add fresh water in the system and to maintain the target water level, only the pump at the 'Kagertocht' (see brown dots in figure 4.1) is used during summer the other one is not in use anymore (G Tempelaar, Personal communication, 6 March 2018). This water comes from the main water course in this area 'Kagertocht', which connects to the boezem system via a weir (see the yellow marks in figure 4.1).

The higher target water level causes the water to be stagnant since the area is closed off by weirs, only due to precipitation such a rise in water level is expected by which weirs overflow. North of the wander forest, the water flow is also almost stagnant because of the elevated water level area in between. From fieldwork (see Appendix B) it becomes clear that the water in Hoofddorp park does not flow when the pumping station is turned off.

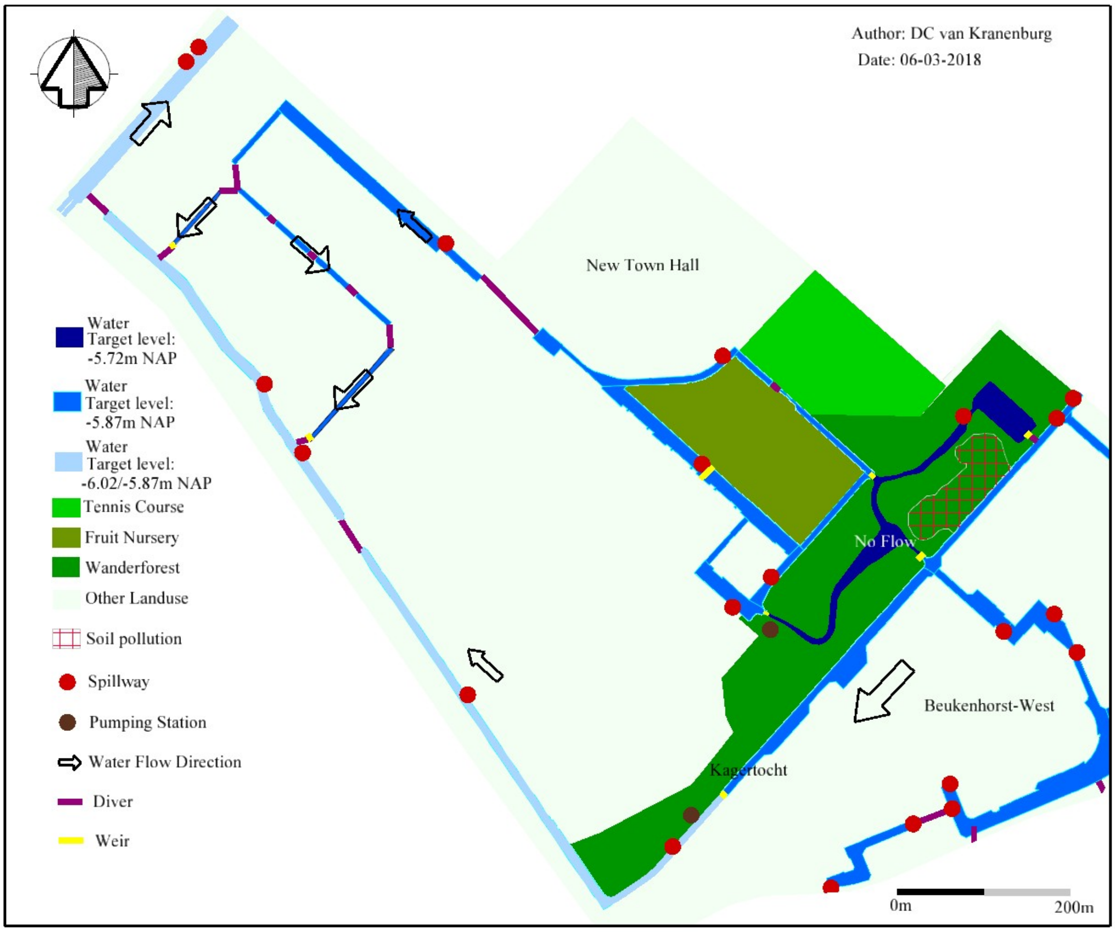

Figure 4.1.: Current situation and developments in Hoofddorp park with a winter and summer target level respectively for the light blue water entity

4.1.4. Water quality

At European level, the Water Framework Directive (WFD) arranges the targets on water quality of different types of water bodies (European Parliament and European Council, 2000). This legislation has been implemented in the Dutch law in Rijksoverheid (2009) and requires policy for monitoring and improving water quality. Accordingly, there is documentation on ecological and chemical water quality of the main water courses of the Haarlemmermeer polder. These water courses are labeled as artificial water bodies (Hoogheemraadschap Rijnland, 2017). The results of the main water courses in Haarlemmermeer are shown in table 4.2.

Table 4.2.: Biological water quality explained in Ecological Quality Ratio (EQR) and chemical water quality in main water courses Haarlemmermeer polder. blue = excellent, green = good, yellow = mediocre, orange = inadequate, red = poor. Adjusted from Hoogheemraadschap Rijnland (2017)

	Required level	2015
Macro fauna (EQR)	$\geq 0,45$	
Other water flora (EQR)	$\geq 0,40$	
Fish (EQR)	$\geq 0,60$	
Phytoplankton (EQR)	$\geq 0,60$	
Total Phosphorus (mg P/l)	$\leq 0,39$	
Total Nitrogen (mg N/l)	$\leq 2,80$	
Salt (mg Cl/l)	≤ 600	
Temperature (max value ℃)	$\leq 25,0$	
pH	$5,5 - 8,5$	
Oxygen saturation (%)	$40 - 120$	
Transparency	$\geq 0,65$	

Table 4.2 shows that water quality in the polder is not at the level it should be. Concerning the chemical quality, the following issues arise: the incoming water to flush the polder is not of high quality; in the polder fertilizers, pesticides, salt water seepage, and organic material affect the water quality (Van Paridon et al., 2012).

In Hoofddorp park, salt water seepage in Hoofddorp park amounts up to 2 mm per day (Deltares, 2015). In the wander forest, bird feces of the petting zoo birds pollute the water and falling leaves from trees close to the water cause a high oxygen demand (see Appendix B). The results of the water quality analysis done by Eurofins (see Appendix D) show that the water quality in the wander forest is significantly lower than the other water courses. The main problems, low pH, high phosphorus, salt and arsenic concentrations are explained by the separate small system in which there is no water flow. Of these indicators, the pH is still within the standards of the WFD, phosphorus is scores above the boundary with 0,41 mg P/L and the salt content is within the boundaries. The water in the target level area of the wander forest does not mix well, the two samples differ significantly on pH, EC and chloride. The main water course 'The Kagertocht' contains arsenic as well.

Concerning the biological water quality, habitat issues arise. Table 4.2 shows that in the whole of Haarlemmermeer the flora and fauna scores inadequate. From Appendix B, which contains the fieldwork results, it becomes clear that almost all banks in Hoofddorp park are steep and/or wooden. These bank types are difficult for birds to access and do not provide a suitable water habitat. Plants and fish in the water would improve the chemical water quality (Karr and Dudley, 1981). In the whole area of Hoofddorp park, there is no flow when the pumping station is turned off (see Appendix B) resulting in a accumulation of contaminants including biodegradable material and likely a very low oxygen level.

4.1.5. Developments

In Hoofddorp park, the tennis course will be renovated. The amount of total outside courses might be decreasing from 12 to 10 (W van der Lee, personal communication, 9 January, 2018). As a result, the surface area of paved surfaces may decrease and potential water storage underneath the courses may become available.

Around Hoofddorp park are two major developments to be started in the foreseeable future. These developments are the development of office area Beukenhorst west into apartment skyscrapers and the parking lot and city council on the north side of Hoofddorp park will be developed into a new city council and apartments (Y van der Sterre, personal communication, 8 Januari, 2018).

4.2. Scenario definition

The scenario definition is based on two different trends, urban development and climate change. Figure 4.2 shows the different scenarios that evolve from these trends.

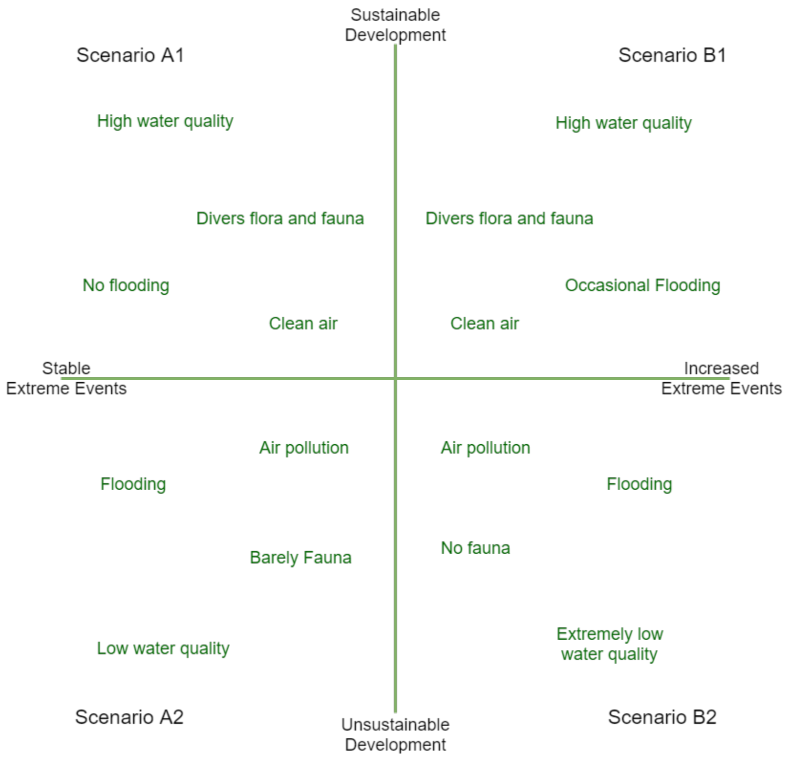

Figure 4.2.: Scenarios with climate change and development trends

4.2.1. Scenario A1

This scenario, combining ustainable development with stable extreme weather events, assumes that climate changes occurs according to table 4.3. The sea level rise implies a rise in hydraulic pressure underneath the polder up to 30 cm extra causing increased seepage (Klein Tank et al., 2014).

Development of the surrounding area is performed sustainably by including climate regulating measures as green roofs and bio-retention areas.

Green roofs and bio-retention areas allow to maintain water in the area longer than a concrete or paved surface (Van Woert et al., 2005; Davis et al., 2009). It provides water during spring and

Table 4.3.: A1: climate change around 2050 with reference period 1981-2010, adjusted from Klein Tank et al. (2014)

Sea level rise	15-30 cm
Average yearly temperature	+1,0 ℃
Yearly precipitation	+4,0% to 885 mm
Potential evapotranspiration	+3,0% to 576 mm
Winter 10-day precipitation sum exceeded once per 10 years	+6,0% to 94 mm
Highest precipitation shortage exceeded once per 10 years	+5,0% to 242 mm

summer for evapotranspiration and therefore reduces the heat in the build-up areas. By storing the water in green roofs and bio-retention areas waterlogging is not a persistent problem. Because of these green areas, the air is filtrated better, divers habitat for flora and fauna is provided and human psychological well-being is improved. Damage costs because of climatic events are low because the area is developed sustainably.

Hoofddorp park is used extensively by the increased population. The pressure on water quality is low, because clean water comes into the system. The area can easily handle the extreme events because it can store enough water before waterlogging problems occur.

4.2.2. Scenario B1

This scenario, combining sustainable development with increased extreme weather events, assumes that climate changes occurs according to table 4.4. The sea level rise implies a rise in hydraulic pressure underneath the polder up to 30 cm extra causing increased seepage (Klein Tank et al., 2014).

Table 4.4.: B1: climate change around 2050 with reference period 1981-2010, adjusted from Klein Tank et al. (2014)

Sea level rise	15-30 cm
Average yearly temperature	+ 1,4 ℃
Yearly precipitation	+2,5/% to 872 mm
Potential evapotranspiration	+5,0% to 587mm
Winter 10-day precipitation sum exceeded once per 10 years	+10% to 98 mm
Highest precipitation shortage exceeded once per 10 years	+17% to 269 mm

Development of the surrounding area is performed sustainably by implementing drain and storage systems under paved areas and the implementation of green roofs and bio retention areas to manage the water increased extreme weather events (Van Woert et al., 2005; Davis et al., 2009).

For most events, the water storage capacity of the drain and storage systems, green roofs and bio retention areas are sufficient to store the water of extreme events and to provide the green spaces with water during summer (Van Woert et al., 2005; Davis et al., 2009). This makes sure that ecosystem services improve: the climate in the city is better regulated, air is filtrated, diverse habitat for flora and fauna is provided and human psychological well-being increases. Damage cost because of extreme events have not increased over time.

Hoofddorp park is used extensively by the increased population. The pressure on water quality is low, because clean water comes into the system. The area can handle most of the increased extreme events because it can store enough water before long term waterlogging problems occur.

4.2.3. Scenario A2

This scenario, combining unsustainable development with stable extreme weather events, assumes that climate changes occurs according to table 4.5. The sea level rise implies a rise in hydraulic pressure underneath the polder up to 40 cm extra causing increased seepage (Klein Tank et al., 2014).

Table 4.5.: A2: climate change around 2050 with reference period 1981-2010, adjusted from Klein Tank et al. (2014)

Sea level rise	20-40 cm
Average yearly temperature	+ 2,0 °C
Yearly precipitation	+5,5/% to 898 mm
Potential evapotranspiration	+4,0% to 581 mm
Winter 10-day precipitation sum exceeded once per 10 years	+12% to 100 mm
Highest precipitation shortage exceeded once per 10 years	+4,5% to 240 mm

Development of the surrounding area is performed unsustainably with hard covered high buildings and barely green spaces. Water discharge is directly to the ditches.

The increased amount of precipitation cannot be stored in the area or pumped away in time. Therefore the area experiences waterlogging and flooding for longer periods. During summer the temperature rises in the city creating a hot spot. Because of the high buildings there is not much wind (Mendis et al., 2007) and the air stays unfiltered in the area. Habitat for flora and fauna decreases and becomes monotone. The result is a decreased human psychological well-being.

Hoofddorp park is used extensively but cannot handle the high pressure. Vegetation dies partly due to waterlogging and the resulting oxygen shortage at the roots. The water quality decreases over time due to the bad quality of the incoming water and storm water runoff.

4.2.4. Scenario B2

This scenario, combining unsustainable development with increased extreme weather events, assumes that climate changes occurs according to table 4.6. The sea level rise implies a rise in hydraulic pressure underneath the polder up to 30 cm extra causing increased seepage (Klein Tank et al., 2014).

Table 4.6.: B2: climate change around 2050 with reference period 1981-2010, adjusted from Klein Tank et al. (2014)

Sea level rise	20-40 cm
Average yearly temperature	+ 2,3 °C
Yearly precipitation	+5,0/% to 894 mm
Potential evapotranspiration	+7,0% to 598 mm
Winter 10-day precipitation sum exceeded once per 10 years	+17% to 104 mm
Highest precipitation shortage exceeded once per 10 years	+25% to 288 mm

Development of the surrounding area is performed unsustainably with hard covered high buildings and barely green spaces. Water discharge is directly to the ditches.

The extreme precipitation events contain very high amounts of water that cannot be stored. Pumps cannot handle the amount and ditches flood during these events. The damage that comes along with these events is high. Because of the high buildings there is not much wind (Mendis et al., 2007) and the air stays unfiltered in the area. Habitat for flora and fauna decreases and becomes monotone. This situation results in a decreased human psychological well-being.

Hoofddorp park is used extensively but is not able to handle the high pressure. The summer precipitation shortages and high salt concentrations in water causes flora and fauna to die. Most vegetation disappears enhancing soil erosion (Gyssels et al., 2005). The water quality in the water courses declines to a new low point in which no life is possible anymore and animals cannot drink it anymore.

4.3. Criteria

The criteria are essential for measurement selection because the current situation shows that the criteria of the municipality Haarlemmermeer for climate adaptation are not met, the water barely flows, the water quality is unsatisfactory and soil contamination is present. For a more resilient system, biodiversity improvement is also an important factor.

The selected criteria were weighted by experts according to the SIMOS method. Their average opinion and the equal weight method weights are shown by figure 4.3. The weights assigned to risk and costs are low compared to the other criteria, whereas the soil contamination stability and water quality are relatively high. The other criteria are assigned similar weights compared to the equal weight method.

The experts barely showed consistency with their backgrounds and function within the municipality Haarlemmermeer. Experts with similar backgrounds, as the water advisor and the water manager, assigned very different weights to water flow and water quality. However, the project leader and the project initiator assigned more similar weights to all the criteria except for the risk criterion. The landscape architect and the water administrator assigned a much higher score to the water flow than the other experts, although their backgrounds are very different.

The experts did not assign high weights to cost and risk, which might not be congruent with actual decision making on this topic. The water manager and the manager were the only two that assigned higher scores to risk and cost, which represents their function. Remarkably, the project leader and administrator assigned low weights which does not represent their function.

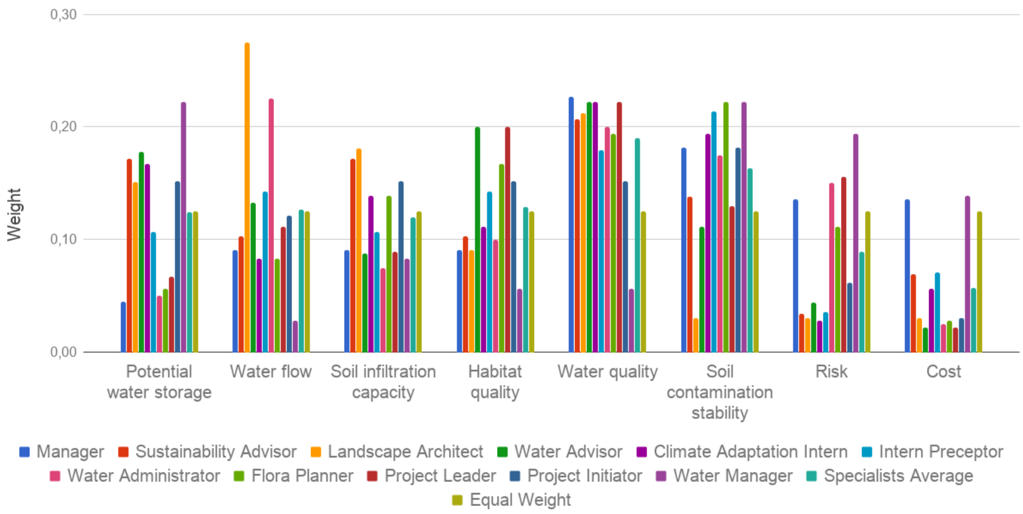

Figure 4.3.: Criteria weights of the SIMOS and equal weights method

4.4. Measurement analysis

A literature study and interviews with three stakeholders resulted in fifteen possible measurements. The proposals of the possible measurement and their location were explained and assessed for each criterion in the following subsections.

4.4.1. Measurements

Natural banks

Natural banks along watercourses are banks that allow vegetation to grow, birds to get out of the water easily and provide habitat for water animals. A natural bank includes a decreased steepness of the bank is decreased and thereby a place with shallow water is created (Sollie et al., 2011).

This measurement increases the potential water storage capacity. The water will not flow as fast at the edges because of increased roughness by vegetation. The vegetation of mostly reed improves the water quality by using nutrients and increasing oxygen levels, although it has to be maintained to prevent obstructions in the water course. This improves the habitat for fauna resulting in increased biodiversity (Coops, 2002; Sollie et al., 2011). This measurement does not influence soil infiltration capacity nor water flow and soil contamination stability.

The risks involved with this measurement are: overgrowth of vegetation occurring yearly with moderate consequence giving low risk, no growth of vegetation occurring monthly with moderate consequence giving high risk or no divers vegetation occurring monthly with low consequence giving low risk. Therefore, this measurement scores average on risk. The total costs for implementation and maintenance for the coming 100 years at all proposed locations are estimated at k€49 (Gemeente Haarlemmermeer, 2018). The proposed locations for implementing natural banks are shown by figure 4.4 and the final scoring of this measurement by table 4.7.

Lowering target water level

This measurements proposes to decrease the target water level of the wander forest with 15 cm to -5,87m NAP. A lower target water level results in the possibility of removing weirs which are now used to maintain the water within the wander forest.

The flow of the water will be improved by connecting the watercourses (Mellor et al., 2017). Because the weirs are removed, water organisms can more easily migrate through the water, also anaerobic conditions in the soil occur less often improving the growth conditions for trees (Lõhmus et al., 2015; Mellor et al., 2017). These factors both improve the habitat quality. The potential water storage decreases due to a smaller water surface, since it is not proposed to deepen the courses. The latter would decrease the hydraulic conductivity of the closing layer which already allows salt water to pass. The change of target water level does not influence the soil infiltration capacity nor the soil contamination stability. The soil contamination stability is not influenced because water as transport medium is less available and pH remains the same.

The risks involved with this measurement are: running dry of personal groundwater pumps in the fruit nursery neighbourhood occurring weekly with large consequence giving very high risk, by connecting the water courses at once the oxygen poor water causes flora and fauna to die occurring less than once per year with catastrophic effect giving a low risk, trees die due to low groundwater levels occurring yearly with moderate effect giving low risk, the heightened salt concentration is caused by a weak spot in the confining layer causing all water in the area to be more salty when the target water level is lower occurring weekly with small effect giving low risk. Therefore, this measurement scores average on risk. The costs of removing the weir and pumping stations as well as pressing the wooden banks into the ground are estimated at k€22 (Gemeente Haarlemmermeer, 2018). There are no extra maintenance costs for this measurement. The location of changing the water level is shown by figure 4.4 and the final scoring of this measurement by table 4.7.

Change water courses

It is proposed to divert the water of the wander forest at the corner of the petting zoo and fruit nursery. The water coming from the petting zoo will flow in northwest direction and the water coming from the center of the wander forest will flow in southwest direction. This is implemented with a weir from northwest to southeast over the water course in the grey block of figure 4.4. The measurement can only be implemented if the target water level of the wander forest is changed.

This measurement contributes to flushing the wander forest in separate ways to lower the pressure on the ecosystem with bad water quality further in the system (Mellor et al., 2017). In this way, it has a positive effect on the total water quality, habitat quality and the water flow in the whole system. It does not change the potential water storage nor soil infiltration capacity and soil contamination stability.

The risk involved with this measurement is: the water quality does not improve which occurs monthly with moderate effect giving low risk. Therefore, this measurement scores low on the risk criterion. The total costs for implementation and maintenance for the coming 100 years at for the weir are estimated at k€75 (Gemeente Haarlemmermeer, 2018). The location of the changed water courses is shown in figure 4.4 and the final scoring of this measurement by table 4.7.

Flexible target water level

The target level of the water is not set at one level but becomes a bandwidth. Pumping water out of the polder and the inlet of water starts only when the respectively upper or lower limit is reached.

This system creates water level differences which promotes biodiversity (Sollie et al., 2011). The total water demand for flushing the polder decreases with the use of this system. However, decreased flushing of the polder allows nutrients and salt water seepage to accumulate to higher levels than before, decreasing water quality (Schuetze and Chelleri, 2011). The potential space for storage of water during extreme precipitation events increases (Hoogvliet et al., 2014), whereas the total flow of the water decreases since less water is coming into the polder. This measurement does not influence the soil infiltration capacity nor the soil contamination stability.

The risks involved with this measurement are: a decreased water quality damaging water vegetation, the groundwater level decreases too much for vegetation to keep up, the ground water level fluctuates too often to adjust groundwater pumps in the fruit nursery neighbourhood causing damage, which are all occurring on a monthly basis with large consequence giving high risk. Therefore, this measurement scores high on the risk criterion. There are no implementation costs for constructive work or maintenance for this measurement (Gemeente Haarlemmermeer, 2018). The final scoring of this measurement is shown by table 4.7

Weir removal

This measurement proposes to remove the weir that is not in use (see black circle in figure 4.4).

The flow of water is improved by the removal. Biodiversity is also improved since the obstructions for migrations are gone (Mellor et al., 2017). The removal of this weir does not influence potential water storage nor the soil infiltration capacity, water quality, and soil contamination stability.

The risks involved with this measurement are: the improved habitat quality does not bring along more biodiversity which occurs yearly with moderate consequence giving low risk, the cabomba plant easily overgrows other vegetation causing the water to clog which occurs yearly with large consequence giving low risk. Therefore, this measurement scores low on the risk criterion. The cost of removing the weir is estimated at k€10 (Gemeente Haarlemmermeer, 2018). The final scoring of this measurement is shown by table 4.7.

Tree removal

This measurement proposes to remove trees close to the water edge in the center of the water forest (see brown color in figure 4.4). Because of this less leaves will fall into the water.

The reduction of leaves reduces the oxygen demand in the water course, which will improve the water quality and reduce the smell (Sollie et al., 2011; Mellor et al., 2017). Unfortunately, removing trees affect the soil infiltration capacity because important preferential flow routes via the tree roots are removed as well. The habitat quality is affected because the trees close to the water edge provide variety in the height of trees. The potential water storage, water flow, and soil contamination stability are not influenced by this measurement.

The risk involved with this measurement is: the trees grow back fast causing the measurement to be repeated every couple years which occurs less than once per year with large consequence giving very low risk. Therefore, the measurement scores low for the risk criterion. The costs for removing trees are estimated at k€8 (Gemeente Haarlemmermeer, 2018). The proposed locations are shown by figure 4.4 and the final scoring of this measurement by table 4.7.

Fountain

This measurement proposes to implement a fountain in the center and upper part of the wander forest as shown by the blue dots in figure 4.4.

A fountain in the wander forest improves the water quality by adding oxygen to the water through spraying and causing some flow when the water falls back into the water body (Boyd, 1998). Hereby, the high oxygen demand of the water is met resulting in a healthier water body. The fountain does not contribute to potential water storage, soil infiltration capacity or habitat quality. There is also no influence on the soil contamination.

The risks involved with this measurement are: the extra oxygen does not meet the total demand for oxygen which occurs monthly with moderate consequence giving low risk and the fountain is turned of in the period that the oxygen demand is high which occurs yearly with large consequence giving low risk. Therefore, this measurement scores low on the risk criterion. The total costs for implementation and maintenance for the coming 100 years at all proposed locations are estimated at k€91 (Gemeente Haarlemmermeer, 2018). The possible location for a fountain is shown by figure 4.4 and the final scoring of this measurement by table 4.7.

Petting zoo management

This measurement proposes to change the petting zoo management. The number of birds is high and there are screens at the edges of the petting zoo. The first reduces the water quality (Whelan et al., 2015) and the latter forms an obstacle for dredging the water course. The introduction of cleaning the screens and regular dredging is proposed as well as reducing the amount of birds.

These adjustments should help improving the flow through the watercourse as well as the water quality (van Heukelum, 2012). This measurement does not contribute to potential water storage nor to soil infiltration capacity, habitat quality or soil contamination stability.

The risk involved with this measurement is: the advice is not implemented causing the water flow and quality to remain the same which occurs weekly with moderate consequence giving high risk. Therefore, this measurement scores high on the risk criterion. There are no costs for constructions or maintenance for this measurement (Gemeente Haarlemmermeer, 2018). The location is shown by figure 4.4 and the final scoring of this measurement by table 4.7.

Debris funded paths

This measurement proposes to rebuild all the paths in the fruit nursery and wander forest on a meter of debris (see figure 4.4).

This measurement results in extra water storage space in the soil. These paths are better accessible during extreme rain events because the water can infiltrate and stored underneath. This measurement does not influence water flow in the water courses, habitat quality, water quality and soil contamination stability. It improves the infiltration capacity at the paths in the wander forest and fruit nursery by having large pores in the construction (Evans and Wilcox, 2014).

The risks involved with this measurement are: the drainage system is not connected to surface water causing the storage space to overflow which occurs monthly with large consequence giving high risk, clogging of the pores with clay which occurs monthly with large consequence giving high risk and the system allows water to flow into the surface water quickly increasing peak flow after rain events which occurs weekly with small consequence giving low risk. Therefore, this measurement scores high on the risk criterion. The total costs for implementation and maintenance for the coming 100 years at all proposed locations are estimated at k€295 (Gemeente Haarlemmermeer, 2018). The final scoring of this measurement is shown by table 4.7

Drainage ditches

Implementing small drainage ditches in the fruit nursery improve the surface water drainage.

This should reduce the waterlogging currently experienced there (Needelman et al., 2007). These drainage ditches increase the potential water storage in the area by adding extra space for surface water. The water flow in the water courses is not influenced by this measurement, and neither are the water quality, soil infiltration capacity and soil contamination stability. The drainage ditches improve the habitat quality by providing height differences in the landscape (IPC Groene Ruimte, 2015).

The risks involved with this measurement are: an increased peak flow after rain events due to slightly quicker discharge from the ditches which occurs weekly with small effect giving low risk, the soil remains too wet during autumn and winter which occurs weekly with moderate consequence giving high risk, and the ditches get stuck to high usage of the fruit nursery and cannot drain the water well which occurs weekly with moderate consequence giving high risk. Therefore, this criterion scores high on the the risk criterion. The total costs for implementation and maintenance for the coming 100 years at all proposed locations are estimated at k€63 (Gemeente Haarlemmermeer, 2018). The location where this could be implemented is shown by figure 4.4 and the final scoring of this measurement by table 4.7.

Sand columns

This measurement proposes to implement sand drainage between the trees of the fruit nursery should improve the drainage and reduce the waterlogging currently experienced there.

This measurement results in delayed discharge to the surface water (Najjar et al., 2010). Since sand has a higher hydraulic conductivity it has a higher infiltration rate and provides space to water more easily. This measurement does not influence the water flow in the water courses, habitat quality, water quality, and soil contamination stability.

The risks involved with this measurement are: sand has to be replaced more often to maintain the effect of the measurement which occurs less than once per year with moderate consequence giving very low risk and the soil remains too wet during autumn and winter which occurs weekly with moderate consequence giving high risk. Therefore, this measurement scores average on the risk criterion. The total costs for implementation and maintenance for the coming 100 years at all proposed locations are estimated at k€23 (Gemeente Haarlemmermeer, 2018). The location at which this could be implemented is shown by figure 4.4 and the final scoring of this measurement by table 4.7.

Fruit nursery management

This measurement proposes to alter the management of the fruit nursery. This includes not using heavy machinery when the soil is wet, increasing the surface contact with the soil of the machinery by using plates or larger tiles (Hamza and Anderson, 2005), and not cleaning up organic material so micro organisms are promoted and can loosen up the soil.

Management of the past has led to compaction of the soil which reduces the permeability of the soil (see field forms in Appendix B). The waterlogging should decrease when maintenance is executed with caution for the soil. When the soil improves water can infiltrate easier via preferential flow paths, the soil should be able to store more water and a higher variety of micro organisms can life in the soil (Gerke, 2006). The measurement does not influence the water flow, water quality or soil contamination stability.

The risks involved with this measurement are: the advice given does not work as well as expected which occurs weekly with moderate consequence giving high risk and the advice is not implemented causing the waterlogging problems to continue which occurs weekly with large consequence giving very high risk. Therefore, this measurement scores high on the risk criterion. There are no costs for implementation (Gemeente Haarlemmermeer, 2018). The location is shown by figure 4.4 and the final scoring of this measurement by table 4.7.

Maintenance water courses

Improving the water flow by doing maintenance to weirs, culverts, wooden banks and water courses frequently once a year.

This measurement should decrease the oxygen demand in the water and improve the flow in the courses (van Heukelum, 2012). This measurement does not influence potential water storage, soil infiltration capacity, habitat quality or soil contamination stability.

The risk involved with this measurement is: an increased peak flow after a rain event which occurs monthly with large consequence giving high risk. Therefore, this measurement scores high on the risk criterion. The usual yearly maintenance costs double leading to a total of k€410 for the coming 100 years for maintenance (Gemeente Haarlemmermeer, 2018). The final scoring of this measurement is shown by table 4.7

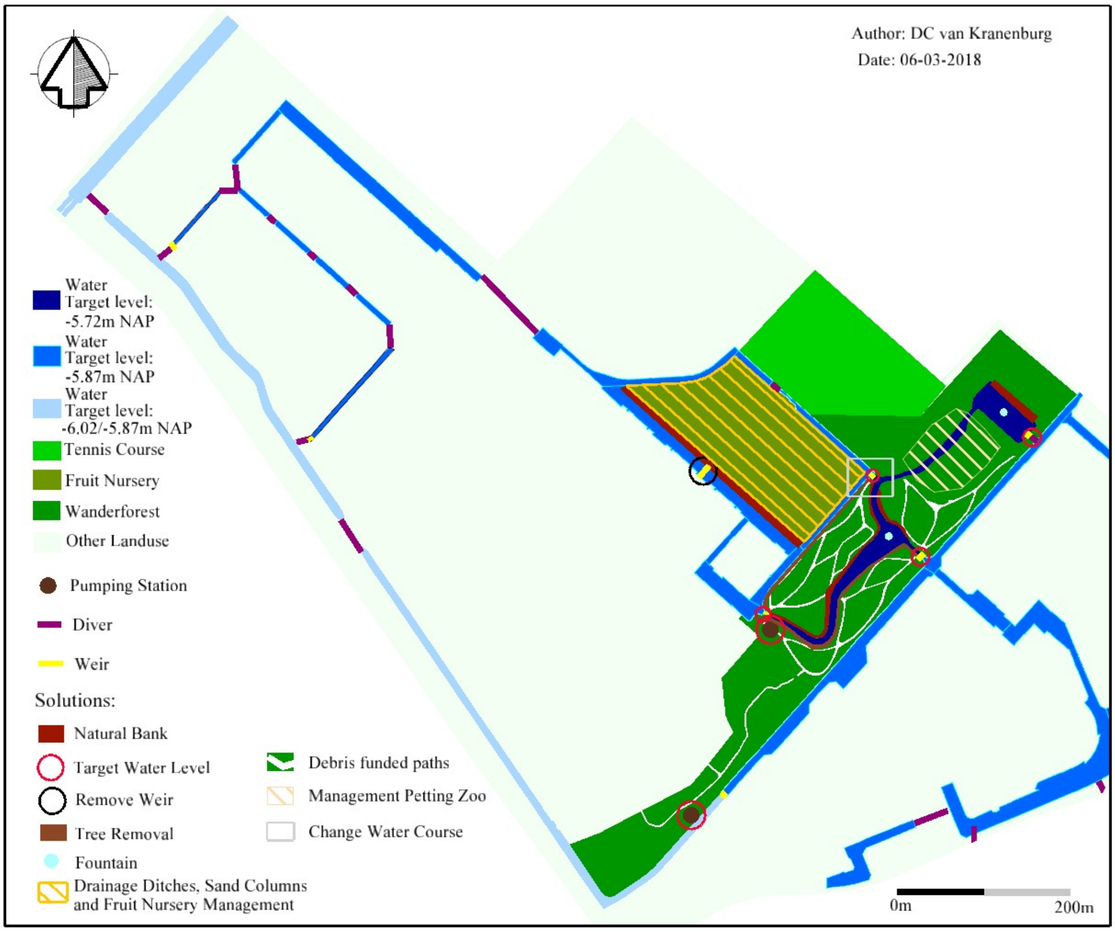

Figure 4.4.: Measurement proposals in Hoofddorp park with a winter and summer target water level respectively for the light blue water entity

4.4.2. Criteria evaluation

Table 4.7 shows all the scores of each measurement on each criterion. Only a few measurements have a positive effect on the soil infiltration capacity, because most measurements are targeting the watercourses and not the land.

All the possible measurements score well on the soil contamination stability. This is caused by the fact that the contamination is not very mobile and is only expected to become somewhat

Table 4.7.: Criteria evaluation of measurements

	Natural bank	Target water level	Change water courses	Flexible target level	Remove weir	Tree removal	Fountains
Potential water storage	1	-1	0	1	0	-1	0
Water flow	0	1	1	0	1	0	1
Soil infiltration capacity	0	0	0	0	0	-1	0
Habitat quality	1	1	1	1	1	-1	0
Water quality	1	1	1	-1	0	1	1
Soil contamination stability	1	1	1	1	1	1	1
Risk	0	0	1	-1	1	1	1
Cost	0	0	-1	1	0	1	-1

	Petting zoo management	Debris funded paths	Drainage ditches fruit nursery	Sand columns	Fruit nursery management	Maintenance water courses
Potential water storage	0	1	1	1	1	0
Water flow	1	0	0	0	0	1
Soil infiltration capacity	0	1	0	1	1	0
Habitat quality	0	0	1	0	1	0
Water quality	1	0	0	0	0	1
Soil contamination stability	1	1	1	1	1	1
Risk	-1	-1	-1	0	-1	-1
Cost	1	-1	0	0	1	-1

mobile when the pH decreases below 6 (Angehrn et al., 1998; Wenzl et al., 2006; Wuana and Okieimen, 2011).

On the risk criterion, most negative scores were assigned. This was mostly caused by a risk on not being able to implement the measurement or the effect of the measurement was uncertain.

Table 4.7 shows that flexible target water level, tree removal, debris funded paths, and maintenance water courses are evaluated with two or more red scores. The natural bank, weir removal, and sand columns are the only two measurements that do not have red scores at all.

4.5. Evaluation

Figure 4.5 shows the evaluation of each measurement for all the criteria of the two different weighing methods. In general, the scores of both methods suggest a similar outcome. This indicates that the scoring of each criteria has more influence on the outcome than the weighting.

The lower scores ($< 0,35$) are for the flexible target level, tree removal, debris funded paths, drainage ditches, and water maintenance, although the water maintenance scores higher by the specialists. Lowering target water level, fountain, petting zoo management and sand columns score average $(0,35-0,40)$. The high scores $(>0,40)$ are for the measurements: natural bank, change water course, weir removal and fruit nursery management.

The difference in scoring between the equal weight and the average of the specialists is more evident for the higher scores. The natural bank, changing the target water level, fountain and the petting zoo management score higher than the equal weights. The SIMOS method proposes a high score for the natural bank, lowering target water level, and fountain, whereas the equal weights method does not.

Because all of the measurements scored the same on the soil contamination stability, the evaluations is also performed without this criterion. The results are shown by figure 4.6. The scores of all measurements are lower, but the high scoring measurements remain the same. The measurements that scored low are now close to zero or negative.

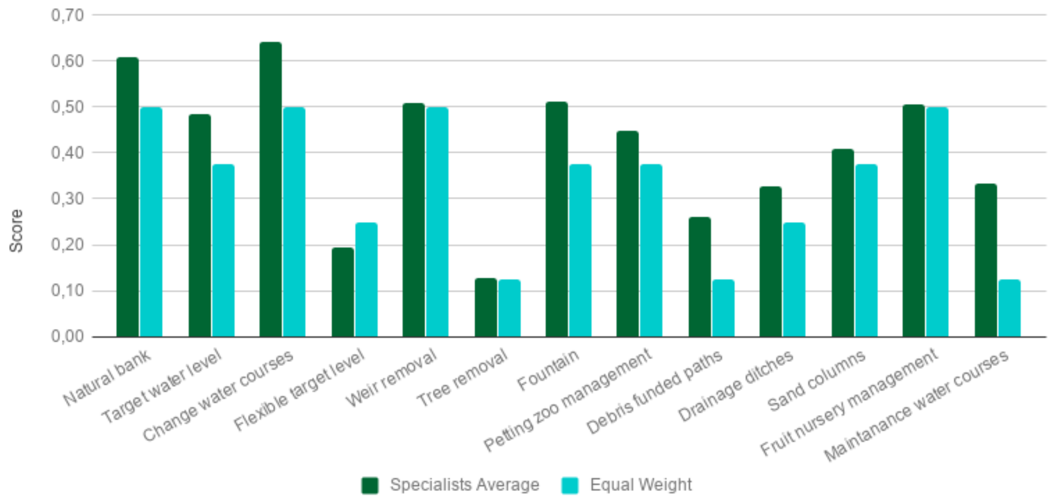

Figure 4.5.: Scores of measurements for the average of the specialists and equal weight method

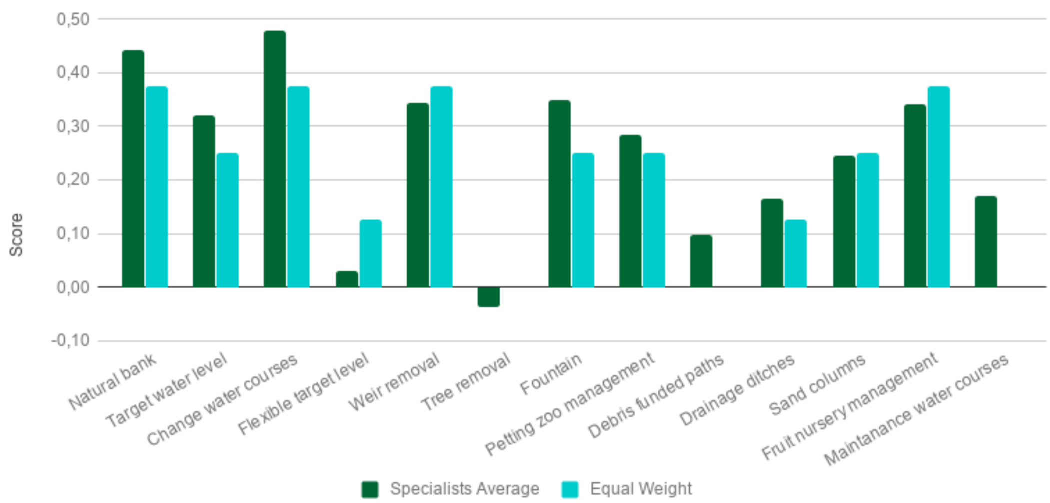

Figure 4.6.: Scores of measurements for the average of the specialists and equal weight method without soil contamination stability

When looking at the more detailed figure 4.7, it shows negative scores for tree removal, debris funded paths, drainage ditches and maintenance water courses. These are explained by high weights for negative scoring criteria by these specialists. The range of scores by the specialists individually is fairly broad, especially at the tree removal where the lowest score is around $-0,15$ and the highest close to $0,5$. It shows that the different weights have effect on the total score per individual.

For the detailed figure without the criterion on soil contamination stability, similar effects are shown as figure 4.6 compared to figure 4.5. All the measurements score lower, but the relative high scoring measurements remain the same. The negative scores are less compensated by the positive influence of the soil contamination stability criterion.

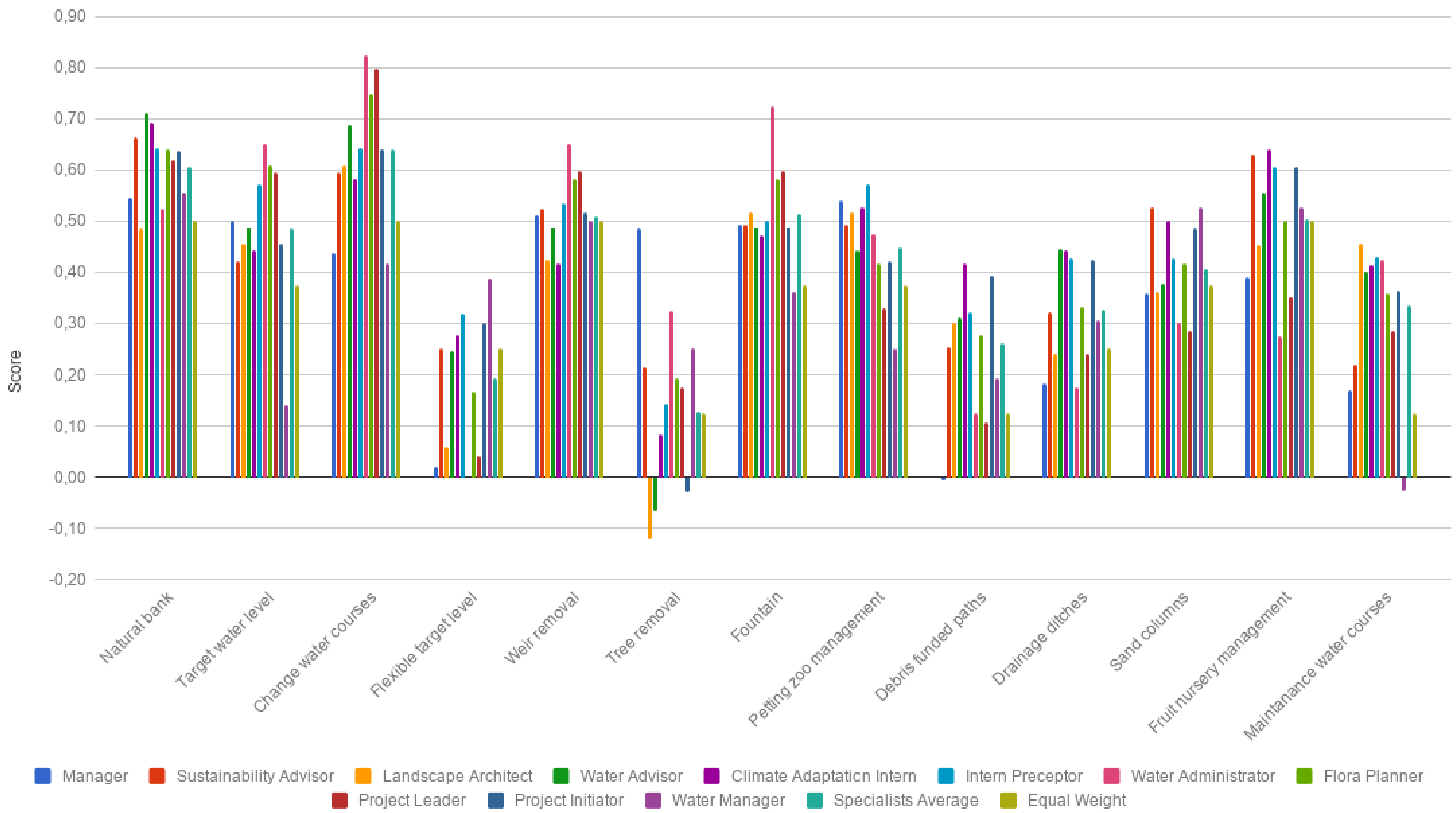

Figure 4.7.: Scores of measurements of the specialists and equal weight method

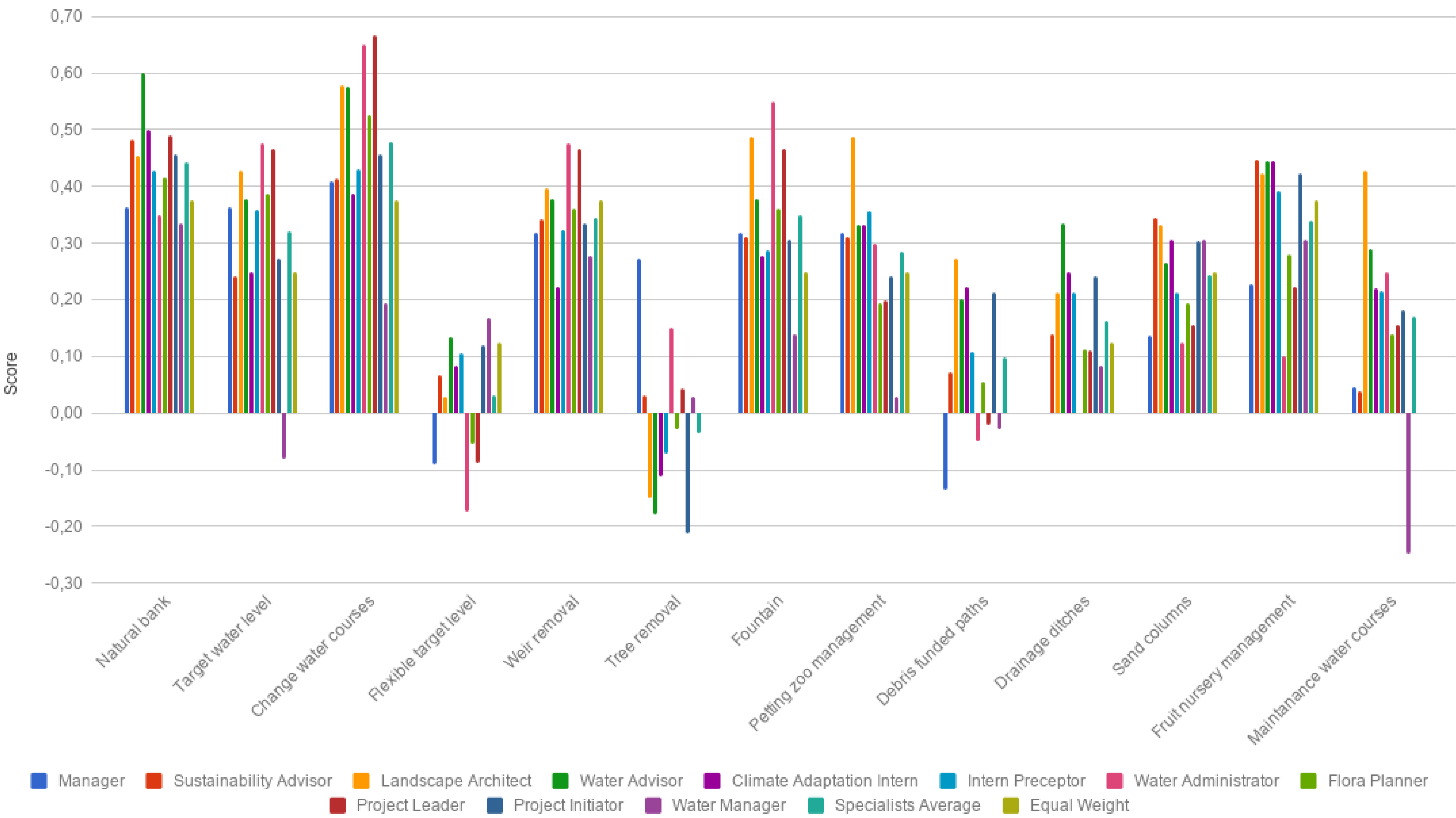

Figure 4.8.: Scores of measurements of the specialists and equal weight method without soil contamination stability

5. Discussion

5.1. Reliability of results

The scoring of the criteria by the specialists was biased towards hydrological criteria instead of practical ones. However, the results of the MCDA showed to be not sensitive of a bias towards a low influence of costs and risk. This bias by the specialists is remarkable, since within organizations the costs and risk are often ranked higher in similar decision making processes (Soltani et al., 2015). However, the scores of these criteria were equally divided in red, yellow and green scores, creating a difference between the measurements. There is a difference between the two different weighing methods (equal weights and SIMOS) in the exact scores for the measurements, still the two methods are suggesting the implementation of similar measurements. In general, the specialists score the measurements higher. Only the measurement maintenance water courses scores much higher by the specialists than by the equal weights method, yet it does not score higher than any of the best scoring measurements which score above $0,35$. Since these two weighing methods suggest the same measurements and the limitation do not affect the scoring of the measurements, the results of the MCDA are reliable.

5.2. Implications of results

5.2.1. Municipality Haarlemmermeer

The results show an emphasis on changing the water course, implementing natural banks, weir removal, and changing the fruit nursery management. To improve the water system it is important to combine measurements to address all aspects of the problem and to create a resilient system. However, it is impossible to change the water courses without lowering the target water level, therefore that measurement has to be included in the basic option of improving this system. When the separate target water level is removed, a fountain is not necessary for improving the water flow and quality anymore. Since the fountain only contributes to the system physically by improving water flow and quality and the costs are high it is not reasonable to implement this measurement. This set of measurements addresses all issues by improving the water flow, water quality, habitat quality, and potential water storage and costs around k€156 for construction and maintenance up to 100 years.

The water system would improve even more when the measurements sand columns and petting zoo management are implemented. The first can contribute to reduce the waterlogging problems, especially when the drainage system is directly under the main walking route in the fruit nursery. Changing the fruit nursery management alone has a high risk because behavioral change is necessary, adding the sand columns would make the system more resilient and reduce the total risk. The second can improve the water quality of the water flowing past the petting zoo. When these are implemented as well the total costs for construction and maintenance up to 100 years are estimated on k€179.

The flexible target level, tree removal, debris funded paths, drainage ditches, and water maintenance are not contributing to a more resilient system. The flexible target level contributes to potential water storage and habitat quality, however it has a negative effect on the water water quality and the implementation risk is high. The tree removal has a negative effect on the potential water storage, soil infiltration capacity, and habitat quality therefore it would undermine the effects of the other measurements when implementing this. The debris funded paths could add to the potential water storage and soil infiltration capacity, however when implementing the sand columns in the fruit nursery the infiltration issues are already addressed and in the wander forest this is not a profound issue. Moreover, the costs of the debris funded paths are high as well as the involved risk. The drainage ditches score lower than the sand columns on potential water storage and soil infiltration capacity resulting in a preference for the sand columns over the drainage ditches. Increased maintenance of the water courses is not improving the resilience of the system, due to the increased artificial influence, the effects on the quality of the system are low and the involved risk and costs are high.

For the municipality Haarlemmermeer, the results can be transferred to other urban areas with similar water related problems. Measurements as natural bank, removal of obstructions in the water courses, and the usage of sand columns for drainage may improve water quality and biodiversity. These measurements can improve the resilience of other green areas in the municipality Haarlemmermeer. Also, it became evident that implementing a flexible target water level is not necessarily favourable for water quality and involves high risk with implementation. Similar arguments are present for the removal of trees, debris funded paths and drainage ditches.

5.2.2. Further research

Scientifically, this case study shows that a MCDA can be used for inclusive decision making on sustainable urban water systems. In a MCDA, various criteria can be included, providing an option for an interdisciplinary approach and creating support for implementation among all included stakeholders. It provides a transparent way of decision making on sustainable urban water systems with criteria from different perspectives.

The theory used on resilience and sustainability has never been used in relation to a polder system. The conceptual framework showed that polder systems are not completely able to become resilient or sustainable, because they are artificially managed. There is room for improvement and creation of more sustainable management. This research provides only an answer for small areas. It is recommended to extend the research focus to polders as a whole, to see whether the polder system can be managed in a way that improves the resilience and the sustainability of the artificial system.

Further research is also recommended for the ecosystem services that can be provided on polder level. The ecosystem services used for this research are focused on urban areas, whereas polders mainly consist of agricultural land use.

The pressure on urban water systems increases as climate is changing and demands more research on urban water systems and how they can evolve the light of climate change and sustainability. Hoofddorp park is an example of this, however more examples are necessary to create a complete picture on the kind of measurements for a resilient urban water system.

6. Conclusions

In this study, a MCDA was performed to investigate how the water system of Hoofddorp Central can be be improved to cost effectively reach a resilient water system for the future up to 2050.

The water system of Hoofddorp Central can be cost effectively improved with the measurements target water level, changing the water course, implementing natural banks, weir removal and changing the fruit nursery management, to reach a resilient water system for the future up to 2050. Ideally, a more resilient system can be reached by implementing the measurements sand columns and petting zoo management. However, the costs of implementing the sand columns increase the total costs from k€156 to k€179.

These measurements provide an improvement in potential water storage, water flow, soil infiltration capacity and habitat quality. Soil contamination remains stable and the risk involved for all measurements varies from low to high. The technical simple measurements are more effective and efficient in reaching resilience.

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A. Interviews

A.1. Semi-structured interview

For all interviews I have used the following format:

1. Introduction of research area
    - Explanation of problems found so far: waterlogging, water quality mostly concerning wander forest, soil contamination and future proof concerning constructions and climate change.
2. Which problems do you encounter in this area?
3. What are options for improvement in your opinion?
4. What criteria are important for you for solutions?
    - costs
    - maintenance
    - water quantity
    - water quality
    - etc
5. Explain how the project will evolve and when a follow up questionnaire can be expected

A.2. Waterboard Rijnland

Interview with Fetze Visser on 4-1-2018

1. Introduction of research area
   Explanation of problems found so far: waterlogging, water quality mostly concerning wander forest, soil contamination and future proof concerning constructions and climate change.
2. Which problems do you encounter in this area?
   At the moment, Rijnland is searching for connecting different level decision areas and starting a flexible water decision level in order to induce higher water quality, create a higher peak storage capacity. This higher level at the wander forest cannot be part of this strategy right now, what we do not like. However we do not know the reason for this higher water level decision area. It might have grown like this with renewed water level decisions over time. The area used to be for agriculture only and it became a growing city only more recently. For agriculture we used to have two levels over year, winter and summer level, of which winter level is lower than summer level. When cities started to develop it was thought to be best to have winter level all year long. it also might have to do with other reasons, but for that you need to look into the archive for old decisions. The dumping ground is probably not the reason for the higher level since the groundwater is not held into this area by a higher water level decision area. When doing maintenance in the wander forest once per two years, there is not much sludge coming out. This has to do with a low water quality, plants cannot grow here.

3. What are options for improvement in your opinion?
    - Lowering the water level of the wander forest would be a good idea, including the removal of some then useless weirs. If these could eventually be connected to the winter and summer flexible water level decision, that would be even better. However going in to steps is probably better for the trees. It would be nice if the pump providing the fruit orchard with water could be turned off and possibly even removed.
    - The screen at the petting zoo might need to be removed, when more water is coming through a lot of leaves might be getting stuck in it.
    - The municipality might need to remove leaves from the banks twice a year, to make sure the water does not start to smell.
    - Natural banks instead of the wooden edges there are now
4. What criteria are important for you for solutions?
    - costs, there is an integral agenda between the municipality and the water board, they might have a budget for this
    - maintenance, the leaves might need to be removed more often
    - water quantity, storage is not allowed to decrease. Increasing storage is always nice
    - water quality, not first priority
    - no new criteria
5. Explain how the project will evolve and when a follow up questionnaire can be expected

A.3. Policy advisor gemeente Haarlemmermeer

Interview with Wim van der Lee on 9-1-2018

1. Introduction of research area
    - Explanation of problems found so far: waterlogging, water quality mostly concerning wander forest, soil contamination and future proof concerning constructions and climate change.
2. Which problems do you encounter in this area?
   Waterlogging in the fruit nursery, walking is almost impossible there at the moment. The tennis course is not used optimal due to too much water in the winter and too much tap water is used. The terrain will be developed and the terrain will change, they have too because the permit for the indoor hall is expiring and will not be extended with the usage it has right now.
3. What are options for improvement in your opinion?
   Underneath the new courses, water can be stored. I heard of hockey clubs building their arena on top of water basin. The water stored can be used during summer for keeping the gravel wet and during winter it can be used for storage of rain water.
4. What criteria are important for you for solutions?
    - costs
    - maintenance
    - water quantity
    - biodiversity
    - waterlogging
5. Explain how the project will evolve and when a follow up questionnaire can be expected

A.4. Water Specialist gemeente Haarlemmermeer

Interview with Nienke Bouwma on 19-1-2018

1. Introduction of research area
    - Explanation of problems found so far: waterlogging, water quality mostly concerning wander forest, soil contamination and future proof concerning constructions and climate change.
2. Which problems do you encounter in this area?
   The most important problems are the waterlogging in the fruit nursery and the water use of the tennis course.
3. What are options for improvement in your opinion?
   I like maintaining polder characteristics. Therefore I would recommend drainage ditches between the trees in the fruit nursery. Other things as lowering the target level of the wander forest and removal of weirs, you mentioned already.
4. What criteria are important for you for solutions?
    - costs
    - maintenance
    - water quantity
    - water quality
    - climate adaptive

   I cannot think of other important criteria at the moment. The costs for the plan have to be discussed with water board Rijnland.
5. Explain how the project will evolve and when a follow up questionnaire can be expected

B. Field Work

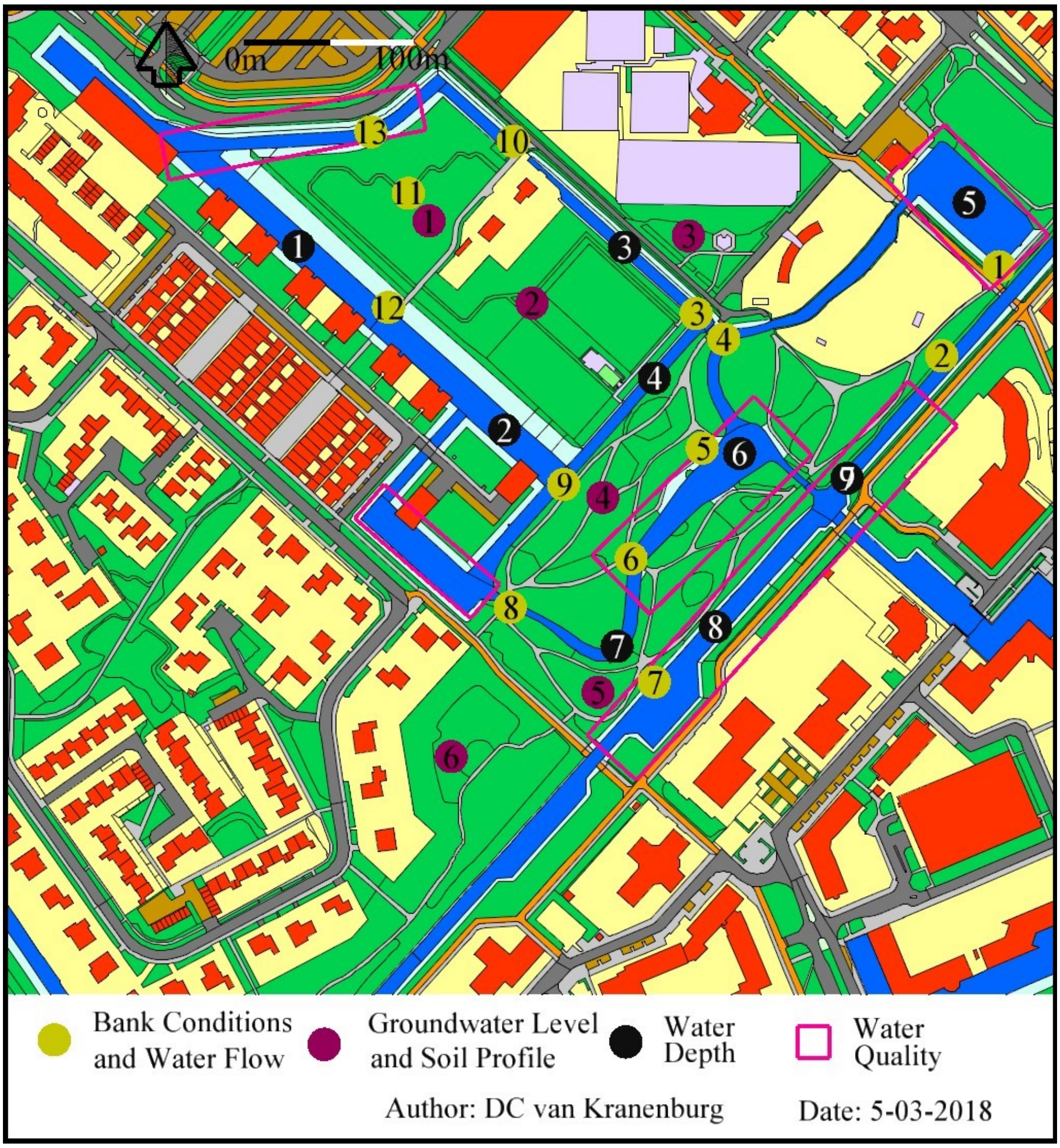

Figure B.1.: Locations of observations with observation numbers

B.1. Water depth

Table B.1.: Water depth and sludge depth observations

Observation Nr	1	2	3	4	5	6	7	8	9
Date	12-1-2018	12-1-2018	12-1-2018	12-1-2018	12-1-2018	12-1-2018	12-1-2018	12-1-2018	12-1-2018
Location	1	2	8	9	5	3	4	6	7
Water Depth (cm)	110	110	110	103	60	120	120	120	45
Sludge Depth (cm)	10	10	10	50	80	10	20	45	25

B.2. Groundwater depth and soil profiles

Table B.2.: Groundwater depth and soil profile observations

Observation nr	1			2			3		
Date	22-1-2018			22-1-2018			22-1-2018		
Time	11.30			11.45			12.00		
Location	1			2			3		
	Depth (cm)	Texture	Note	Depth (cm)	Texture	Note	Depth (cm)	Texture	Note
Soil	0-15 cm	organic matter with clay	dark grey	0-15	organic matter with clay	dark grey	0-15	organic matter with clay	dark grey
	15-115	clay	oxidized	15-65	clay	reduced	15-120	clay	oxidized
	115-160	clay	reduced	65-135	clay	oxidezed	120-160	clay	reduced
				135-160	clay	reduced			
Groundwaterdepth	60 cm below surface			90 cm below surface			80 cm below surface		
General Note	Soil very compact			Soil very compact					

Observation Nr	4			5			6		
Date	22-1-2018			22-1-2018			22-1-2018		
Time	12.15			12.45			13.15		
Location	4			5			6		
Soil	Depth (cm)	Texture	Note	Depth (cm)	Texture	Note	Depth (cm)	Texture	Note
	0-25	clay	granular structure	0-50	clay	granular structure	0-5	organic matter with clay	
	25-135	clay	oxidized	50-145	clay	oxidized	5-120	clay	oxidized
	135-160	clay	reduced						
Groundwater Depth	140 cm below surface			135 cm below surface			90 cm below surface		
General Note	No compaction			No compaction					

B.3. Banktypes and waterflow

Table B.3.: Banktypes and waterflow observations

Observation Nr	1	2	3	4	5	6	7
Date	12-1-2018	12-1-2018	12-1-2018	12-1-2018	12-1-2018	12-1-2018	12-1-2018
Time	9.45	9.50	9.55	9.57	10.00	10.05	10.10
Location	1	2	3	4	5	6	7
Vegetation	Grass	Grass	Grass	Trees/Shrubs	Trees/Grass	Trees/Ivy	Trees/Ivy
Tree Density (nr trees/10m^2)	0	0,5	0	2	2	1	1
Bank type	Gentle and Wooden	Wooden	Steep	Steep	Wooden	Wooden	Steep and Wooden
Water Flow Direction	No Flow	Southwest	Northeast	No Flow	No Flow	No Flow	Southwest
Note	Petting Zoo has a lot of birds			Trees very close to water	Trees very close to water	Trees very close to water	

Observation Nr	8	9	10	11	12	13
Date	12-1-2018	12-1-2018	12-1-2018	12-1-2018	12-1-2018	12-1-2018
Time	10.15	10.25	10.35	10.45	10.55	11.05
Location	1	9	10	11	12	13
Vegetation	Trees/Ivy	Trees/Ivy	Grass	Trees/Grass	Trees/Grass	Grass
Tree Density (nr trees/10m^2)	2	2	0	1	0,5	0
Bank type	Gentle and Wooden	Wooden	Wooden	Wooden	Gentle	Steep and Wooden
Water Flow Direction	No Flow	Northeast	Northeast		Northeast	East
Note	Trees very close to water	Trees very close to water, pumping station off	No diver visible	Middle of Fruit Nursery no waterlogging between trees	Useless weir willows close to water	

C. Water Storage

C.1. Water storage

Table C.1.: Surface water storage of Hoofddorp park, equation 3.1

ID	Length [m]	Bottom width [m]	Water surface width [m]	Depth [m]	Surface Area [m^2]	Storage Bottom [m^3]	Storage Bank [m^3]	Total Storage [m^3]
1498	155	2,89	7,39	0,75	447,95	336,0	261,6	597,5
1668	72	12,67	17,17	0,75	912,24	684,2	121,5	805,7
1779	8	2,98	7,48	0,75	23,84	17,9	13,5	31,4
1868	7	3,06	7,56	0,75	52,92	16,1	11,8	27,9
1976	224	5,60	10,10	0,75	1.254,40	940,8	378,0	1.318,8
2017	16	1,75	6,25	0,75	100,00	21,0	27,0	48,0
2173	195	1,64	3,89	0,75	758,6	239,9	164,5	404,4
2689	18	9,15	13,65	0,75	245,53	123,5	30,4	153,9
2786	75	2,87	7,37	0,75	215,25	161,4	126,6	288,0
2906	50	8,35	13,03	0,75	417,50	313,1	87,8	400,9
2945	43	2,17	4,42	0,75	190,1	70,0	36,3	106,3
3081	169	1,60	3,73	0,55	630,4	148,7	99,0	247,7
3427	211	0,62	5,12	0,75	130,82	98,1	356,1	454,2
3438	152	11,53	16,03	0,75	1.752,56	1.314,4	256,5	1.570,9
3606	118	4,10	6,35	0,75	749,3	362,9	99,6	462,4
3896	82	4,79	9,29	0,75	392,78	294,6	138,4	433,0
4152	127	0,68	5,18	0,75	86,36	64,8	214,3	279,1
4547	235	14,93	19,43	0,75	3.508,55	2.631,4	396,6	3.028,0
4639	73	11,09	15,59	0,75	809,57	607,2	123,2	730,4
4834	66	1,60	3,85	0,75	254,1	79,2	55,7	134,9
4835	82	4,75	7,00	0,75	574,0	292,1	69,2	361.3
4836	36	1,60	3,85	0,75	138,6	43,2	30,4	73,6
4837	67	10,75	13	0,75	871,0	540,2	56,5	596,7
Sum:					14.516,37			12.555,0

Table C.2.: Soil water storage, equations 3.2 and 3.3

ID	Area [m^2]	Ground surface level [m NAP]	Target water level [m NAP]	δ height [m]	Groundwater depth [m]	η	Lower limit soil water storage [m^3]	Upper limit soil water storage [m^3]	Lower limit potential soil water storage [m^3]	Upper limit potential soil water storage [m^3]
1	13.187	-4,4	-5,87	1,47	0,60	0,35-0,7	4.015,4	8.030,9	6.784,7	13.569,4
2	13.620	-4,4	-5,87	1,47	0,90	0,35-0,7	2.717,2	5.434,4	7.007,5	14.015,0
3	20.770	-4,6	-5,87	1,27	0,90	0,35-0,7	2.689,7	5.379,4	9.232,3	18.464,5
4	28.130	-4,4	-5,72	1,35	1,35	0,35-0,7	-295,4	-590,7	12.996,1	25.992,1
5	29.615	-4,3	-5,72	1,42	0,90	0,35-0,7	5.389,9	10.779,9	14.718,7	29.437,3
sum	105.322						14.516,9	29.033,8	50.739,2	10.1478,4
in mm							138	276	482	964

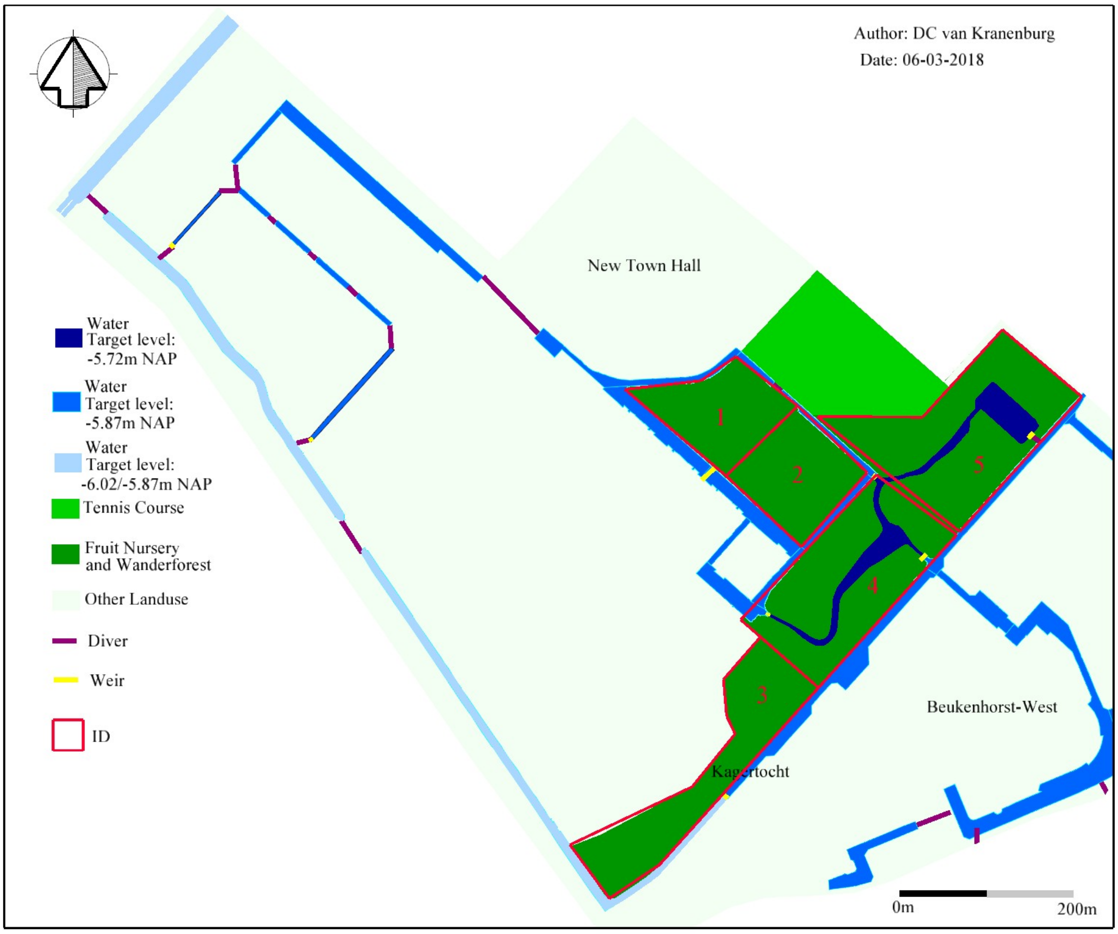

Figure C.1.: Identification of areas for table C.2

D. Water Quality Lab Results

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RvA L 086

Grondslag Heerhugowaard
T.a.v. de heer L. Smits
Galileistraat 69
1704 SE HEERHUGOWAARD

Uw kenmerk	:	26882-Burg van der Wilgenlaan
Ons kenmerk	:	Project 739895
Validatieref.	:	739895_certificaat_v1
Opdrachtverificatiecode	:	IRID-OKRA-ZFVK-PTFS
Bijlage(n)	:	3 tabel(len) + 1 bijlage(n)

Amsterdam, 16 februari 2018

Hierbij zend ik u de resultaten van het laboratoriumonderzoek dat op uw verzoek is uitgevoerd in de door u aangeboden monsters.

De resultaten hebben uitsluitend betrekking op de monsters, zoals die door u voor analyse ter beschikking werden gesteld.

Het onderzoek is, met uitzondering van eventueel uitbesteed onderzoek, uitgevoerd door Eurofins Omegam volgens de methoden zoals ze zijn vastgelegd in het geldende accreditatie-certificaat L086 en/of in de bundel "Analysevoorschriften Eurofins Omegam". De in dit onderzoek uitgevoerde onderzoeksmethoden van de geaccrediteerde analyses zijn in een aparte bijlage als onderdeel van dit analyse-certificaat opgenomen. De methoden zijn, voor zover mogelijk, ontleend aan de accreditatieprogramma's/schema's en NEN- EN- en/of ISO-voorschriften.

Ik wijs u erop dat het analyse-certificaat alleen in zijn geheel mag worden gereproduceerd. Ik vertrouw erop uw opdracht volledig en naar tevredenheid te hebben uitgevoerd. Heeft u naar aanleiding van deze rapportage nog vragen, dan verzoek ik u contact op te nemen met onze klantenservice.

Hoogachtend,
namens Eurofins Omegam,

Ing. J. Tukker
Manager productie

ANALYSECERTIFICAAT

Project code : **739895**
Project omschrijving : **26882-Burg van der Wilgenlaan**
Opdrachtgever : **Grondslag Heerhugowaard**

Monsterreferenties
5600601 = W1 2018-1
5600602 = W2 2018-1
5600603 = W3 2018-1

Opgegeven bemonsteringsdatum		:	**09/02/2018**	**09/02/2018**	**09/02/2018**
Ontvangstdatum opdracht		:	**09/02/2018**	**09/02/2018**	**09/02/2018**
Startdatum		:	**09/02/2018**	**09/02/2018**	**09/02/2018**
Monstercode		:	**5600601**	**5600602**	**5600603**
Matrix		:	**Afvalwater**	**Afvalwater**	**Afvalwater**
Algemeen onderzoek - fysisch					
Q	zuurgraad (pH)		**7,6**	**7,8**	**5,7**
	meettemperatuur pH	°C	**13,9**	**12,9**	**15,3**
Q	elektrische geleiding (EC)	mS/m	**95,5**	**104,2**	**140,3**
	meettemperatuur EC	°C	**13,3**	**12,6**	**11,8**
Anorganische parameters - metalen					
Metalen ICP-MS (totaal):					
Q	arseen (As)	µg/l	**< 4**	**< 4**	**4,9**
Q	cadmium (Cd)	µg/l	**< 1**	**< 1**	**< 1**
Q	chroom (Cr)	µg/l	**< 5**	**< 5**	**< 5**
Q	koper (Cu)	µg/l	**< 5**	**< 5**	**< 5**
Q	kwik (Hg) (niet vluchtig)	µg/l	**< 0,02**	**< 0,02**	**< 0,02**
Q	lood (Pb)	µg/l	**< 5**	**< 5**	**< 5**
Q	nikkel (Ni)	µg/l	**< 5**	**< 5**	**< 5**
Q	zink (Zn)	µg/l	**< 20**	**< 20**	**< 20**
Anorganische parameters - overig					
Q	chloride	mg/l	**67**	**79**	**200**
Q	totaal stikstof als N	mg N/l	**1,1**	**1,4**	**2,5**
Q	totaal fosfaat als P	mg P/l	**0,20**	**0,34**	**0,41**
Q	totaal cyanide	µg/l	**< 3,0**	**< 3,0**	**< 3,0**

ANALYSECERTIFICAAT

Project code : **739895**
Project omschrijving : **26882-Burg van der Wilgenlaan**
Opdrachtgever : **Grondslag Heerhugowaard**

Monsterreferenties
5600604 = W4 2018-1
5600605 = W5 2018-1

Opgegeven bemonsteringsdatum		:	**09/02/2018**	**09/02/2018**
Ontvangstdatum opdracht		:	**09/02/2018**	**09/02/2018**
Startdatum		:	**09/02/2018**	**09/02/2018**
Monstercode		:	**5600604**	**5600605**
Matrix		:	**Afvalwater**	**Afvalwater**
Algemeen onderzoek - fysisch				
Q	zuurgraad (pH)		**7,7**	**7,9**
	meettemperatuur pH	°C	**12,4**	**11,5**
Q	elektrische geleiding (EC)	mS/m	**86,5**	**108,3**
	meettemperatuur EC	°C	**12,4**	**11,3**
Anorganische parameters - metalen				
Metalen ICP-MS (totaal):				
Q	arseen (As)	µg/l	**< 4**	**4,2**
Q	cadmium (Cd)	µg/l	**< 1**	**< 1**
Q	chroom (Cr)	µg/l	**< 5**	**< 5**
Q	koper (Cu)	µg/l	**< 5**	**< 5**
Q	kwik (Hg) (niet vluchtig)	µg/l	**< 0,02**	**< 0,02**
Q	lood (Pb)	µg/l	**< 5**	**< 5**
Q	nikkel (Ni)	µg/l	**< 5**	**< 5**
Q	zink (Zn)	µg/l	**< 20**	**< 20**
Anorganische parameters - overig				
Q	chloride	mg/l	**140**	**91**
Q	totaal stikstof als N	mg N/l	**0,95**	**1,4**
Q	totaal fosfaat als P	mg P/l	**0,18**	**0,13**
Q	totaal cyanide	µg/l	**< 3,0**	**< 3,0**

- De met een 'Q' gemerkte analyses zijn door RvA geaccrediteerd (registratienummer L086).

A N A L Y S E C E R T I F I C A A T

Project code	:	**739895**
Project omschrijving	:	**26882-Burg van der Wilgenlaan**
Opdrachtgever	:	**Grondslag Heerhugowaard**

Opmerkingen m.b.t. analyses

Opmerking(en) algemeen

Geleidbaarheid (EC-meting)
Het gemeten electrisch geleidingsvermogen is door middel van automatische temperatuurcompensatie gecorrigeerd naar een referentietemperatuur van 25 °C.

A N A L Y S E C E R T I F I C A A T

Project code	:	**739895**
Project omschrijving	:	**26882-Burg van der Wilgenlaan**
Opdrachtgever	:	**Grondslag Heerhugowaard**

Analysemethoden in Afvalwater

In dit analysecertificaat zijn de met 'Q' gemerkte analyses uitgevoerd volgens de onderstaande analysemethoden. Deze analyses zijn vastgelegd in het geldende accreditatie-certificaat met bijbehorende verrichtingenlijst L086 van Eurofins Omegam BV.

Elektrische geleiding (EC)	:	Conform NEN-ISO 7888
Zuurgraad (pH)	:	Conform NEN-EN-ISO 10523
Arseen (As)	:	Conform NEN-EN-ISO 17294-2 en destructie conform NEN-EN-ISO 15587-1
Cadmium (Cd)	:	Conform NEN-EN-ISO 17294-2 en destructie conform NEN-EN-ISO 15587-1
Chroom (Cr)	:	Conform NEN-EN-ISO 17294-2 en destructie conform NEN-EN-ISO 15587-1
Koper (Cu)	:	Conform NEN-EN-ISO 17294-2 en destructie conform NEN-EN-ISO 15587-1
Kwik (Hg) (niet vluchtig)	:	Gelijkwaardig aan NEN-EN-ISO 12846
Lood (Pb)	:	Conform NEN-EN-ISO 17294-2 en destructie conform NEN-EN-ISO 15587-1
Nikkel (Ni)	:	Conform NEN-EN-ISO 17294-2 en destructie conform NEN-EN-ISO 15587-1
Zink (Zn)	:	Conform NEN-EN-ISO 17294-2 en destructie conform NEN-EN-ISO 15587-1
Chloride	:	Gelijkwaardig aan NEN-EN-ISO 15682
Totaal stikstof als N	:	Eigen methode; gebaseerd op NEN 6643 (2003)
Totaal fosfaat als P	:	Eigen methode; gebaseerd op NEN-EN-ISO 15681-2
Totaal cyanide	:	Conform NEN-EN-ISO 14403-2