Master Thesis

CLIMATE RESILIENT WATER SYSTEM IN HAARLO-OLDEN EIBERGEN

A DESIGN STUDY

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Climate resilient water system in Haarlo-Olden Eibergen

A design study

Master Thesis

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PREFACE

In front of you lies my master thesis 'Climate resilient water system in Haarlo-Olden Eibergen – A design study'. This thesis describes the research process and result of my master graduation research to obtain the Master of Science (MSc) degree in Civil Engineering and Management (CEM) at the University of Twente in Enschede, The Netherlands. This research has been commissioned by Waterboard Rijn and IJssel.

As a young child I played in the ditches in my neighbourhood and today I am still fascinated by water systems. When my graduation approached and I had to choose a research project, I quickly knew that it had to be about a water system in combination with climate change. I am therefore thankful for the fact that I was allowed to conduct this research. I could not have completed my studies and this thesis without the support of everyone involved.

I would like to thank the members of my graduation committee for their supervision and support during this research. First of all, I want to thank Joanne Vinke – de Kruijf for making time to give me valuable feedback and to discuss my research. When I got stuck in my research you always managed to get me through. I also want to thank Martijn Booij for his constructive feedback and discussions about my research. I would like to thank my external supervisors from Waterboard Rijn and IJssel Nila Taminiau and Rutger Engelbertink for their support and help during my research. Despite their overloaded agendas they always managed to find a moment to discuss my research.

I would like to thank all the interview and focus group session respondents that were held during my research. Without them, this research could not have taken place.

Finally, I would like to thank my friends and family for their support during my studies and for always being there for me. In particular, I want to thank Huub for always supporting and being there for me, even though you had to hear nightly that I worked the whole day on my thesis at home. I would like to thank you also for encouraging me to get the best out of myself. I would also like to thank my friend Lorraine for our good talks about my research, and not unimportantly, for the wonderful relaxing moments together with the horses. Finally, I would like to thank my parents, brother and sister. They also always encourage me to get the best out of myself and always give me good advice. I would like to thank my mother and brother for the fact that I could spend the last few weeks of my research in Reutum at the home office of my brother to make it possible to spend breaks no longer alone.

I am looking forward to starting my career at DIJK53 and I am curious about all the opportunities that will come my way.

I hope you enjoy reading my thesis report.

Linde Hagedoorn
Hengelo, November 2021

SUMMARY

Background information

In the coming decades, the world will undergo climate change. This climate change will result in a change in freshwater availability. The availability of freshwater in the Netherlands is crucial since many economic sectors are dependent on freshwater. To cope with climate change, we must work on climate adaptation: preparing our country for changing circumstances. According to the Delta Programme, the goal is that in 2050 the Netherlands is resilient against freshwater shortages. Similarly to the entire Netherlands, the management area of Waterboard Rijn and IJssel face climate change and water shortages. The Berkel is one of the five catchment areas of WRIJ. Within the Berkel catchment area, drinking water extraction locations are located. The extraction of water takes place from groundwater and results in a declination of the groundwater table. Water from the Berkel is supplied to decrease the declination of the groundwater table and to provide enough freshwater. However, the water in the Berkel is polluted by five small wastewater treatment plants located in Germany. This study focuses on the area Haarlo-Olden Eibergen, located in the Berkel catchment area. The water system in the area is designed such that water is quickly drained for agriculture. Together with climate change, this results in desiccation in the area. In addition, even more desiccation than only caused by climate change is caused by the declination of the groundwater table since drinking water is extracted in the area. Due to contamination by the effluent of wastewater treatment plants and the leaching of pesticides and nutrients, the water quality in the area Haarlo-Olden Eibergen is not sufficient. The contamination concentrations in the groundwater are a problem for the extraction of drinking water as well as for other functions in the area such as nature. It is not easy to come to a solution to decrease the desiccation in an area, to maintain good water quality and at the same time as obtain the goal to be climate resilient by 2050. An integrated approach is needed for the challenge of solving the aforementioned problems.

The research objective and method

The objective of this research is to ‘design a climate resilient water system for the area Haarlo-Olden Eibergen by re-designing the current water system’. To design a climate resilient water system, this research adopts a design science methodology. In this design science methodology, three design phases are distinguished: the problem investigation phase, the design phase and the validation phase. The problem investigation is divided into four parts: 1) problem introduction; 2) system analysis, 3) stakeholder analysis; and 4) preparing a list of requirements for the new design. Interviews and focus group sessions are used to formulate the problem from the perspective of the stakeholders. In the design phase, the current water system is re-designed and in the validation phase, the re-design is validated. There are two different validations during this study, first, the design is validated during designing by expert judgement of the researcher herself and finally, the re-design is validated with the key stakeholders.

The problem investigation phase

As a result of climate change, extreme summer precipitation events will occur more often with increasing precipitation intensities, the winter season will become wetter, longer periods of drought will occur and the average temperature and extremes in high temperatures will increase in summer. The current water system is not designed to absorb this climate change. Desiccation caused by climate change combined with the water system that is designed for quick drainage of water is a problem. The extraction of drinking water results in a declination of the groundwater table and therefore even more desiccation than only caused by climate change. The water extracted is vulnerable to pollution since it is of the type phreatic.

Resilience principles are used to re-design the current water system to be climate resilient. For the re-design to be climate resilient, the resilience principles; redundancy, omnivory and buffering are implemented. To comply with these principles, the re-design must contain backups of critical sources, it must spread the risks by spreading over multiple resources and it must contain buffers to absorb disturbances.

Nine stakeholders were identified of which WRIJ is the problem owner. According to the respondents of the stakeholders, drought and water quality are the most pressing issues in the current situation. Drought will also be the most prominent issue in the future due to climate change according to the stakeholders. Within the problem formulation, the gap between the desired and current/expected situation becomes clear. The water system is now designed such that the water is quickly drained but it is desired that the water is retained in the area. It is also desired that the water system will be designed more naturally which is now not the case as the water system is constructed and contains civil technical means. To maintain good water quality the system must no longer be dependent on the supplied water from the Berkel and the leaching must be reduced. Besides formulating the problem, the stakeholders also propose solutions for the re-design.

Based on the problem investigation, four overarching requirements were formulated: 1) the water system should be climate resilient; 2) the water system should aim at maintaining good water quality; 3) the design should satisfy the needs of the stakeholders; and 4) the water system should be re-designed more naturally. Each of these requirements contains sub-requirements that are more specific for the area. The list of requirements is validated and found to be complete by the key stakeholders.

The design and validation phase

The list of requirements together with the solutions posed by the stakeholders is used to re-design the current water system. In the new design, the main waterways are restored to a natural stream valley system, the smaller waterways that drain into the Leerinkbeek and Berkel are all made shallower and widened into wadis and the even smaller waterways are filled up. Recreational lakes and lands sensitive to waterlogging are used as buffers to store excess water and for water retention. The pumping wells for water extraction are spread out over the area and a new form of water extraction is added in the area. The inlet that supplies water from the Berkel is no longer used year-round but can be used only as a backup in times of extreme drought. In addition, a helophyte filter is placed which purifies the water before it enters the area. Lastly, an adjustment to the agricultural sector is added to the design. The whole area will be set up as a pilot for nature-inclusive agriculture.

Throughout the design phase, the requirements are validated by the researcher herself. Finally, a validation session with the three key stakeholders (WRIJ, Vitens and HOE Duurzaam) in a focus group session is executed. The re-design was approved by the key stakeholders.

The conclusion

This research presents a design of a climate resilient water system for the area Haarlo-Olden Eibergen. A design science method is applied to re-design the current water system. The premise is that this design will stimulate discussion about possible solutions in the area and the challenges that the area faces in the transition towards becoming a climate resilient water system.

The recommendations

To change the area Haarlo-Olden Eibergen to an area with a climate resilient water system, lots of steps have to be taken. First, further research is needed to quantify the effects of the solutions in the re-design. Second, some design elements in the re-design need more research, for instance, more information about different strategies in nature-inclusive agriculture and their effects on the water system is needed. Lastly, discussions in the area with more stakeholders is needed. To change the area, all residents and agrarians need to be approached and included in the discussion about the re-design.

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IPCC	Intergovernmental Panel on Climate Change
WRIJ	Waterboard Rijn and IJssel (In Dutch: Waterschap Rijn en IJssel)
WWTP	Wastewater treatment plant

CHAPTER 1. INTRODUCTION

1.1 An urgency for water systems to become climate-resilient

The availability of freshwater in the Netherlands

The availability of freshwater in the Netherlands is crucial for the stability of dikes, the preservation of nature, agriculture and drinking water supply. Many economic sectors are dependent on freshwater. Freshwater is important for public health and the environment and to prevent soil subsidence (Rijksoverheid, 2021a). The availability of freshwater does not always meet the demand. This was evident during the long drought periods in the Netherlands in 2018, 2019 and 2020, which caused multiple problems in different sectors (Rijksoverheid, 2021a). In the coming decades, the climate will change and this will have consequences for freshwater availability.

Changing climate

Climate change poses challenges for the management of both natural systems and human systems worldwide (Wardekker et al., 2016). In the past decades, the global concentration of greenhouse gasses has increased which leads to global warming. The atmosphere and the ocean have warmed up, the amount of snow and ice has decreased and the sea level has risen (Ligtvoet et al., 2015, IPCC (Intergovernmental Panel on Climate Change, 2007 and IPCC, 2021). More extreme weather events in the Netherlands – wetter, drier and warmer – pose major challenges to our society. The best strategy is the one of climate mitigation, to decrease global warming as much as possible. However, global warming and extreme weather events can no longer be completely prevented and are already occurring (Rijksoverheid, 2021a). In 2010 the first Delta Programme has been set up. The purpose of this Delta Programme is to protect the Netherlands from flooding now and in the future, to provide sufficient freshwater and climate-proof the landscape (Rijksoverheid, 2021b). One of the goals of the Delta Programme of 2015 is that by 2050 the Netherlands is prepared against freshwater shortages (Rijksoverheid, 2021b). Our society faces the challenging task of climate proofing the landscape to warrant the long term viability of freshwater systems. This challenging task, however, is plagued by large uncertainties. Different approaches exist to deal with uncertainties in climate-proofing (Wardekker et al., 2016). One such approach is to enhance the resilience of the impacted system.

Resilience

Originally the term resilience was used in physics and engineering, nowadays resilience is used in many fields (Helfgott, 2015). A system can respond in different ways to a disturbance or change. The term resilience relates to the response of the system (Helfgott, 2018). Generally speaking, there are three types of responses, all these responses are described as resilience in the literature: robustness/resistance, stability/recovery and adapting/benefiting (Helfgott, 2018). In literature, a lot is written about resilience within many different fields. An example of such a field is the resilience of social-ecological systems (e.g. Berkes et al., 2000). Relatively new fields of resilience are the fields of urban resilience and the resilience of freshwater systems. Relatively few studies write about urban resilience and the resilience of freshwater systems. Within these two fields, more is written about urban resilience (e.g. Wardekker et al., 2010, Leichenko, 2011, Meerow et al., 2016, Meerow & Newell, 2019) than the resilience of freshwater systems. Grantham et al. (2019) and Thissen et al. (2017) already wrote about the resilience of freshwater systems. Grantham et al., (2019) mainly focused on the ecological function within the water system and Thissen et al. (2017) mainly focussed on the uncertainties freshwater systems have to deal with. Literature is written about the resilience of freshwater systems often does not go beyond the assessment of resilience and literature does not provide concrete solutions for making areas resilient. This study aims to address this gap.

Haarlo-Olden Eibergen as a case to design a climate-resilient water system

The eastern provinces of the Netherlands are characterized by relatively higher areas with sandy soils, named high sandy soils (Rijksoverheid, 2021a). Large parts of these high sandy soils do not receive freshwater from the main water system, i.e. the large rivers in the Netherlands, and are free-draining water systems. The high sandy soils have been experiencing desiccation for decades. Due to climate change, desiccation is projected to increase, groundwater tables will decline and brook valleys will run dry (Rijksoverheid, 2021a). Agriculture, nature and urban areas are harmed by this and the water quality will deteriorate. The management area of Waterboard Rijn and IJssel (hereinafter referred to as WRIJ) faces climate change and water shortages, just like many areas on high sandy soils in the East and South of the Netherlands, (e.g. Roos, 2019, Spek et al., 2010, Otermann, 2015). The tasks of the regional water authorities are to protect the land against flooding, to ensure a good regional water system, to ensure sufficient freshwater and to ensure the purification of wastewater (WRIJ, 2015). In their Water Management Plans, regional water authorities describe how they plan to perform these tasks. The regional water authorities also contribute to the goal of the Delta Programme, which is to achieve a climate resilient environment by 2050 (WRIJ, 2015).

The management area of Waterboard Rijn and IJssel (WRIJ) is located in the Achterhoek, Liemers and a small piece of Overijssel. Within the management area of WRIJ, five different catchment areas can be distinguished (Figure 1). This research focuses on the area Haarlo-Olden Eibergen, located in the Berkel catchment area. The Berkel catchment area is located in both the Netherlands and Germany. Haarlo-Olden Eibergen is located in the dutch part of the Berkel catchment area. Just as the rest of the world, Haarlo-Olden Eibergen faces climate change. The water system at Haarlo-Olden Eibergen is designed such that the water is quickly drained for agriculture. Together with climate change, this leads to desiccation in the area. In addition, even more desiccation than only caused by climate change is caused by the declination of the groundwater table since drinking water is extracted in the area. Due to contamination by the effluent of wastewater treatment plants (WWTPs) located in Germany and the leaching of pesticides and nutrients, the water quality in the area Haarlo-Olden Eibergen is not sufficient. The contamination concentrations in the freshwater are a problem for the extraction of groundwater for drinking water as well as for other functions in the area such as nature. It is not easy to come to a solution to decrease the desiccation in an area, maintain good water quality and at the same time achieve the goal to become climate resilient by 2050 (WRIJ 2015 & Rijksoverheid, 2021b). An integrated approach is needed to address these aforementioned problems.

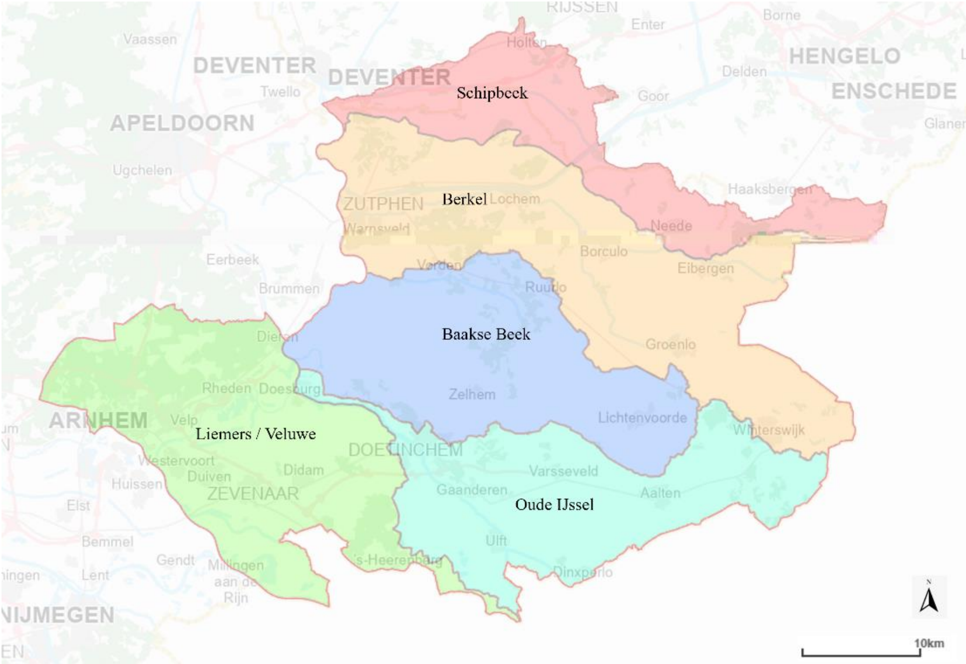

Figure 1 The management area of WRIJ with the five different catchment areas. In orange, the Berkel catchment area is depicted.

1.2 Research objective

The objective of this research is to *design a climate resilient water system for the area Haarlo-Olden Eibergen by re-designing the current water system.*

To re-design the current water system, a design science methodology is adopted. In a scientific design project, one iterate over activities of designing and investigating (Wieringa, 2014). A design is a solution to a field problem, a problem regarding the realization of a better reality (Van Aken, 2007).

Sub-objectives

To achieve the main research objective, the following sub-objectives are formulated:

- understanding the current water system and its uses and users
- describe the shortcomings within the current water system
- prepare a list of requirements for the new design
- re-design the current water system
- validate the re-design of the water system

1.3 Research relevance

Scientific relevance

This study will add to the existing literature since a design science methodology is adopted to re-design the current water system, something that has not been done before. Insights from different literature streams (i.e. design science, system analysis and stakeholder analysis) are integrated to apply resilience thinking to a concrete case. This integration is used to re-design a water system and to gain knowledge about water management for and by, for example, regional water authorities.

Practical relevance

This study is practically relevant because it potentially contributes to solving a concrete problem in the area Haarlo-Olden Eibergen. This study should stimulate discussion about possible solutions for the water system in the area and the challenges that the area faces in the transition towards becoming a climate resilient water system.

1.4 Research scope

This research focuses on re-designing the surface water system that influences the groundwater system. In the Water law the water system is defined as follows: "Coherent entity of one or more surface water bodies and groundwater bodies, with corresponding retention areas, flood defences and supporting structures. " (Chapter 1, Article 1.1) (Waterwet, 2021). However, it is not possible to re-design the groundwater system.

The Berkel itself is not taken into account for re-designing as the Berkel is taken as the boundary of the system. To re-design the Berkel, the whole Berkel needs to be examined including the German and Dutch parts of the catchment.

This study will consider the supply of freshwater. Climate change will change the availability of freshwater in two different ways. Firstly, climate change leads to changes in the supply of freshwater. However, the other side is the change in water demand due to climate change. In the future the freshwater demand may increase due to, for example, an increase in freshwater demand in the summer to fill swimming pools and water the garden (Deltares & HKV, 2019) or a decrease due to, for example, water conservation. Only the supply of freshwater will be considered in this research, as it is not feasible within the time frame of this study to include both the supply, as well as demand.

The costs and benefits of the design are not considered in the validation of the design.

Within the stakeholder analysis, local inhabitants in the area are not included in the analysis. Stakeholder at this scale is too detailed for this study.

1.5 Thesis outline

This report consists of six chapters. In **Chapter 1** the research background, relevance and objective are introduced. In **Chapter 2** the design science methodology that was adopted to achieve the research objective is elaborated on. Additionally, the methods used to gather data are explained.

In **Chapter 3** the results of the problem investigation phase are presented. This chapter aims to achieve the first three sub-objectives; understanding the current water system and its uses and users, describing the shortcomings of the current water system and preparing a list of requirements for the new design. This is done by introducing the problem and presenting the results of the system analysis and the stakeholder analysis. Finally, the problem investigation is merged into a list of requirements for the design.

The re-design of the current water system and the explanation of the design is elaborated in **Chapter 4**. This chapter aims to achieve the last two sub-objectives; re-design the current water system and validate the re-design of the water system. This is done by presenting the results of the re-design and the results of the validation. The validation is divided into two parts; the validation during designing and the validation with key stakeholders.

In **Chapter 5** the limitations of the study, added value to literature, the applicability of the final design, the validity and the generalisability of the results are discussed. Finally, **Chapter 6** concludes and provides recommendations.

CHAPTER 2. METHOD

This section elaborates on the method used during this study. Section 2.1 describes the design science methodology and section 2.2 describes the data collection methods.

2.1 Design science

As the aim of this study is to design an object, this study adopts a design science methodology. In design science, academic research and design are combined. This is in contrast to more traditional research approaches which aim to tackle the problem experienced in practice by providing a solution. In this research, the design science methodology described by Wieringa (2014) is used. According to Wieringa (2014), the design task consists of three different phases, the problem investigation phase (phase A), the design phase (phase B) and the design validation phase (phase C). During a design science project, one iterate over the activities of designing and investigating, therefore the three phases are called the design cycle (Wieringa, 2014). The design cycle is part of the larger engineering cycle in which also the phases of implementation and evaluation are present (Wieringa, 2014). However, the implementation and evaluation phase are beyond the scope of this research and are therefore not executed.

Figure 2 depicts the activities per design phase that are executed during the research. The three phases are introduced below the figure.

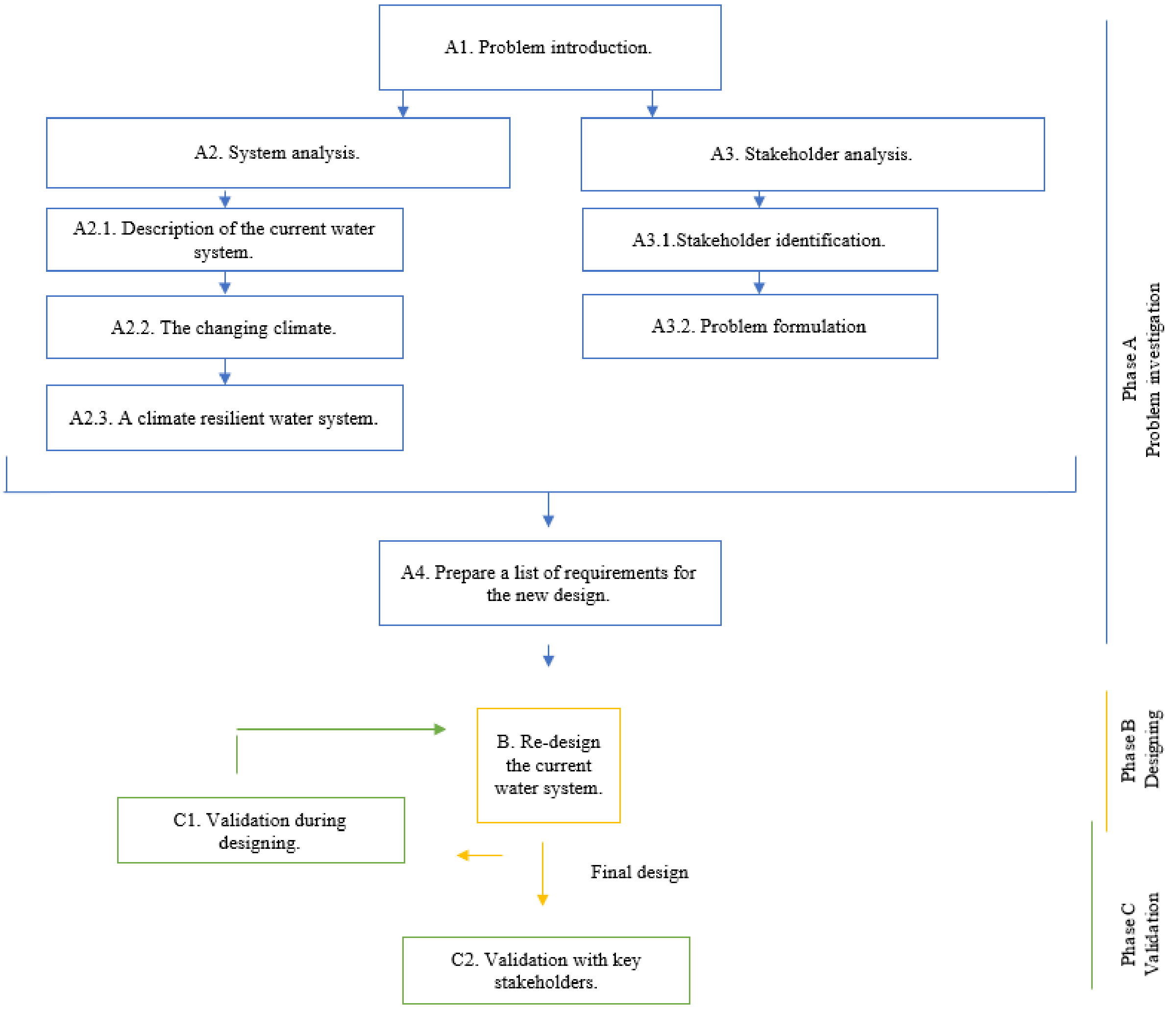

Figure 2 The activities per design phase executed during the research.

In the problem investigation phase **(phase A)**, the goal is to prepare for the design by learning more about the problem to be treated (Wieringa, 2014). The first step in the problem investigation phase is to introduce the problem **(A1)**. This initial problem formulation acts as a point of departure and this problem is formulated by the problem owner (Enserink et al., 2010).
Secondly, a system analysis **(A2)** and stakeholder analysis **(A3)** are carried out. A system analysis provides structure and helps to make assumptions and expectations explicit to provide a basis for communication with the stakeholders (Enserink et al., 2010). The system analysis is used to define the boundaries of the system and to define the main elements and the relationships among them (Walker, 2000). In the system analysis, the physical properties of the water system are described. This is divided into three steps: physical description of the current water system, describing the changing climate and determining what a climate resilient water system is. The term resilience is further elaborated and with the use of resilience principles, specific characteristics that contribute to the resilience of a system are described (Wardekker, 2016).
Next to the system analysis, a stakeholder analysis is carried out. According to Krywkow (2009, p.42), stakeholders are "organisations, individuals or their representatives with a particular interest in the course and/or outcome of an investment project". It is more likely that stakeholders have more knowledge of specific aspects of a project (Krywkow, 2009). The goal of a stakeholder analysis is to establish a basis for cooperation among the involved parties to achieve a successful outcome (Hare & Pahl-Wostl, 2002). In the stakeholder analysis, the problem perception of the stakeholders is investigated. Reed et al., (2009) described different methods of stakeholder analysis. The first step in this stakeholder analysis is to identify the system boundaries and therefore a system analysis must be carried out (Reed et al., 2009). Within the stakeholder analysis, the problem is formulated. A problem formulation goes beyond defining the discrepancy between the desired state and a given state (Hommes et al, 2009). A problem formulation consists of a description of the present and future situation, a definition of objectives and a direction for solutions (Hommes et al., 2009). The problem formulation in this study consists of five parts: the stakeholders perception of the current situation, the situation that is expected by the stakeholders, the desired situation, the gap between the desired and the current/expected situation and finally the possible solutions seen from the stakeholders point of view. With the use of both the system analysis, stakeholder analysis and literature the sub-objective, prepare a list of requirements for the new design, is achieved **(A4)**. These requirements form the basis for the design and validation phase.

When the list of requirements for the design is prepared, the designing phase **(phase B)** starts. In this phase, the design is made such that it deals with the problems defined in phase A and meets the requirements (Wieringa, 2014). The designing phase (phase B) is intertwined with the validation phase **(phase C)**. In the designing phase the fourth sub-objective, re-design the current water system, is executed and in the validation phase the fifth sub-objective, validating the new water system, is executed. During the stakeholder analysis in phase A, the solutions seen from the stakeholders point of view are described. The design is composed of these possible solutions suggested by the stakeholders. During the design, the list of requirements is constantly checked **(C1)**. When the requirements are not met, the design is further refined. Finally, a design for a new water system is prepared. In the final phase of the research, the design is validated with the key stakeholders **(C2)**.

2.2 Data collection methods

In this research, different data collection methods were used. Literature was studied, documents about the area and maps have been analysed and interviews were conducted. Table 1 summarizes the data collection methods that were used to conduct the design science phases. In this section, the data collection methods are elaborated in more detail.

Table 1 Summary of the data collection methods used in each of the design phases.

Activities per design phase		Data collection method
Phase A - Problem investigation		
A1. Problem introduction.		Document analysis
A2. System analysis.	A2.1 Description of the current water system.	Document analysis Maps analysis
	A2.2 The changing climate.	Literature study
	A2.3 A climate resilient water system.	Literature study
A3. Stakeholder analysis.	A3.1 Stakeholder identification.	Literature study Document analysis Maps analysis
	A3.2. Problem formulation.	Four interviews (2 nature organisations 1 local founding and 1 cattle farm) Four focus group sessions (3 government organisations and 1 drinking water company)
A4. Prepare a list of requirements for the new design.		Synthesis of data collected during phase A
Phase B - Designing		
B. Re-design the current water system.		Synthesis of phase A Literature study Document analysis Maps analysis
Phase C - Validation		
C1. Validation during designing		Expert judgement researcher
C2. Validation with key stakeholders		Expert judgement from focus group session consisting of the three key stakeholders (WRIJ, HOE Duurzaam and Vitens)

Phase A – Problem investigation

Documents about the area Haarlo-Olden Eibergen were analysed to **explore the problem**. The documents used were obtained through WRIJ. In Appendix A the documents used are described.

For the **system analysis,** first documents and maps about the area Haarlo-Olden Eibergen were analysed to describe the current water system. The maps were analysed with the programme ArcMap 10.8. In Appendix A, a list of used maps is included. To describe climate change in general terms, literature about global climate change and climate change in the Netherlands was studied. To gain more detailed insight into the consequences of climate change on the area Haarlo-Olden Eibergen, the climate impact atlas was used (Klimaateffectatlas, September 2021). Literature on resilience principles was used to operationalize what a climate resilient water system involves.

From consultations with the problem owner, stakeholders were identified as the first step of the **stakeholder analysis**. The list of stakeholders was supplemented by the stakeholders that have a direct link to the physical water system. These stakeholders were identified from the system analysis with the use of landowner maps obtained from WRIJ. Finally, documents about the water system in the area

Haarlo-Olden Eibergen were analysed to see which organisations contributed to these documents to complete the stakeholder analysis.
To formulate the problem from the perspective of the stakeholders, four semi-structured interviews and four focus group sessions were held during the research. Focus group sessions allow the participants to respond to each other by adding information and criticizing each other's statements (Eliot, 2005). Therefore, focus group sessions were conducted when possible. When only one person was available for an interview, no focus group session was conducted but an interview was held. Interviews allow to ask questions and ask for individual opinions.

Appendix B describes the functions of the participants. In this research, the participants were not only asked for their individual opinion but also to represent other groups (of individuals). In appendix B, Table A-3 the role of the participants is displayed. The questions asked were the same for the interview and focus group sessions. A protocol was set up in advance, this protocol is displayed in Table A-5 in appendix B. Due to the Covid situation during the research, the interviews and focus group sessions were held online. To collect data from the interviews and focus group sessions a recording device has been used. From these recordings a report was set up that was sent for review to the participants. In the focus group sessions, the review has been sent to one participant chosen in consultation with the focus group. After finishing the report of the interviews and focus group sessions, the recordings were deleted. The reports were used to elaborate on the different components in the problem formulation (activity 3.2); perception of the current situation, the expected situation, the desired situation and possible solutions. The gap was deducted from the perception of the current situation, the expected situation and the desired situation. Additionally, the possible solutions were categorised based on the judgement of the researcher. The reports of the interviews and focus group sessions are the raw data and are not included in this report. The interviews and focus group sessions were held in Dutch because both the researcher and all participants are Dutch. Therefore, also the reports of the interviews and focus group sessions are in Dutch.

To set up a list of requirements, all previous information of the problem investigation was synthesised. This list includes the design requirements that the re-design of the water system should comply with and forms the starting point for phase B.

Phase B and C – Designing and validation
The water system was re-designed by the researcher in ArcMap. The design is stakeholder-driven as the solutions posed by the interviews and focus group sessions are used for the re-design (activity A3.2.5.). First, a general view of solutions became clear from the interview and focus group sessions. This general view of solutions was first described. Then the solutions posed by the problem owner that fit the overall view of solutions were applied in the re-design. The solutions posed by the problem owner were refined and supplemented with solutions posed by the other stakeholders. Solutions that do not fit the overall view of solutions were not implemented but are described separately. Also, maps and additional literature were studied and additional documents have been consulted.

The validation was performed through two types of validation. First, the re-design is validated by the expert judgement of the researcher. It was validated whether the re-design meets all the requirements. Re-design was needed if not all requirements were met. When this was the case, phase B is executed again followed by validation by expert judgement. This cycle continued until all requirements were met. The second type of validation is the validation with the key stakeholders. In this validation, multiple aspects were validated in a focus group session. This focus group session included three persons, one person on behalf of the problem owner and two persons on behalf of the other two most important stakeholders. First, the list of requirements was validated. It was validated whether this list was complete and all requirements were incorporated to design a climate resilient water system. Second. the re-design of the water system itself was validated. It was validated whether this re-design meets all the requirements in the eyes of the key stakeholders. Finally, the generalizability of the research itself, the list of requirements and the re-design was validated.

CHAPTER 3. RESULTS PROBLEM INVESTIGATION

This chapter describes and discusses the results of the problem investigation phase (phase A). This chapter aims to identify the problems in the area Haarlo-Olden Eibergen both physically and based on stakeholders perception. At the end of the problem investigation, a list of requirements for the new design is set up.

This chapter starts with an introduction of the problem in section 3.1. Next, the results of the system analysis are elaborated in section 3.2, section 3.3 give the results of the stakeholder analysis and section 3.4 elaborates on the list of requirements.

3.1 Introduction of the problem

The problem is introduced from WRIJ perspective, the problem owner and key user of the design. Haarlo-Olden Eibergen is located in the Berkel catchment area, one of the five catchment areas of the management area of WRIJ. In the German part of the Berkel, the water is charged with the pollution of five relative small wastewater treatment plants (hereinafter referred to as WWTP) (Royal Haskoning DHV, 2019). Since the amount of effluent stays the same and the discharge of the Berkel fluctuates with the season, the contamination concentration in the Berkel is higher in dry periods (Grontmij, 2016). The waterways in the area Haarlo-Olden Eibergen are designed to drain water quickly for agriculture which leads to desiccation. In the Dutch part of the Berkel catchment area, drinking water extraction locations are located. The extraction of water takes place from the groundwater, which results in a declination of the groundwater table and therefore even more desiccation than only caused by climate change in the area (Deltares & HKV, 2019). In the Berkel catchment area in the Netherlands, water is supplied from the Berkel to decrease the declination of the groundwater table and to provide enough freshwater. The extraction of water takes place from a sand layer that is not covered by an impermeable layer (Royal Haskoning DHV & Aequator, Factsheet). Because of this, water extraction is vulnerable to pollution (Grontmij, 2016). The contamination concentrations of the Berkel are a problem for the extraction of drinking water as well as for other functions in the area such as agriculture and nature.

3.2 System analysis

This section describes the results of the system analysis. It is divided into three parts. First, a description of the current water system is given, then climate change and the effects of climate change on the area Haarlo-Olden Eibergen are described and finally the term resilience is defined.

Description of the current water system.

Haarlo-Olden Eibergen is located in the eastern part of the Netherlands in the province of Gelderland. Haarlo is a small village and Olden Eibergen is a neighbourhood, both located west of the town Eibergen and south of the town Borculo in the municipality Berkelland. The important waterways in the area are the Berkel and the Leerinkbeek which discharges into the Berkel. The boundary of the study area is chosen in such a way that all waterways that drain into the Leerinkbeek and the waterways between Eibergen and Borculo south of the Berkel are included. From now on, the area Haarlo-Olden Eibergen refers to the area within the boundary visible in Figure 3.

Figure 3 depicts a synthesis map in which all the important aspects of the water system in the area Haarlo-Olden Eibergen are shown. The explanation of the map follows after the figure. In Appendix C in Figure A-1 the area is depicted with all the names of the waterways included.

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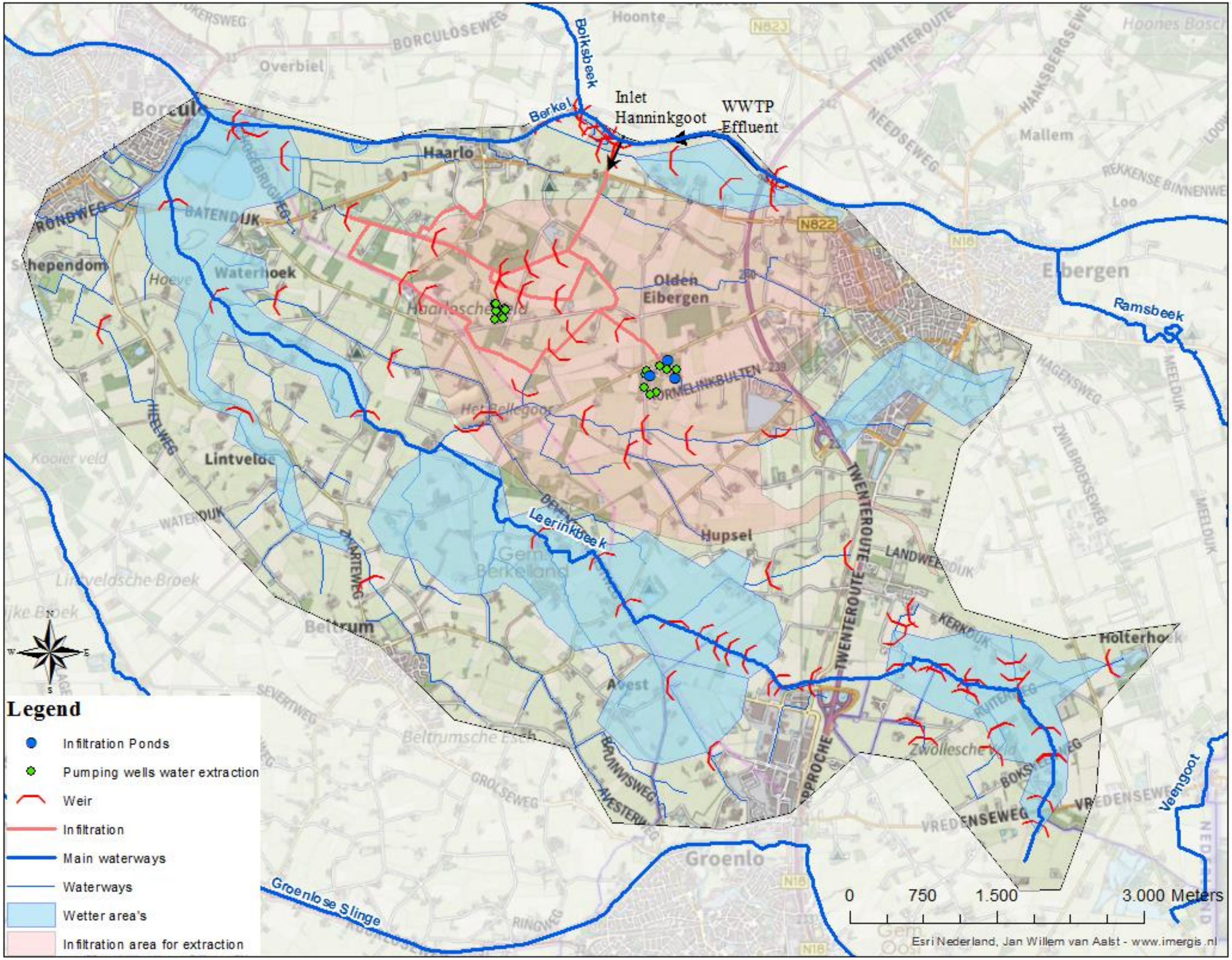

Figure 3 Synthesis map of the system analysis Haarlo-Olden Eibergen.

The Berkel and the Leerinkbeek are the largest waterways in the area. To protect the land from flooding, the Berkel is designed such that flooding may occur once every 100 years (Unit Waterbeheer WRIJ. 2015). The Leerinkbeek has a length of 15.1 km (Unit Waterbeheer WRIJ. 2015). To maintain the water level there are weirs in the Leerinkbeek. The Leerinkbeek does not drain water all year round. During dry periods the upstream parts of the waterway dry up (WRIJ. 2008). There is no WWTP in the Leerinkbeek catchment area. The groundwater in the area flows from east to west, this groundwater flow is mostly determined by the elevation in the area.

In the area, two water extraction locations are located which are named after their location: 1) Haarlo and 2) Olden Eibergen. The pumping wells of these water extractions are indicated by the green diamond symbols. These water extraction locations are used for the exploitation of drinking water. In 1935, Olden Eibergen was set up for the exploitation of drinking water. With the use of six wells, the groundwater is extracted at a depth between 19 and 30 meters below ground level (Royal Haskoning DHV, 2019). In 1968, Haarlo was set up for the exploitation of drinking water. At Haarlo, groundwater is extracted with the use of five wells at a depth between 17 and 22 meters below ground level (Royal Haskoning DHV, 2019). The permitted amount of extraction water at Olden Eibergen is 2.25 million m^3 per year and at Haarlo 1.65 million m^3 per year. However, both drinking water extraction locations together may not extract more than 2.8 million m^3 in one year (Royal HaskoningDHV, 2019). In practice, less water is extracted, at Haarlo 1.2-1.4 million m^3 per year and Olden Eibergen around 1.6 million m^3 per year (Grontmij, 2016). Not only the location of the extraction is visible, but the area depicted in light red is the area in which the water that infiltrates reaches the pumping wells within 100 years. The exploitation of the drinking water causes desiccation in the area. To compensate for this, water is supplied from the Berkel through the inlet Hanninkgoot. A system with ponds and weirs has been built to infiltrate the water in the area in two ways. First, infiltration of water in infiltration ponds (depicted by the blue dots). The water in these infiltration ponds is supplied by the Berkel. The water flows from the Berkel through the Hanninkgoot through the Afwatering van Zaterdag towards the infiltration ponds (Royal Haskoning DHV, 2019 and Grontmij, 2016). Secondly, infiltration from the surface water system itself. The water flows from the Berkel through the Hanninkgoot through the infiltrating waterways (in orange in Figure 3). The water in these waterways enables infiltration of surface water (Royal Haskoning DHV, 2019).

In the area, water is supplied by the Berkel from April till September. During winter, less water or even no water is supplied from the Berkel. In 2020, 5.2 million m^3 water was supplied through the inlet and 1.7 million m^3 water was discharged from the area, this means that 3.5 million m^3 water was infiltrated (WRIJ, 2021).

The water extracted at Haarlo and Olden Eibergen is of the type phreatic (Royal HaskoningDHV, 2019). Since the extraction is of the type phreatic and the polluted water from the Berkel is infiltrating the area, the pollution is found back in the raw water that is extracted.

At the wetter locations in the area, seepage occurs (in blue in Figure 3). These locations are also known from the inundation map. At these locations, the ground level is flooded when extreme precipitation causes a run-off that occurs every ten years.

The changing climate
In the coming decades, the climate will change globally. As a result naturally and human systems together with their management will be exposed to considerable challenges (Wardekker et al., 2016). The Intergovernmental Panel on Climate Change (IPCC) published different reports for assessing the science related to climate change (IPCC, 2007 & IPCC, 2021). In 2014, the IPCC published the fifth assessment report. Ligtvoet et al., (2015) published a summary of this fifth assessment report of the IPCC and translated this for the Netherlands. In the next century, the Netherlands will face higher average temperatures, changing precipitation patterns and a rising sea level. The chance of heatwaves in the summer increases and precipitation extremes will be more common (Ligtvoet et al., 2015).
The climate impact atlas indicates the consequences of climate changes in the Netherlands and is used to describe the consequences of climate change in the area Haarlo-Olden Eibergen (Klimaateffectatlas, September 2021). The climate impact atlas is divided into four themes: floods, waterlogging, drought and heat. In this research, floods are not included since the area Haarlo-Olden Eibergen is not sensitive to floods as there are no large rivers and the area is not close to the sea.

In Appendix C the graphs that visualise climate change for the area Haarlo-Olden Eibergen are displayed. The effects of climate change on flooding, drought and heat are described below.

Waterlogging
Extreme precipitation regularly leads to waterlogging in summer. Due to climate change, extreme summer precipitation events can occur more often and they will also become more extreme. Not only do the extreme summer precipitation events become more extreme, but it is also likely that the winter season becomes wetter.

Drought
Due to climate change, longer periods of droughts are possible, especially in summer. Low surface water levels pose a threat to water availability and quality of surface water. The precipitation deficit may increase due to climate change. On the one hand, annual evaporation increases and on the other hand summer precipitation changes. Due to climate change, dry periods can last longer. A low groundwater level poses a threat to many functions and a low groundwater level also leads to the drying up of streams and other water bodies. In 2050 the groundwater level will locally sink deeper. Also, ditches and streams will more often dry up as a result of the drought.

Heat
The average temperature is not only increasing, the extremes will increase. This can lead to damage to nature. The temperature of the surface water influences the hygienic and ecological quality of the water. Blue-green algae grow quickly in warm water and heat leads to dense layers of algae and lack of oxygen with negative consequences for aquatic life.

A climate resilient water system

In literature, there are many perspectives and interpretations of resilience. However, there is no consensus on how the concept can be made operational or how it should be defined (Klein et al., 2003). Some examples of the definition of resilience in the system engineering literature are as follows: Holling defined resilience as “a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables” (Holling, 1973, p.14). Walker et al., (2004, p. 2) defined resilience as “the capacity of a system to absorb disturbance and re-organize while undergoing change so as to still retain essentially the same function, structure, identity and feedbacks”. However, resilience is not only about absorbing disturbances. Folke (2006) described that resilience “is also about the opportunities that disturbance opens up in terms of recombination of evolved structures and processes, renewal of the system and emergence of new trajectories” (Folke, 2006, p. 259). The IPCC defined resilience as “the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity of self-organization, and the capacity to adapt to stress and change” (IPCC, 2007, p. 86).

Carpenter et al. (2001, p.766) describe resilience in terms of three properties: 1) “the amount of change the system can undergo and still remain within the same domain of attraction”; 2) “the degree to which the system is capable of self-organization”; and 3) “the degree to which the system can build the capacity to learn and adapt”. These three properties of resilience correspond to the three types of responses described by Helfgott (2018); 1) robustness/resistance; 2) stability/recovery; and 3) adapting/benefiting. According to Carpenter et al., (2001) and Helfgott (2018), a system can be called resilient if the system can withstand a disturbance, if the system can recover from a disturbance and if a system can improve after a disturbance.

Resilience principles are mechanisms and behaviours that help policies and practices improve resilience. Resilience principles can also help make the concept of resilience more specific and translate it to practice (Wardekker, 2018). The resilience principles all aim to improve one or more of the above-described characteristics of resilience. Wardekker (2018) distinguishes between six different resilience principles; 1) redundancy; 2) omnivory; 3) buffering; 4) flatness; 5) homeostasis and 6) high flux. The principles redundancy, omnivory and buffering focus on absorbing disturbances, while the others focus on recovery, reorganization, quick response, self-organization and learning.

Resilience principles can be used to design new solutions. Here, the resilience principles are used to re-design the water system in Haarlo-Olden Eibergen. Considering that this study’s focus is on the physical system, all principles that relate to the governance of the system under concern (flatness, homeostasis and high flux) are not taken into account. For this study, this means that the principles of redundancy, omnivory and buffering make the system resilient. Table 2 depicts the selected resilience principles for this study. All three resilience principles aim to absorb disturbances and omnivory additionally also aims to recovery and reorganization.

Redundancy refers to having overlapping functions within a system. These overlapping functions act as a backup to absorb disturbances. Omnivory refers to spreading the risks by spreading over multiple resources and thus a diversification of resources and means. Buffering refers to the over dimensioning of essential capacities. This over-dimensioning increases the ability to absorb. (Wardekker, 2016 and 2018).

Table 2 Selected resilience principles, their aim and description (Wardekker, 2016, p. 11)

Resilience principle	Aim	Description
Redundancy	Absorbing disturbances	Overlapping functions; if one fails, others can take over. Multiple copies of one approach, function, or service.
Omnivory	Absorbing disturbances, recovery, reorganization	Diversification of resources and means. Multiple different approaches can be used alongside each other, rather than copies of one approach.
Buffering	Absorbing disturbances	Essential capacities are over-dimensioned such that critical thresholds are less likely to be crossed.

3.3 Stakeholder analysis

This section elaborates on the results of the stakeholder analysis. It is divided into two parts. First, the results of the stakeholder identification are given and then the problem is formulated. This problem formulation is divided into five steps; stakeholders perception of the current situation, the expected situation, the desired situation, the gap and finally possible solutions suggested by the stakeholders.

Stakeholder identification

Table 3 lists the identified stakeholders for this study. Within the governance system, there are three stakeholders: WRIJ, Province Gelderland and Municipality Berkelland as the area Haarlo-Olden Eibergen is located in the municipality Berkelland and the Province Gelderland.

As the system analysis shows, water extraction plays an important role in the area. These extraction locations are owned by drinking water company Vitens. Vitens is, therefore, an important stakeholder. Because the area Haarlo-Olden Eibergen mainly consists of agricultural land, stakeholders are also the group of local farmers. The organisation LTO represents the farmers and is, therefore, a stakeholder. Since the local farmers are important in this area, one local farmer with land ownership in the area is taken as a stakeholder.

Based on the document analysis and discussions with the problem owner, three additional stakeholders were identified: HOE duurzaam, Natuur and Milieu Gelderland and Staatsbosbeheer. HOE duurzaam is a foundation in the area **'H**aarlose veld and **O**lden **E**ibergen', residents of the area participate and work together. Natuur and Milieu Gelderland is committed to protecting and enhancing Gelderland's nature and a sustainable living environment. Staatsbosbeheer manages the green heritage of the Netherlands and owns land in the area.

In appendix B in A-3 a list of the stakeholders with whom the interviews were conducted is provided. All stakeholders except LTO were interviewed.

Table 3 The identified stakeholders and their number to refer to in the text.

Selected based on	Stakeholder	Reference in text
Governance	• Waterboard Rijn and IJssel • Municipality Berkelland • Province Gelderland	F1 F2 F3
Land use	• Staatsbosbeheer • Cattle farm	I2 I4
Drinking water extraction company	• Vitens	F4
Other organisations	• HOE Duurzaam • LTO • Natuur and Milieu Gelderland	I1 - I3

Problem formulation

This section presents how the stakeholders formulate the problem. In Appendix E, F, G and H the results for every single stakeholder are given.

Perception current situation

According to our respondents, drought is the most pressing issue in the study area. Yet, how stakeholders perceive droughts differs. According to four stakeholders drought is reinforced by drinking water extraction (F1, F4, I1, I2) and according to two stakeholders drought is reinforced by the extraction of water for irrigation (I4, F2). The water system is designed to drain the water quickly, this is identified as a problem in the area because there is little water storage possible in the area (F2, I2, I3 F3). Respondents named multiple consequences of droughts. According to the respondents of WRIJ, there is a positive effect of the drought, namely that there is less vegetation that has to be mowed and sludge dries in which reduces the management effort (F1). According to three other respondents, drought has negative effects on flora and fauna (I2, F2, I4). During drought periods, the demand for drinking water increases and more water extraction is needed according to respondents of Vitens (F4). The respondents of Vitens see the system of water infiltration with the inlet Hanninkgoot as a good system as there is more water infiltrated than extracted (F4). According to the respondents of WRIJ, the inlet of water through the Hanninkgoot can be closed to prevent flooding but in times of extreme drought, the inlet must be closed to maintain the water level in the Berkel (F1). Due to the closing of the inlet in times of extreme droughts, waterways dry up which have negative effects on the flora and fauna (F3, I2, I3).

According to our respondents, water quality is also a pressing issue in the area, since it is negatively influenced in two different ways. First, the Berkel water that is added to the system through the inlet is contaminated by the effluent of WWTPs in Germany (F1, F3, F4, I3). Second, the surface water contains nutrients and pesticides from leaching according to almost all respondents except the cattle farm (F1, F2, F3, F4, I3, I2, I3). According to the Province and Vitens, the extraction of water causes a downward flux which in combination with the extraction of the type phreatic can cause pollution of groundwater (F3, F4). In addition, according to Vitens, the agricultural residues together with the pollution by effluent is found in the raw water from the drinking water extraction which results in an extra purification burden (F4). However, poor water quality is not only a problem for the extraction of drinking water. According to Staatsbosbeheer, the surface water also contains too many agricultural residues for nature (I2). According to HOE Duurzaam, the leaching of agricultural residues increases in times of drought since water is needed for the mineralisation of nutrients (I1).

Expected situation

According to most respondents, drought is not only the most prominent issue in the current water system but also in the expected situation (F1, F2, F3, F4 I4). Due to extreme droughts, the inlet will have to be closed more often, and consequently, waterways will dry up (F1). Due to droughts, the area is expected to be less interesting for recreants and the increasing drought harms flora and fauna (F2, F4, I2, I3). The biodiversity will decrease and the damage to nature can be such that nature is not capable of self-recovery anymore (F4, I3). According to almost all respondents except WRIJ, the water demand will also increase due to increases in agrarian uses, recreative use as for the use of drinking water due to the increased drought (F2, F3, F4, I1, I2, I3, I4).

Although waterlogging is not a problem in the current situation, it could cause problems due to climate change. Also, it is expected, according to governmental representatives, that the known wet areas are going to be larger (F1, F3) and there will be an increase in nuisance due to extreme precipitation (F1, F2). However, according to HOE duurzaam, the system is designed for the drainage of water and is capable to drain more precipitation and an increase in precipitation also means that there is more water available in the area (I1).

According to the respondents, the rising temperature will lead to more evaporation of water and more crop evaporation so that more water is needed (F1, F2, I1, I4). The rising temperature will also harm the quality of the surface water which will lead to ecological decline (F2, F3). According to HOE duurzaam, the leaching of agricultural residues will also increase due to the enhanced drought and therefore the water quality will decrease (I1).

Desired situation
According to the respondents of the province Gelderland, the water system should be designed such that the system can cope with both extremes of waterlogging and drought (F3). All respondents prefer to see that the water is no longer drained but retained in the area (F1, F2, F3, F4, I1, I2, I3, I4). According to the respondents of WRIJ, Municipality Berkelland and Staatsbosbeheer, the water system should be designed more naturally with stream valleys that retain the water and a more gradual border between agricultural land and nature (F1, F2, I2). Additionally, the respondents of WRIJ desire that the water system should no longer be dependent on the water from the Berkel that is supplied through the Hanninkgoot to maintain good water quality (F1). It is also desired that the water contamination by leaching of nutrients and pesticides reduces (I1, I3). Only the respondent of the cattle farm desires that the water should be still drained during extreme precipitation events (I4).

What is the gap?
The following gap has been deducted from the perception of the current/ expected situation and the desired situation. The water system is now designed such that the water is quickly drained but the respondents desire that the water is retained in the area. The respondents also desire that the water system will be designed in a natural way which is now not the case as the water system is constructed and contains civil technical means, for example, weirs. To maintain good water quality the system must no longer be dependent on the supplied water from the Berkel and the leaching must be reduced.

Possible solutions.
The stakeholders posed different stakeholders which are identified in five directions for solutions; 1) solutions to retain water in the area, 2) solutions to come to a natural water system, 3) solutions to improve the water quality, 4) solutions against waterlogging, and 5) solutions for the extraction of drinking water. In appendix H the solutions per single stakeholder are given and the solutions are also classified in these six directions.

3.4 List of requirements

Based on the problem investigation, four requirements that the design of the water system should meet are formulated (Table 4). These four requirements contain together nine sub-requirements that the design should meet.

The first requirement is that the water system should be climate resilient. This is an important requirement from the problem owner WRIJ and the objective of this study is to design a climate resilient water system. Climate change projections show that the water system should be able to both absorb longer periods of drought and extreme precipitation events. To make this requirement operational this study focuses on three resilience principles: buffering, redundancy and omnivory. This means that the system must contain overlapping functions, diversification of resources and essential capacities must be over-dimensioned to absorb these longer periods of drought and extreme precipitation events.

The second requirement is also a requirement from the problem owner WRIJ and the requirement is that the water system should aim to maintain good water quality. According to the stakeholders, the water system should aim to reduce water contamination by leaching and the water should no longer be polluted by the water supplied through the inlet Hanninkgoot.

According to the problem owner WRIJ, the design should satisfy the needs of the stakeholders. This means that the design should not only focus on one stakeholder but should satisfy all stakeholders in the area. Therefore, the third requirement is that the design should satisfy the needs of the stakeholders. Requirements from the stakeholders that are not already incorporated in the other three requirements are therefore listed in this final requirement.

The final requirement is that the water system should be re-designed more naturally. This is not a requirement as the first three requirements but more a widely supported wish by WRIJ, Municipality Berkelland and Staatsbosbeheer and is therefore included in this list of requirements. According to the stakeholders, the water system should have more accompanying streams of forest, swamps and meadows and the border between agricultural land and nature must be more gradual.

Table 4 List of requirements for the design.

	Requirement	Sub-requirements
1	The water system should be climate resilient	• The water system should be able to absorb longer periods of drought (since the principles of buffering, redundancy and/or omnivory have been applied). • The water system should be able to absorb extreme precipitation events (since the principles of buffering, redundancy and/or omnivory have been applied).
2	The water system should aim to maintain good water quality.	• The water system should aim to reduce water contamination by leaching. • The water should no longer be polluted by the water supplied through the inlet Hanninkgoot.
3	The design should satisfy the needs of the stakeholders.	• The water system should be designed such that drinking water extraction is possible in the area. • The water system should no longer drain the water but should retain the water in the area. • There should be no damage to agricultural land caused by waterlogging.
4	The water system should be re-designed more naturally.	• The water system should have more accompanying streams of forest, swamps and meadows. • The border between agricultural land and nature must be more gradual.

Validation of the list of requirements

The list of requirements has been approved by the stakeholders in the validation focus group session. The respondents of the validation focus group session expect that the list of requirements will trigger a discussion in the area of what is positive. According to the respondent of Vitens, water quality is the main issue for the extraction of drinking water. The respondents agree that this is taken into account in requirement two.

CHAPTER 4. RESULTS DESIGN AND VALIDATION

This chapter elaborates first on the results of the design and validation done by the researcher in section 4.1. Section 4.2 elaborates on the validation according to the key stakeholders.

4.1 Re-design of the current water system.

This section elaborates first on the general view of solutions deducted from the solutions posed by the stakeholders. Then how the solutions posed by the problem owner WRIJ were implemented is described and how these solutions were refined and supplemented with solutions posed by the other stakeholders. Finally, the re-design is depicted and the design elements are elaborated separately.

General view of solutions

The solutions posed by the stakeholders have been divided into five directions for solutions; 1) solutions to retain water in the area, 2) solutions to come to a natural water system, 3) solutions to improve the water quality, 4) solutions against waterlogging, and 5) solutions for the extraction of drinking water. From the solutions posed by the stakeholders, a general view of solutions is deducted.

First of all, the water in the area must be retained instead of drained. To retain water in the area, first, the area of the Leerinkbeek must be adjusted to have maximum storage and retention of water. Smaller waterways must be made shallower or even filled up. Recreational lakes and already known wetter places must be used to store excess water. The storage of excess water also prevents waterlogging. In addition to shallow or filled up waterways, waterways must be turned into wadis which retain temporarily a surplus of water and also infiltrate the water. The pumping wells must be spread over the area to both decreases the local impact of desiccation and to prevent waterlogging. To design the water system more naturally, the Leerinkbeek must be re-established in its natural course with more robust nature. The border between nature and agriculture can be made more gradual by incorporating agrarians in the maintenance of shallow waterways and the robust nature. To improve the water quality in the area, the inlet Hanninkgoot must be used only as a backup. Lastly, lots of solutions in adjustments in the agrarian sector were given. These are not solutions directly made to the water system, but these solutions do affect the water system. The whole area must act as a pilot of nature-inclusive agriculture combined with the extensification of agriculture.

Applied solutions in the re-design

In the design, first, the solutions posed by the problem owner WRIJ that fit the general few of solutions are implemented. In Appendix H, the solutions that do not fit the general view of solutions are depicted in red. The solutions implemented were refined and supplemented with the solutions from the other stakeholders. However, not all solutions fit the general view of solutions and are therefore not implemented in the design. Solutions not incorporated in the design are depicted in red in Appendix H.

There are solutions posed that focus on the agricultural sector and for instance the crops they should use. However, these kinds of solutions are all incorporated in the fact that the area must act as a pilot for nature-inclusive agriculture combined with the extensification of agriculture. The exact way of how this nature-inclusive agriculture will look like is not described as there is more research needed on this kind of agriculture and how this will positively affect the water system. Solutions that also are not incorporated in the design are solutions focusing on the policy of WRIJ, such as the mowing policy.

The re-design

Figure 5, depicts the re-design of the water system. This re-design of the water system meets all requirements and therefore no re-designing was needed. This section elaborates both on the design elements within the re-design as well as on the requirements that are met by the design. The design elements are given in order of first design elements on the main waterways, then design elements on the smaller waterways, then to buffering of water in recreational lakes and on land, then to the extraction of drinking water, then to the inlet Hanninkgoot and finally to the agriculture.

Connection Groenlose Slinge and Leerinkbeek, emergency drain

The Berkel is not changed. The first big adjustment to the water system is that the Groenlose Slinge is put back in her old course (in red). Originally the Groenlose Slinge drained into the Leerinkbeek. In 1350 and 1750 the direction of the Groenlose Slinge is changed to promote shipping (Figure 4) (Unit Waterbeheer WRIJ. 2015). To find the old course of the Groenlose Slinge, the map of the stream valley morphology in the area has been examined (appendix I). The channel that remains in the new design is now used as an emergency drain. When the discharge in the Groenlose Slinge is too high, the emergency drain can be used so that flooding in the area is prevented. The connection Groenlose Slinge and Leerinkbeek ensures that the water system is re-designed more naturally because the Groenlose Slinge has traditionally drained into the Leerinkbeek and the new connection is located in the original stream valley. Additionally, the emergency drain that remains from the Groenlose Slinge ensures that the water system is climate resilient, the emergency drain acts as a backup and thus complies with the resilience principle of redundancy.

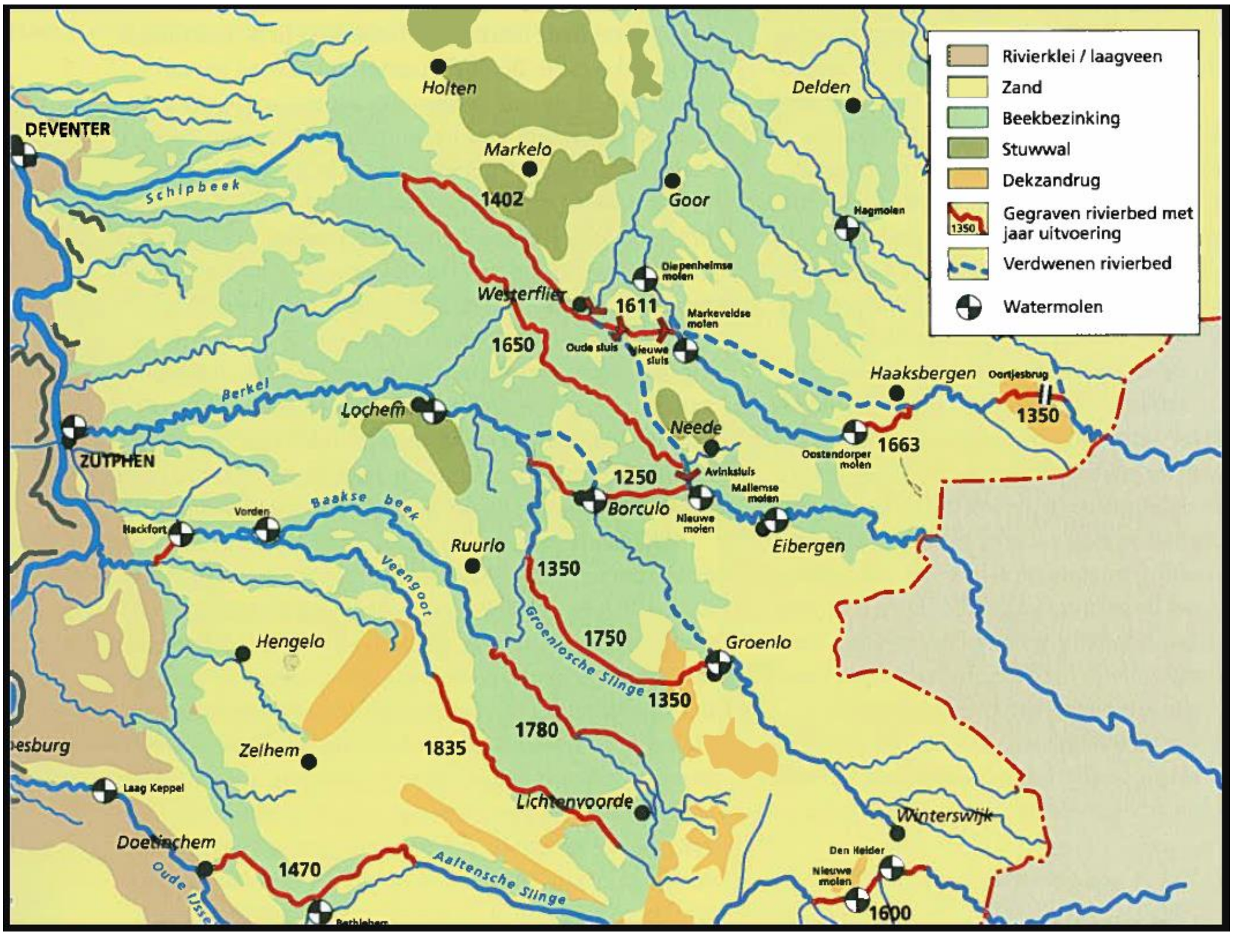

Figure 4 Original watercourses (blue) and excavated parts (red) (Driessen et al., 2000).

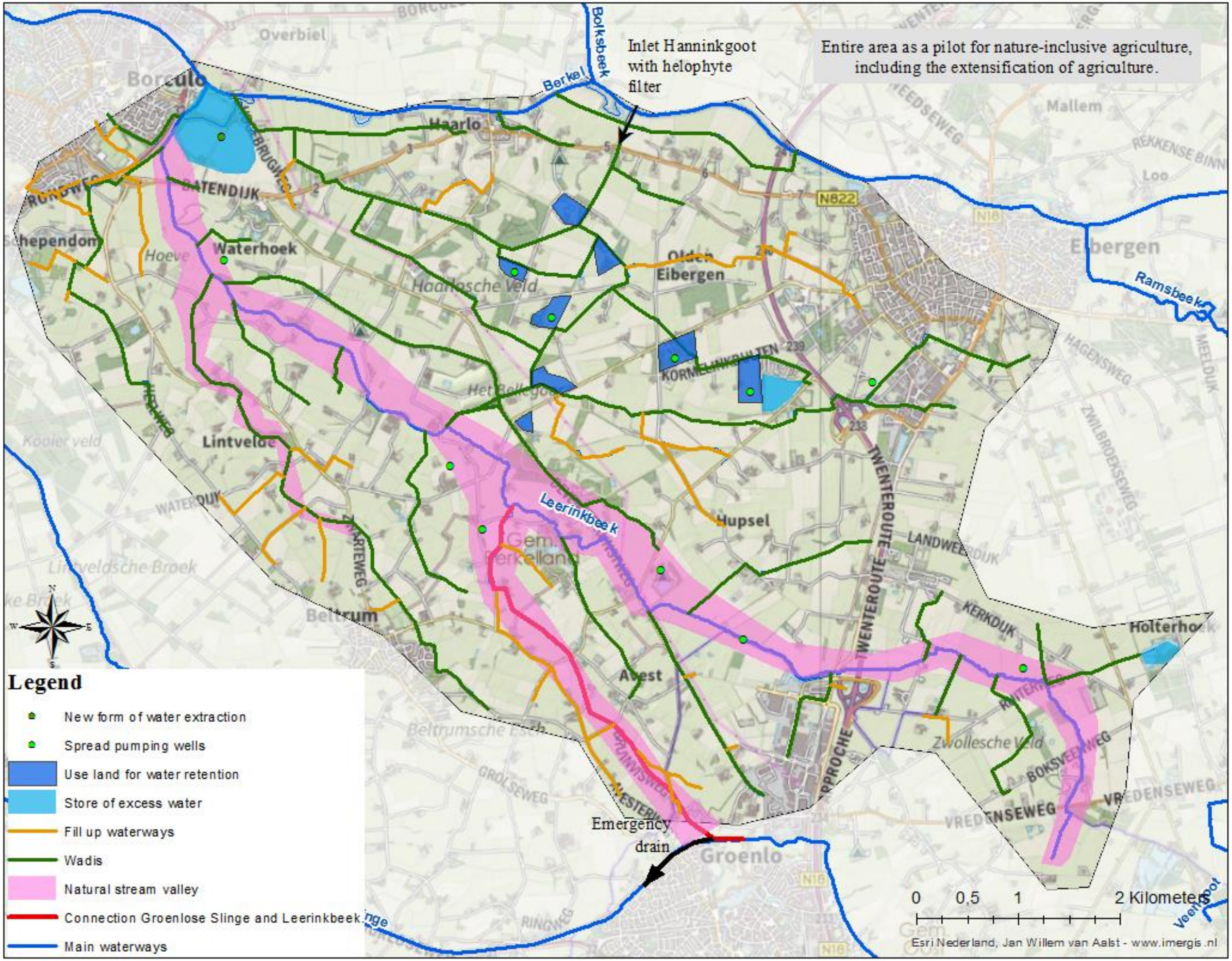

Figure 5 Re-design of the current water system to satisfy the requirements.

Natural stream valley
The shifted Groenlose Slinge and the Leerinkbeek are restored to a natural stream valley system (depicted in pink). To realize a natural stream valley, brooks are re-designed according to the 5B principle of Verdonschot. (2010) This principle is chosen from the literature study as it contributes to more than one requirement listed in table 4. Figure 6 depicts the five zones of the 5B principle; 1) the brook zone, 2) forest zone, 3) grove zone, 4) buffer zone and 5) brook flank.

Figure 6 The zones according to the 5B-concept (Verdonschot et al., 2010).

The brook zone (1) is the wet part of the stream valley, the forest zone (2) borders directly along the stream and native tree species grow here. The grove zone (3) is the transition from the forest to the buffer zone. The buffer zone (4) is the actual buffer zone between the stream and the intensively managed land and the brook flank (5) consists of all the agricultural plots, paved zones and/or built-up areas located outside the buffer (Verdonschot. 2010). Each zone offers its advantages for a more climate-proof water system, each zone is therefore briefly explained in the following section.

The brook zone
The brook zone consists of the stream itself, variations in flow patterns are provided by fallen branches, fallen trees and blown leaves. This provides living space for fish and other small aquatic animals and increases the water storage capacity of the stream (Verdonschot. 2010). The Leerinkbeek and connection Groenlose Slinge must become shallower and the stream must be able to flood every now and then.

The forest zone
The water in the stream stays cool because the trees provide shade. The shading effect of the trees results in a reduction of algae growth, high oxygen concentrations and low-temperature fluctuations. The tree roots fix the bank of the stream and bring variation in the flow pattern. The forest zone also increases the water storage capacity (Verdonschot. 2010).

The grove zone
The grove zone is the transition between the forest zone and the buffer zone. It is arranged as managed (not grazed) grove and can be used for recreational purposes such as walking and cycling paths (Verdonschot, 2010). The soil has a purifying effect through chemical processes and the zone also increases the water storage capacity (Verdonschot. 2010).

The buffer zone
In the buffer zone sediment, nutrients and other chemicals are stored. Roots of the grass vegetation in the buffer zone provide a porous bottom so that the water running off the flank can easily infiltrate and the groundwater is replenished (Verdonschot. 2010). The buffer zone can absorb incidental inundations.

Brook flank
At the brook flank, the land is used by cities and agriculture (Verdonschot. 2010).

The natural stream valley Leerinkbeek and shifted Groenlose Slinge contributes to all the requirements. First of all, it ensures that the water system is climate resilient in different ways. A natural stream valley has a high water storage capacity and therefore it can absorb extreme precipitation events. The natural stream valley can inundate and also act as a buffer and thus complies with the resilience principle of buffering. Water in these buffers can infiltrate to maintain the groundwater level and to compensate for the extraction of drinking water. Due to this infiltration, the area can absorb longer periods of drought. Second, the natural stream valley contributes to maintaining good water quality. Nutrients and other agricultural residues are captured and removed by the natural stream valley. The soil in a natural stream valley has a better sponge effect so that the nutrients can be converted and less leaching occurs. Third, the natural stream valley contributes to a more natural water system. The water system will have more accompanying streams of forest, swamps and meadows. In addition, the border between agricultural land and nature will be more gradual since the buffer zone can be maintained and used by agrarians. Finally, the natural stream valley contributes to satisfying the needs of the stakeholders. Water extraction is still possible in the area (see solution spread pumping wells), water is retained in the area and the natural stream valley prevents waterlogging on agricultural land.

Wadis

Then we look at the smaller waterways, the waterways that drain into the Leerinkbeek or Berkel. These waterways are all made shallower and widened into wadis (depicted in green). These wadis store excess water during extreme precipitation and are very suitable for the infiltration of water.

The construction of wadis is added to the design for several reasons. First, it ensures that the water system is climate resilient. Wadis contribute to both the absorption of long drought periods and the absorption of extreme precipitation events. Wadis can store the excess of precipitation and the water can infiltrate to maintain the groundwater level and therefore act as a buffer. Second, wadis contribute to a more natural water system, in two different ways: 1) The agrarians can use and maintain the wadis, therefore the border between nature and agriculture becomes more gradual. 2) The wadis itself contains more flora and fauna. Finally, the wadis contribute to satisfying the needs of the stakeholders. The water is no longer drained but retained in the wadis and due to the large storage capacity of the wadis, damage on agricultural land due to excess precipitation is prevented.

Fill up waterways

The even smaller waterways, draining into the previously mentioned smaller waterways, are filled up (depicted in orange). However, there is one exception. The small waterway right beneath Eibergen is not filled up but shallowed and widened into a wadi. This is because this waterway is located in a natural stream valley and therefore is a wet area (appendix I&J). The filling up of waterways contribute to satisfying the needs of stakeholders, the water is no longer drained but retained in the area.

Store excess water in recreational lakes and use the land for water retention

The recreational lakes in the area are used as buffers to store excess water (three lakes are depicted in light blue). These lakes are used to set up the water level in the winter such that this water can act as a buffer in the summer. The water in the Hambroekplas (top left) is then pumped back into the area. The storage of excess water in recreational lakes ensures that the water system is climate resilient and also contributes to satisfying the needs of the stakeholders. Water extraction is still possible through a new form of water extraction (see solution water extraction) and the water is retained in the area.

The already known lands sensitive to waterlogging are used for water retention (eight locations depicted in dark blue). These locations are chosen based on indicated wet locations by the respondent of HOE Duurzaam. These lands are used to store precipitation in the area. These areas will become wet and will therefore no longer be suitable for all types of agriculture. Water retention on land is added to the design for several reasons. First, it ensures that the water system is climate resilient. Excess water can be stored on land and act as a buffer after which water can infiltrate. Second, water retention on land contributes to a more natural water system. The land used for water retention becomes wet and the flora and fauna will adapt to these more wet circumstances. Finally, water retention contributes to satisfying the needs of the stakeholders, the water is no longer drained but retained in the area, and excess water will be stored at the designated locations to prevent damage from waterlogging.

Spreading of pumping wells and a new form of water extraction
The locations of the pumping wells for water extraction are changed. The pumping wells for water extraction are now spread over the area (depicted with the light green dots). To select locations for the pumping wells, the already known wet places in the area are examined (appendix J) and pumping wells are placed at these locations.

The extraction of water at these locations will reduce the chance of waterlogging. The spreading of the pumping wells ensures that the water system is climate resilient and also contribute to satisfying the needs of the stakeholders. The spreading of pumping wells ensures climate resilience by the fact that the spreading of needs complies with the resilience principle omnivory. The extraction is no longer located on two spots but is spread out over the area. The pumping wells are located at wetter places in the area to both decreases the drought damage and decrease the chance of waterlogging. The needs of the stakeholders are satisfied since water extraction for drinking water is still possible.

There is also a new form of extraction added in the Hambroekplas (depicted with the dark green dot). This can be for instance bank water extraction or surface water extraction. However, to choose the most efficient extraction here, more research is needed. The new form of extraction at the Hambroekplas ensures that the water system is climate resilient and also contribute to satisfying the needs of the stakeholders. Just as the spreading of pumping wells the new form of water extraction ensures climate resilience by the fact that it complies with the resilience principle omnivory. The extraction of drinking water is now not only from groundwater. The needs of the stakeholders are satisfied because bank water extraction contributes to the extraction of drinking water.

Inlet Hanninkgoot with helophyte filter and pilot for nature-inclusive agriculture
Finally, measures are taken to maintain good water quality. The inlet Hanninkgoot is no longer used year-round but can be used only as a backup in times of extreme drought. However, to make sure that the water quality of the water supplied from the Berkel through the Hanninkgoot does not pollute the water in the area, a helophyte filter is placed. This helophyte filter will purify the water before it enters the area. The fact that the inlet is only used as a backup ensures that the water system is climate resilient. The inlet contributes to climate resilience since the inlet is now used as a backup and therefore complies with the resilience principle redundancy. The helophyte filter contributes to maintaining good water quality.

Lastly, an adjustment to the agricultural sector that influences the water system is added to the design. To reduce leakage of nutrients and pesticides, a pilot for nature-inclusive agriculture will be set up in the entire area. Agrarians are no longer allowed to use pesticides in the area. In addition, agrarians are encouraged in helping to maintain the wetter areas and buffer zones. Nature-inclusive agriculture contributes both to maintaining good water quality and to a more natural water system. This way of agriculture increases a good soil structure and therefore increases the sponge effect that reduces the leaching. The border between nature and agriculture will also fade because these two are combined.

4.2 Validate the new water system.

The respondents of the validation focus group agree that the re-design meet all the requirements. The re-design is very valuable to have an idea of what kind of solutions are possible in the area depending on whether or not all or some of them are used. However, the stakeholders have a few remarks about some design elements that are described here. In Table 5, the requirements and the design elements that contribute to these requirements are listed. Additionally, whether the requirements are met is depicted.

The respondents of the validation focus group agree that the re-design is designed such that the water system will be climate resilient as discussed in section 4.1. Different design elements contribute to this requirement (Table 5).

According to the respondents of the validation focus group session, there are some concerns about the connection Groenlose Slinge and Leerinkbeek. On the one hand, the inlet Hanninkgoot is only used as a backup to improve the water quality, on the other hand, water from the Groenlose Slinge is allowed in the area. It is therefore important that the water in the Groenlose Slinge is of good quality. At the Groenlose Slinge effluent is discharged from the WWTP Winterswijk. Other than the WWTP effluent in the Berkel, this WWTP is located in the management area of WRIJ itself and can therefore be controlled better. Apart from the issue around water quality, it is also important to look at the drainage area of the Groenlose Slinge. Due to the connection, less or even no more water will drain into the current Groenlose Slinge downstream of Groenlo. Nature in this area mustn't be harmed by this.

Apart from the question of whether the water quality of the Groenlose Slinge is sufficient enough, the respondents of the validation focus group agree that the re-design is designed such that the water quality in the area will increase. Therefore, the requirement of maintaining good water quality is partially met (Table 5).

The respondents of the validation focus group agree that the re-design satisfies the needs of the stakeholders and is designed more naturally. The respondents agree on how the design elements contribute to these requirements as described in section 4.1.

The new form of water extraction at the Hambroekplas has an added value for the extraction of drinking water according to the respondents of the validation focus group. The Hambroekplas act as a kind of ‘end of the pipe’, all the water from the area drains towards the Hambroekplas. Therefore, enough water for extraction can be guaranteed and risks are spread.

More detailed information about the wadis is needed, how do they exactly look like and work in the area. The respondents of the validation focus group however appreciate the idea of agrarians that can maintain and use the wadis. In addition, the respondents of the validation focus group appreciate the fact that the buffer zones of the natural stream valley can be maintained and used by the agrarians.

Table 5 The validation of the re-design.

	Requirement	Design element	Satisfaction
1	The water system should be climate resilient.	• Emergency drain • Natural stream valley • Wadis • Store of excess water (in recreational lakes • Use land for water retention • Spread pumping wells • New form of water extraction • Inlet Hanninkgoot with helophyte filter	Met
2	The water system should aim to maintain good water quality.	• Natural stream valley • Inlet Hanninkgoot with helophyte filter • Entire area as a pilot for nature-inclusive agriculture	Partially
3	The design should satisfy the needs of the stakeholders.	• Natural stream valley • Wadis • Fill up waterways • Store of excess water (in recreational lakes • Use land for water retention • Spread pumping wells • New form of water extraction	Met
4	The water system should be re-designed more naturally.	• Connection Groenlose Slinge and Leerinkbeek • Natural stream valley • Wadis • Use land for water retention • Entire area as a pilot for nature-inclusive agriculture	Met

CHAPTER 5. DISCUSSION

This section elaborates on the limitations within this study in section 5.1, on how this study contributes to the literature in section 5.2, the applicability of the re-design in section 5.3, the validity in section 5.4 and the generalisability of the results in section 5.5.

5.1 Limitations

In this study, stakeholder-driven design is applied. There are some limitations to this stakeholder-driven design. Since the solutions applied in the design are posed by the stakeholders, the stakeholders that are chosen for an interview or focus group session are of high importance and have a lot of influence on the design. Different stakeholders can therefore also lead to different solutions and a different design. The opinion of the stakeholders used in this study may also change over time as more knowledge is gained and due to developments in science. Besides, those other stakeholders could lead to another outcome, solutions in the design could also be found through literature study. This can also lead to another design.

5.2 Added value to literature

This study contributes to the current body of literature by enhancing the resilience of a concrete case. Insights from literature streams about design science, system analysis and stakeholder analysis are integrated to apply resilience thinking to this concrete case. In section 3.2 resilience has been explained, in literature, there are six different resilience principles described. This study shows that some of the resilience principles that come from resilience literature apply to water systems, but not all. In this study, only three of the six resilience principles were used.

This study also adds to the literature by showing the importance of stakeholder perceptions to arrive at a design that satisfies.

5.3 The applicability of the re-design

The design cycle is part of the larger engineering cycle in which also the phases of implementation and evaluation are present (Wieringa, 2014). However, the re-design is not yet ready to implement into practice. This is because the costs and benefits of the re-design are not taken into account. To implement the re-design, first, the consequences on the water system of the different solutions must be quantified. Then a cost-benefit analysis has to take place to see which solutions are feasible. Further research is needed to implement the re-design. However, the re-design made in this study can be used by WRIJ as a first start to stimulate discussion about possible solutions in the area and the challenges that the area faces in the transition towards becoming a climate resilient water system.

5.4 Validity

Descriptive validity is used to describe the validity of the interpretations (Wieringa, 2014). The best strategy for achieving descriptive validity is by use of triangulation and member checking. Triangulation is the use of multiple, independent ways of producing interpretation. For instance by using multiple independent data sources (Wieringa, 2014). In this study, triangulation is applied in all three design phases. In the problem investigation phase, literature, documents and maps were analysed to describe the system analysis and in the stakeholder analysis, interviews and focus group sessions have been added. In the design phase, the synthesized data of the problem analysis and additional documents, literature and maps were used. Finally, in the validation phase, the design is validated by the expert judgement of the researcher and using a focus group session. Within the focus group session, experts with different backgrounds participated.

Next to triangulation, descriptive validity is also achieved using member checking. In a member check the people who provided data are asked to verify the research results (Wieringa, 2014). This is done in a few stages. First, the interpretations of the interviews and focus group sessions themselves were checked by sending the interview/focus group session report to the respondents. This also determines the stability of the results. The data acquired in the problem investigation phase is translated into a list of requirements. With the use of a validation session in a focus group, it is validated whether the information was correctly interpreted and translated into the list of requirements. In addition during this validation session, it was discussed whether the design meets the requirements and whether the experts agree with the result.

5.5 Generalisability of the results

Generalization of the method

The entire design methodology used in this study is generalizable in different contexts. In this study, WRIJ is the problem owner. However, the method used in this study is also usable for a different problem owner. This study focus on the area Haarlo-Olden Eibergen, however, the method can be used not only in this specific area but for the whole management area of WRIJ. Besides the management area of WRIJ, the method can be used for other areas with a water system that face problems due to climate change. The method is usable for looking at the possibilities in an area and based on that to start discussions. However, to take the next steps more quantitative research is needed.

As said, this study shows that three of the six resilience principles can be used to design a climate resilient water system. These three resilience principles are generalizable for other water systems. The use of stakeholder perceptions is generalisable for every other water system that needs to be changed and where the participation of stakeholders is of high importance.

Generalization of the list of requirements

The list of requirements contains both requirements and sub-requirements. The (sub-)requirements are made based on the problem investigation of the area. The sub-requirements are specifically prepared for the area Haarlo-Olden Eibergen with use of the stakeholders used in this study. The sub-requirements are therefore not generalisable. For different areas, characteristics of the water systems and stakeholders change and therefore the sub-requirements will change. However, the fact that the list of sub-requirements is specifically made for the area Haarlo-Olden Eibergen makes the list of sub-requirements powerful.

Three of the four requirements set up in this study are very useful for generalisation. Only the last requirement can change if it is not a widely supported wich by the stakeholders. Whenever an area with a water system faces problems due to climate change, the first three requirements can be used to design a climate resilient water system. For instance, other water systems at high sandy soils in the Netherlands can use these requirements to design a climate resilient water system.

CHAPTER 6. CONCLUSION AND RECOMMENDATIONS

This chapter concludes on the main findings of this research and additionally provides recommendations for future research and practical recommendations.

6.1 Conclusions

The objective of this study was to design a climate resilient water system in the area Haarlo-Olden Eibergen by re-designing the current water system. To do so, the design cycle of Wieringa (2014) is used. This cycle consists of three phases; the problem investigation phase, the designing phase and the validation phase.

Problem investigation phase

Three sub-objectives were achieved in the problem investigation phase, the conclusion is set up following these sub-objectives.

Understanding the current water system and its uses and users

The important waterways in the area Haarlo-Olden Eibergen are the Berkel and the Leerinkbeek wich discharges into the Berkel. The Leerinkbeek does not drain water all year round. The groundwater in the area flows from east to west, this groundwater flow is mostly determined by the elevation in the area. The water system in the area is designed such that water is quickly drained for agriculture. In the area, there are two water extraction locations located. These water extraction locations are used for the exploitation of drinking water. The exploitation of the drinking water causes desiccation in the area. To compensate for this, water is supplied from the Berkel and a system with ponds and weirs has been built to infiltrate the water in the area. The water extracted in the area is of the type phreatic, the extraction takes place from a sand layer that is not covered by an impermeable layer.

In addition to WRIJ, the problem owner, eight stakeholders were identified. These stakeholders are: Municipality Berkelland, Province Gelderland, Staatsbosbeheer, a Cattle farm, Vitens, HOE Duurzaam, LTO and Natuur and Milieu Gelderland.

Describe the shortcomings within the current water system

In the coming decades, the climate will change for the area Haarlo-Olden Eibergen and this means that extreme precipitation in summer will be extremer and occurs more often, the winters will be wetter, longer periods of drought are possible and the average temperature will increase. The current water system is not designed to absorb this climate change. Desiccation caused by climate change combined with the water system that is designed for quick drainage of water is a problem. The extraction of drinking water results in a declination of the groundwater table and therefore even more desiccation than only caused by climate change. The water extracted is vulnerable to pollution since it is of the type phreatic.

According to the respondents of the stakeholders, drought and water quality are the most pressing issues in the current situation. Drought will also be the most prominent issue in the future due to climate change according to the stakeholders. Within the problem formulation, the gap between the desired and current/expected situation became clear. The water system is now designed such that the water is quickly drained but it is desired that the water is retained in the area. It is also desired that the water system will be designed in a natural way which is now not the case as the water system is constructed and contains civil technical means. To maintain good water quality the system must no longer be dependent on the supplied water from the Berkel and the leaching must be reduced. Besides formulating the problem, the stakeholders also propose solutions for the re-design.

Prepare a list of requirements for the new design
Based on the problem investigation, four requirements are formulated that the re-design of the water system should meet; 1) the water system should be climate resilient, 2) the water system should aim to maintain good water quality, 3) the design should satisfy the needs of the stakeholders and 4) the water system should be re-designedmore naturally. Each of these requirements contains sub-requirements that are more specific for the area. The list of requirements is validated and found to be complete by the key stakeholders.

Resilience principles are used to re-design the current water system to be climate resilient. For the re-design to be climate resilient, the resilience principles; redundancy, omnivory and buffering had to be implemented. To comply with these principles, the re-design must contain backups of critical sources, it must spread the risks by spreading over multiple resources and it must contain buffers to absorb disturbances.

Design and validation phase
Two sub-objectives were achieved in the problem investigation phase, the conclusion is set up following these sub-objectives.

Re-design the current water system
Different design elements were implemented in the new design. The Groenlose Slinge is put back in er old course and will therefore drain into the Leerinkbeek. The channel that remains will be used as an emergency drain. This shifted Groenlose Slinge and the Leerinkbeek are restored to a natural stram vally system. To realize this natural stream valley, the 5B principle of Verdonschot. (2010) is used. The smaller waterways that drain into the Leerinkbeek and Berkel are all made shallower and widened into wadis. The even smaller waterways are filled up. Recreational lakes and the already known lands sensitive to waterlogging are used as buffers to store the excess water and for water retention. The pumping wells for water extraction are spread out over the area and a new form of water extraction is added in the Hambroekplas. The inlet Hanninkgoot is no longer used year-round but can be used only as a backup in times of extreme drought. In addition, a helophyte filter is placed which purifies the water before it enters the area. Lastly, an adjustment to the agricultural sector is added to the design. The whole area will be set up as a pilot for nature-inclusive agriculture.

Validate the re-design of the water system
The re-design meets all requirements and therefore no re-designing was needed. In addition, the re-design was also approved by the key stakeholders. However, there were some remarks about some design elements. There were some concerns about the connection between Groenlose Slinge and Leerinkbeek. Water from the Groenlose Slinge is now allowed in the area and it is therefore important that this water is of good quality. Therefore, the requirement of aiming to maintain good water quality is partially met. From the validation with the key stakeholders, recommendations for further research became clear. These recommendations are described in the next section.

To conclude, this research presents a design of a climate resilient water system for the area Haarlo-Olden Eibergen and therefore the objective is achieved. The premise is that this design will stimulate discussion about possible solutions in the area and the challenges that the area faces in the transition towards becoming a climate resilient water system.

6.2 Recommendations

To change the area into an area with a climate resilient water system, lots of steps have to be taken this section discusses these steps.

First of all, further research is needed to quantify the effects of the solutions in the re-design. The effects of the solutions in the re-design on the water system are only elaborated qualitatively. However, to implement the re-design, the effects on the water system must be described quantitatively and information about the effects of the solutions on the water balance is needed. To do so one can look at cases in which a solution has already been implemented or further investigate the impact of the different solutions.

Second, there are some design elements in the re-design on which more research is needed. In the re-design, the solution of spreading pumping wells is given. In addition to this spreading of pumping wells, the method of extraction can also contribute to a more climate resilient water system. One can think of seasonal water extraction, this means that more water is extracted in winter and less in summer. However, to implement this extraction method in the re-design, more research on seasonal water extraction is needed. Next to the solution of spreading pumping wells, also a new form of water extraction in the Hambroekplas is implemented as a solution. One can think of bank water extraction or surface water extraction as a new form of water extraction. However, to choose the most efficient extraction here, more research on these types of extraction is needed.

More research is also needed on the pilot nature-inclusive agriculture. More information about the different strategies in nature-inclusive agriculture and their effects on the water system is needed.

Lastly, discussions in the area with more stakeholders is needed. In this research, only one agrarian and no residents have been approached. However, to change the area, all residents and agrarians need to be approached and included in the discussion about the re-design.

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APPENDIX A – Data collection

This appendix provides information about the document analysis used in the problem investigation phase. In Table the source and a short description of the document are displayed. In Table the ArcMap maps used are depicted. These maps were obtained from WRIJ.

Table A-1 Document source and description.

Source	Description
Royal Haskoning DHV, 2019	Factual information about the Haarlo-Olden Eibergen area shows the problems and risks for extraction as fully as possible.
Grontmij, 2016	Picture of the current quality and development of pollution in surface water, groundwater and raw drinking water
Deltares & HKV, 2019	Risk approach for drought to provide insight into the current and future drought risk.
Royal Haskoning DHV & Aequator, Factsheet	Factsheet of the factual information about the Haarlo-Olden Eibergen area.
WRIJ, 2021	Estimation of how much water is going in and out of the area to be able to draw up a water balance.

Table A-2 ArcMap maps used (obtained from WRIJ).

Activity	Maps used
A2.1	• Topography • Elevation • Isohypsen • Groundwater extraction • Groundwater infiltration area • Seepage and infiltration • Soil • Morphology • Landuse • Innundation • Weirs
A3.1	• owner file

APPENDIX B - Interview and focus group sessions information

This appendix lists the functions of the participants in the interviews and focus group sessions. Besides the functions of the participants, also the role of the participants during the interview and focus group sessions is described. Additionally, included in this appendix is the protocol used during the interviews and focus group sessions and the questions asked.

More information about the participants.

In Table A-3, the function and role of each participant of the interviews and focus group sessions are described. In Table A-4, only the function of each participant of the focus group session is depicted. The protocol used during the interviews and focus group sessions in the problem investigation phase (Phase A) is described in the following section.

Table A-3 Function and role of the participants per data collection method in the problem investigation phase (Phase A).

Data collection method	Organisation	Function participants	Role of participants
Phase A - Problem investigation			
First focus group session (F1)	Waterboard Rijn and IJssel 5 participants	• Procesmanager advice and strategy • Advisor water systems • Advisor water systems • Policy advisor planning • Policy advisor planning	Participants are asked to anwer on behalf of the Waterboard Rijn and IJssel.
Second focus group session (F2)	Municipality Berkelland 4 participants	• Client spatial and rural development • Rural renewal consultant • Advisor green and landscape • Project leader nature and landscape	Participants are asked to anwer on behalf of the Municipality Berkelland.
Third focus group session (F3)	Province Gelderland 2 participants	• Water policy advisor • Hydrologist	Participants are asked to anwer on behalf of the Province Gelderland.
Fourth focus group session (F4)	Vitens 3 participants	• Environment manager • Project manager drinking water extraction • Junior environment manager	Participants are asked to anwer on behalf of Vitens.
First interview (I1)	HOE Duurzaam	• Secretary, citizen and living in the Haarloseveld	Participant is asked to answer on behalf of HOE Duurzaam but also to answer as citizien living in the area and as informant for lokal citizens and farmers.
Second interview (I2)	Staatsbosbeheer	• Teamleader Achterhoek	Participant is asked to answer on behalf of Staatsbosbeheer.
Third interview (I3)	Natuur en Milieu Gelderland	• Policy officer - project leader	Participant is asked to answer on behalf of Natuur en Milieu Gelderland
Fourth interview (I4)	Cattle farm	• Farmer, also chairman HOE duurzaam	Participant is asked to answer on behalf of himzelf as a farmer and as infomant for other farmers in the area.

Table A-4 Function of the participants per data collection method in the validation phase (Phase C).

Data collection method	Organisation	Function participants
Phase C - Validation		
Fifth focus group session (F5)	• Waterboard Rijn and IJssel (1 participant) • Vitens (1 participant) • HOE Duurzaam (1 participant)	• Advisor water systems • Environment manager • Secretary, citizen and living in the Haarloseveld

Interview and focus group protocol.

The protocol is the same for all the interviews and focus group sessions in the problem investigation phase. The interviews and focus group sessions are built up in five parts. The first part (part I) is the introduction part, in the second part (part II) questions are asked about the current water system, in the third part (part III) questions are asked about the consequences of climate change, in the fourth part (part IV) questions are asked about possible solutions and finally the closing of the interview/focus group session (part V). Table describes the questions asked in each part.

The interviews are held online and to guide the interview/ focus group session a PowerPoint presentation is used.

Table A-5 The interview protocol (in Dutch).

Part I - Introduction
• Voorstellen van mijzelf. • Onderzoek toelichten. • Rol van de participant toelichten. • Toestemming vragen voor opname. • Vragen of er nu al vragen zijn. • Vragen of de participanten zichzelf voorstellen.
Part II - Current water system

• Op welke manier heeft [organisatie] invloed in het gebied Haarlo-Olden Eibergen?
  • Invloed op natuur?
  • Invloed op de verdeling van het oppervlaktewater en grondwater?
  • Invloed op de waterkwaliteit?
  • Veranderd de invloed in tijden van droogte en/of wateroverlast?
• Zijn er aspecten binnen het huidige water systeem waar [organisatie] tevreden over is?
• Heeft [organisatie] wel eens overlast ervaren door een overschot aan water in het gebied Haarlo-Olden Eibergen?
• Hoe heeft [organisatie] de droogte van de afgelopen jaren ervaren in het gebied Haarlo-Olden Eibergen?
• Ervaart [organisatie] knelpunten omtrent de water kwaliteit in het gebied Haarlo-Olden Eibergen?
• Worden er knelpunten ervaren binnen het watersysteem die worden veroorzaakt door andere gebruikers van het watersysteem?

Part III- Climate change
• Hoe denkt [organisatie] dat het watersysteem zal veranderen door de klimaatverandering? • Naar verwachting zal er door klimaatverandering vaker extremere neerslag voorkomen, wat verwacht [organisatie] dat hiervan de effecten zijn op het watersysteem? • Naar verwachting zal er door klimaatverandering een langere periode van droogte zijn, wat verwacht [organisatie] dat hiervan de effecten zijn op het watersysteem? • Naar verwachting zal de temperatuur van het oppervlaktewater stijgen, wat verwacht [organisatie] dat hiervan de effecten zijn op het watersysteem? • Wat voor een effect heeft de klimaatverandering op activiteiten van [organisatie]? • Hoe verwacht [organisatie] dat watervraag zal veranderen in 2050? • Wat is de reden van de veranderende vraag naar water?
Part IV - Possible solutions
• Wat zijn volgens [organisatie] oplossingen voor een klimaatbestendig watersysteem in 2050?
Part V - Closing
• Afspraak maken over sturen verslag interview/focus groep sessie. • Bedanken voor deelname.

APPENDIX C – The names of the waterways in the area.

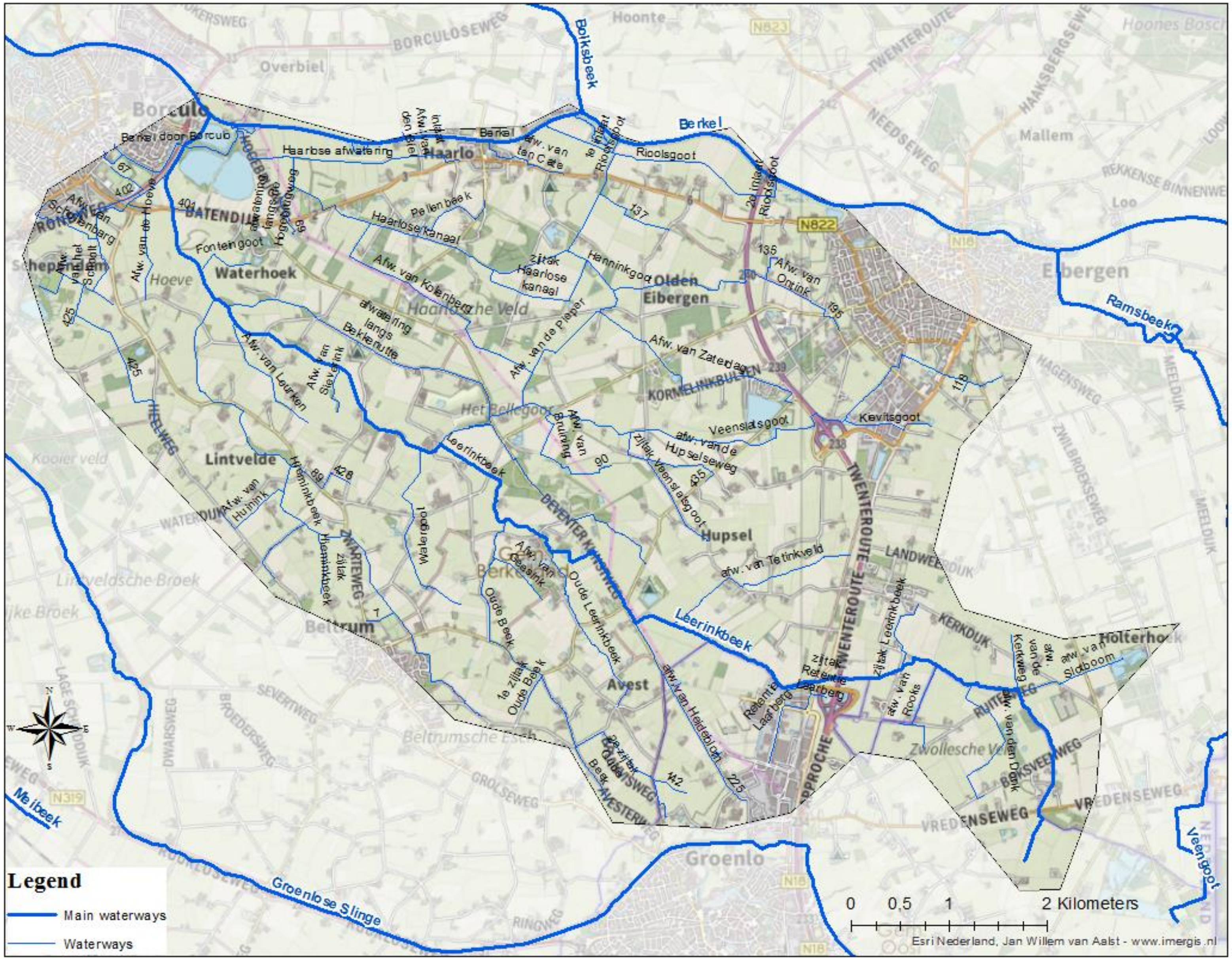

Figure A-1 The names of the waterways in the area.

APPENDIX D – Figures about climate change

The figures in this appendix are from the climate impact atlas (Klimaateffectatlas, September 2021). Climate change is divided into three themes: waterlogging, drought and heat. In this climate impact atlas, the impact on climate change for the whole Netherlands is depicted. However, for this research, the impact on the area Haarlo-Olden Eibergen is needed and therefore the closest weather station chosen is the one in Hupsel. In the figures, the current climate situation is shown in grey and the climate change scenario is depicted in orange. In dark orange, the 2050 low scenario is depicted and in light orange, the scenario 2050 high is depicted. This research looked at the average view of climate change and therefore the average view of the high and low scenario together.

Waterlogging

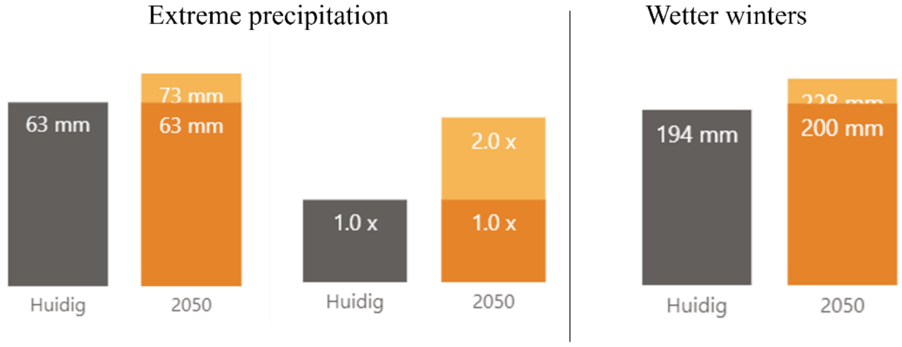

Figure A-2 The changes in extreme precipitation events on the left and the average amount of winter precipitation on the right.

In Figure A-2 the changes in extreme precipitation events and the average amount of winter precipitation is depicted. The most left figure represents the amount of precipitation per 24 hours that is exceeded once every 10 years. The figure in the middle represents the frequency of a precipitation amount that now occurs every 24 hours every 10 years. The right figure represents the average amount of winter precipitation.

Drought

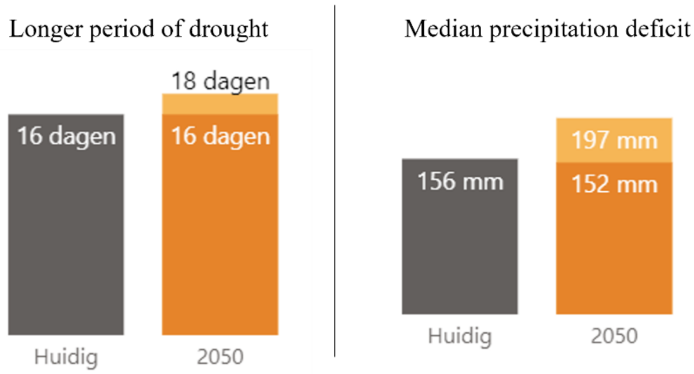

Figure A-3 Climate change effects on drought.

In Figure A-3 the effects of climate change on drought are depicted. In the left figure, the number of consecutive dry days are depicted and in the right figure, the mean precipitation deficit is depicted. If during the growing season the reference evaporation is higher than the precipitation, insufficient moisture is available for optimal growth. This is meant by a precipitation deficit.

Heat

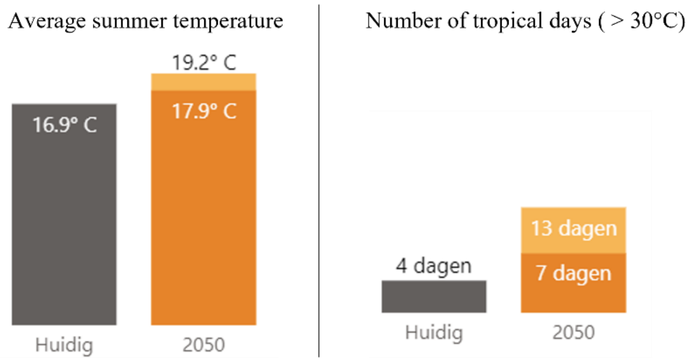

Figure A-4 The changes in average summer temperature and the number of tropical days.

In Figure the changing average summer temperature is depicted in the left figure and the right figure depicts the number of tropical days per year. A day is called a tropical day if the maximum temperature is 30°C or higher.

APPENDIX E – Stakeholders perception current situation (in Dutch)

Table A-6 Stakeholders perception on the current water system.

Organisatie	Perceptie huidige situatie ***Kansen en knelpunten***
Waterschap Rijn en IJssel	*Knelpunten* • Midden stuk van de Leerinkbeek is erg civiel technisch. • Verdrogingsproblemen. • Drinkwaterwinning versterkt de verdrogingsproblemen in het gebied. • Inlaat wordt geknepen wanneer het extreem droog is om de Berkel op peil te houden. Watergangen in het gebied vallen dan droog. • Dichtslibben van watergangen waardoor ze niet meer goed infiltreren en de afvoerfunctie minder wordt. Slib ontstaat door het afsterven van waterplanten. Door een hoog peil en veel nutriënten door uitspoeling vanuit landbouwgronden zijn er veel waterplanten. • Waterkwaliteit is niet voldoende door lozing van RWZI in Duitsland. *Kansen* • Inlaat kan worden geknepen om wateroverlast tegen te gaan. • Door droogte groeit vegetatie minder snel waardoor er minder gemaaid hoeft te worden. • Slib droogt in wanneer watergangen droog vallen.
HOE duurzaam	*Knelpunten* • Grondwaterstand is te laag mede door waterwinning van Vitens. • Uitspoeling van nutriënten is groter tijdens droogte, omdat water nodig is voor de mineralisatie van de nutriënten. • Te kort aan water.
Gemeente Berkelland	Knelpunten • Droogte. • Te snelle afvoer van het water. • Aanplant van houtwallen en landschapselementen mislukken door de droogte. • Flora en fauna wordt aangetast door de droogte. • Overlast door soorten die het goed doen door de droogte. • Uitspoeling van pesticiden en meststoffen beïnvloed de waterkwaliteit • Grondwaterstand daling door water dat wordt opgepompt voor beregening, hierdoor kan de drinkwaterwinning in gevaar komen.
Provincie Gelderland	Knelpunten • Problemen door droogte. • Neerwaardse flux van water door de onttrekking voor drinkwater en beregening. Dit kan leiden tot vergrijzing van het grondwater. • Nitraat en afbraakproducten van gewasbeschermingsmiddelen vervuilen het grondwater. • Water in de inlaat is belast door RWZI's in Duitsland. • Weinig waterberging in het gebied door ondiep pakket.
Staatsbosbeheer	Knelpunten • Droogte. • Droogte verergerd door het wegpompen van grondwater. • Te snelle afvoer van water. • Kwetsbare natuur gaat er erg op achteruit. • Grotere concurrentiestrijd tussen grassen en kruiden. • Schralere gronden hebben grondwater nodig, dit wordt echter vaak weggepompt. • Oppervlakte water bevat teveel landbouw residuen voor de natuur gronden.
Natuur en Milieu Gelderland	Knelpunten • Water is te snel uit het systeem door snelle afvoer. • Water verontreiniging vanuit de landbouw maar ook via beken als de Berkel. • Structurele droogte en vaker optredende extreme droogte. • Flora en fauna wordt aangetast door de droogte. Kansen • Beken die natuurlijk worden ingericht houden het water langer vast.
Vitens	Knelpunten • Grondwaterstand daling door de drinkwaterwinning veroorzaakt droogte. • Drinkwatergebruik neemt toe in tijden van droogte, er zal meer water moeten worden gewonnen. • Water dat infiltreert heeft invloed op de kwaliteit van het grondwater dat wordt opgepompt. Landgebruik heeft daardoor invloed op de kwaliteit van het grondwater. • Water dat wordt ingelaten vanuit de Berkel bevat Riool effluent, dit wordt teruggevonden in het ruwwater. • Gewasbeschermingsmiddelen en nitraat worden teruggevonden in het ruwwater. • Extra zuiveringslast bij onvoldoende goede waterkwaliteit. Kansen • Meer wateraanvoer via de inlaat dan dat er wordt onttrokken door Vitens.
Boer	Knelpunten • Verdroging door wateronttrekking voor beregening. • Gewasverlies door droogte en hitte.

APPENDIX F – Expected situation by the stakeholders (in Dutch)

Table A-7 Stakeholders perception on the expected situation.

Organisatie	**Verwachte situatie** *Klimaat verandering*
Waterschap Rijn en IJssel	• Bekende nattere plekken worden groter. • Gewasverdamping zal toenemen waarvoor water nodig is. • Systemen afhankelijk van neerslag zullen grote klappen krijgen door de droogte • Toename overlast door extreme neerslag. • Droogteschade zal toenemen. • Watergangen zullen vaker droogvallen • Inlaat wordt vaker geknepen door extreme droogte.
HOE duurzaam	• Systeem is goed ingericht op waterafvoer, meer neerslag kan het gebied goed aan. • Meer water beschikbaar om vast te houden. • Meer verdamping van water. • Vraag naar water zal toenemen.
Gemeente Berkelland	• Droogte wordt versterkt • Wateroverlast wordt versterkt • Meer verdamping van water. • Ecologische achteruitgang. • Gebied wordt minder aantrekkelijk voor de recreant door droogte. • Waterbehoefte zal toenemen, zowel voor agrarisch gebruik als recreatief gebruik als voor drinkwater.
Provincie Gelderland	• Drogere zomers. • Nattere winters. • Ook een kans op droge winter en een droge zomer achter elkaar. • Temperatuurstijging heeft een negatief effect op de waterkwaliteit. • Meer vraag naar drinkwater. • Landbouw en natuur zullen ook een grotere watervraag hebben in tijden van droogte.
Staatsbosbeheer	• Droogte is erg nadelig voor de graslanden en bossen. • Biodiversiteit zal erg achteruit gaan. • Watervraag zal gaan toenemen.
Natuur en Milieu Gelderland	• Door de droogte zullen soorten uitsterven, populaties achteruit gaan en beuken- en eiken-lanen sterven. • Soorten worden gevoeliger voor plagen door de droogte. • Schade aan de natuur wordt zo groot dat die zichzelf niet meer kan herstellen. • Watergebruik zal toenemen.
Vitens	• Het wordt steeds moeilijker voor het systeem om te herstellen na een lange periode van droogte. • De extremen worden harder. • De watervraag neemt toe • Winning van water zal in bepaalde gebieden niet meer haalbaar zijn omdat dit tot teveel schade leidt in het gebied.
Boer	• De extreme neerslag zal tijdelijk leiden tot meer wateroverlast. • De droogte zal toenemen, het gebied zal verder gaan verdrogen. • Gewasverdamping neemt toe bij extreme temperaturen. • Meer vraag naar water voor beregening.

APPENDIX G – Desired situation by the stakeholders (in Dutch)

Table A-8 Stakeholders perception of the desired situation.

Organisatie	**Gewenste situatie** *Resilience*
Waterschap Rijn en IJssel	• Gebied zo inrichten dat het water vastgehouden kan worden • Grondwatergestuurd peilbeheer. • Water niet meer afvoeren maar vasthouden. • In een gebied meer ingericht voor de landbouw wil je snel kunnen schakelen. • Een natuurlijker watersysteem. Een natuurlijk beekdalsysteem dat het water langzaam afvoert voor de Leerinkbeek. • Het systeem zo inrichten dat de inlaat niet meer nodig is.
HOE duurzaam	• Water vasthouden. • Uitspoeling tegen gaan.
Gemeente Berkelland	• Water vasthouden. • Beekdalen gebruiken om zoveel mogelijk water vast te houden.
Provincie Gelderland	• Meer ruimte voor het water. • Watersysteem zal zo moeten worden ontworpen dat beide extremen wateroverlast en droogte kunnen worden opgevangen.
Staatsbosbeheer	• Water langer vasthouden. • De harde grens tussen landbouw en natuur zou meer moeten vervagen.
Natuur en Milieu Gelderland	• Water langer vasthouden. • Minder uitspoeling.
Vitens	• Water vasthouden.
Boer	• Water moet bij extreme neerslag afgevoerd kunnen worden. • Nattere winters gebruiken om het water weer op peil te krijgen. • Water langer vasthouden.

APPENDIX H – Possible solutions posed by the stakeholders (in Dutch)

Table A-9 Stakeholders perception on possible solutions to design a climate resilient water system.

Organisatie	Possible solutions
Waterschap Rijn en IJssel	• Grondwater gestuurd peilbeheer • Monitorsystemen voor het beheren van het peil • Sneller schakelen binnen WRIJ zelf, vooral bij calamiteiten • Recreatieplassen gebruiken om piekafvoeren lokaal op te vangen • Hambroekplas als opslagmedium, voor het bergen van een overschot aan water en het terug pompen van dit water stroomopwaarts. Eventueel ook de Hambroekplas gebruiken voor oeverwaterwinning. • Neerslag die valt vasthouden in het gebied. • Alle afvoer in alle seizoenen in het gebied zelf houden, je moet hiervoor wel het gebied hiervoor inrichten. Dat wil zeggen, plekken om tijdelijk overschot op te vangen en gebieden waar effectiever water kan worden vastegehouden en geïnfiltreerd. • De al bekende nattere plekken gaan gebruiken om water tijdelijk te bergen en te infiltreren. • De watergangen in het gebied omvormen tot een soort brede wadi's die zowel tijdelijk overschot aan water bergen en tevens goed water kunnen infiltreren. • Natuurlijk beekdalsysteem maken dat het water langzaam afvoert. De drainage basis verhogen en de beek verbreden (smalle beek in een breed dal). • Gebieden in beekdal van de Leerinkbeek de functie natuur geven, hier kan je maximaal inzetten op bergen en vasthouden. • Normering T=100 en T=10 loslaten in het gebied. Er zal ruimte voor water gemaakt moeten worden, (te) natte gebieden zul je hiervoor een nieuwe functie moeten opleggen. • Nattere gebieden gebruiken om gras te verbouwen. • De inlaat behouden als een back-up om water toe te voeren wanneer er een groot te kort is aan water. • Winning veranderen in een gespreide winning waarbij de pompputten zich zullen bevinden op de natte plekken, hiermee is de wateroverlast dan tegen te gaan. • Water infiltreren op de locatie van de winning. Water dat gewonnen wordt moet gecompenseerd worden doormiddel van het infiltreren van neerslag. • Seizoensgebonden winning, meer in de winter dan in de zomer. • Infiltreren in de winning zelf. • De Groenlose Slinge weer in zijn oorspronkelijke dal leggen. Het kanaal dat nu het water van de Groenlose Slinge afvoert wordt dan een noodafvoerkanaal voor natte tijden.
HOE duurzaam	• Water vasthouden. • Al het regenwater dat valt moet zoveel mogelijk worden opgevangen (bufferen) • Plekken aanwijzen om water te bufferen, dit zijn vooral de nattere locaties in het gebied. • Extensiveren van de landbouw, expliciet voor drinkwatergebieden om duurzaam drinkwater te kunnen blijven winnen. • Meer natuur. • Andere gewassen telen die beter tegen droogte kunnen. • Zorgen dat de bodem voldoende water bevat zodat uitspoeling wordt verminderd. • Een hoog organisch stofgehalte in de bodem, hoe meer water er wordt vastgehouden. Dit is beter om uitspoeling tegen te gaan. • Minder maaien van watergangen, de watergangen mogen dicht groeien. • De huidige inlaat behouden als een back-up. • Toestroom naar de Leerinkbeek verbeteren bij Hupsel.
Gemeente Berkelland	• De winterse neerslag langer vasthouden zodat daar in het voorjaar van geprofiteerd kan worden. • Sponswerking van de bodem vergroten. • Gebieden die van oorsprong nat waren weer vernatten. • Robuuste natuur aanleggen met moerassen en waterpartijen. • Wadi's en aanplant voor de verkoeling en het beperken van de hitte stress. • Verbod op gebruik pesticiden binnen intrekgebied drinkwaterwinning. • Meer natuur-inclusieve landbouw, hierin behoort ook het extensiveren van de landbouw. • Soorten gebruiken die meer hitte resistent zijn. • Minder maaien in de watergangen. • Inlaat niet gebruiken wanneer de kwaliteit van het water slecht is. • De Leerinkbeek weer in zijn natuurlijke loop aanleggen met beek begeleidende bossen, moerassen en hooilanden. • Kleinere watergangen verondiepen en dempen. • De watergangen die zijn gegraven om te ontwateren niet meer maaien en schouwpaden beplanten.
Provincie Gelderland	• Gebieden toewijzen waar het land onder water mag komen te staan bij extreme neerslag. • Borculo en Eibergen zullen wellicht meer naar elkaar toe groeien, dit gebied dan groener gaan inrichten met meer recreatieve mogelijkheden (denk aan voedselbossen). • Beschaduwen van het water bevorderen om temperatuurstijging van het oppervlaktewater te reduceren. • Een boer moet een mix hebben van natte, droge en gemiddelde gronden. Op deze manier heeft de boer in natte tijden de droge gronden en in hele droge tijden de natte gronden voor gewasopbrengst. Bij een gemiddelde zomer is er dan overal opbrengst. Wanneer het bedrijf is geëxtensiveerd heeft die in een gemiddeld jaar te veel gewasopbrengst die die kan bufferen voor een jaar met minder opbrengst. • De manier van irrigeren moet meer water efficiënt.

	• Minder/niet maaien in bepaalde watergangen, de begroeiingsgraad zal toenemen waardoor het water beter wordt vastgehouden. • Meer begroeiing lijdt ook tot een vermindering van algengroei. • De inlaat moet verdwijnen. • Een seizoensgebonden drinkwaterwinning. • Verbreden en verondiepen van sloten of zelfs helemaal dempen. • Alle kleinere watergangen zou je ook kunnen dempen. Wanneer er dan erg veel neerslag valt zal dit water via het maaiveld naar de nattere/lagere gebieden lopen. Wanneer dit gecontroleerd verloopt via graslandbouw dan kan dit nog steeds naar de hoofdwatergangen lopen.
Staatsbosbeheer	• Water langer vasthouden • Organisch stofgehalte in de bodem vergroten zodat er minder gesproeid hoeft te worden. • Gewassen telen die minder gevoelig zijn voor droogte. • Meer combinatie van natte terreinen en natuur. • Accepteren dat bepaalde gebieden natter gaan worden. • De Leerinkbeek verondiepen en daarbij accepteren dat er gebieden zijn die natter worden. • Kleinere watergangen verondiepen en dichtgooien om water langer vast te houden.
Natuur en Milieu Gelderland	• Accepteren dat de nattere gebieden natter zullen worden. Deze gebieden een andere functie geven, in plaats van agrarisch terrein de functie natuur geven of combineren met aangepaste landbouw. • Diepe en rechtgetrokken waterlopen moeten verondiept en versmald worden, met juist een bredere omgeving waarin water kan meanderen en hoog water kan worden opgevangen. • Gewassen telen die beter bestand zijn tegen droogte. • Verhogen organisch stofgehalte van de bodem. • Weer kleinere en lichtere landbouwmachines gaan gebruiken. • Minder maaien in de watergangen. • In en rondom waterwingebieden strengere regels voor de landbouw.
Vitens	• Water vasthouden doormiddel van infiltratievijfers en wadi's • In plaats van afvoerende sloten infiltrerende wadi's. • Landgebruik op een manier dat de uitspoeling van agrarische stoffen en mest zoveel mogelijk beperkt wordt. • Inlaat laten verdwijnen wanneer er voldoende water kan worden vast gehouden in het gebied. • Waterkwaliteit van het ingelaten water verbeteren doormiddel van een natuurlijk filter (helofytenfilter) • Flexibel winnen, zodat de winningen die minder gevoelig zijn de gevoeligere winningen kunnen ondersteunen. • Verspreiden van de winputten.
Boer	• Organisch stofgehalte in de bodem verbeteren. • Ondiepe brede watergangen die door de landbouw gebruikt zouden kunnen worden. • Waterpeil in de Hambroekplas in de winter opzetten zodat dit kan werken als een buffer. • 3 Hectare van de familie zelf gaan gebruiken om te vernatten. • Extensiveren van de landbouw zodat de boeren minder afhankelijk zijn van het klimaat. • Gewassen gebruiken die beter tegen de droogte en hitte kunnen. • De inlaat moet blijven om verdroging tegen te gaan. • De watergangen meer inrichten als wadi's, de kleinere watergangen verontdiepen of zelfs dempen.

Next, the solutions suggested by the stakeholders are divided into six classes and listed below.

Solutions to retain water in the area
Use of recreational lakes (& Hambroekplas) to store excess water.
Set up the water level in the Hambroekplas in the winter so that it can act as a buffer.
Upstream pumping back of stored water.
Retain precipitation in the area.
Use the already known wetter places to temporarily store and infiltrate water.
Give areas in the stream valley of the Leerinkbeek the function nature to bet maximum on storage and retention.
Accept that certain areas will get wetter.
Shallowing the Leerinkbeek.
Retaining water through infiltration ponds and wadis.
Shallow wide waterways that could be used by agriculture.
Deep and straightened waterways must be made shallow and narrowed, with a wider environment in which water can meander and high water can be absorbed.
Shallowing and filling up small waterways.
Less mowing of waterways, the waterways may grow closed. - water is better retained

Solutions to come to a natural water system
Less mowing of waterways, the waterways may grow closed.
Plant chimneys.
More nature, more nature-inclusive agriculture.
Extensification of agriculture.
Use wetter areas to grow grass.
Re-establish the Leerinkbeek in its natural course with accompanying streams of forest, swamps and meadows.
Creating robust nature with swamps and water features.
Return the Groenlose Slinge to its original valley (Towards Leerinkbeek).

Solutions to improve the water quality
Inlet. - keep as a backup to supply water when there is a shortage - do not use with poor water quality - must disappear - improve the water quality of inlet water by means of a natural filter (helophyte filter)
Ensure a high organic matter content in the soil. - increases the sponge effect of the soil - the soil contains more water - reduction of leaching or agricultural residues
Ban on the use of pesticides within extraction areas.
Land use in such a way that the leaching of agricultural residues is limited as much as possible.
Shading of the surface water to reduce temperature rise.
More vegetation in the waterways leads to a reduction in algae growth.

Solutions against waterlogging
Transform the waterways into wide wadis. - retain a temporary surplus of water - good infiltration of water
Use recreational lakes (& Hambroekplas) to locally absorb peak discharges.
Deep and straightened waterways must be made shallow and narrowed, with a wider environment in which water can meander and high water can be absorbed.
Return the Groenlose Slinge to its original valley (Towards Leerinkbeek). The canal that now drains the water from the Groenlose Slinge will then become an emergency drainage canal for wet times.

Solutions for the extraction of drinking water
Spreading pump wells.
Pumping wells in the wet spots.
Seasonal extraction.
Infiltration at water extraction location.
Use Hambroekplas for bank water extraction.

APPENDIX I – Stream valley morphology in the area

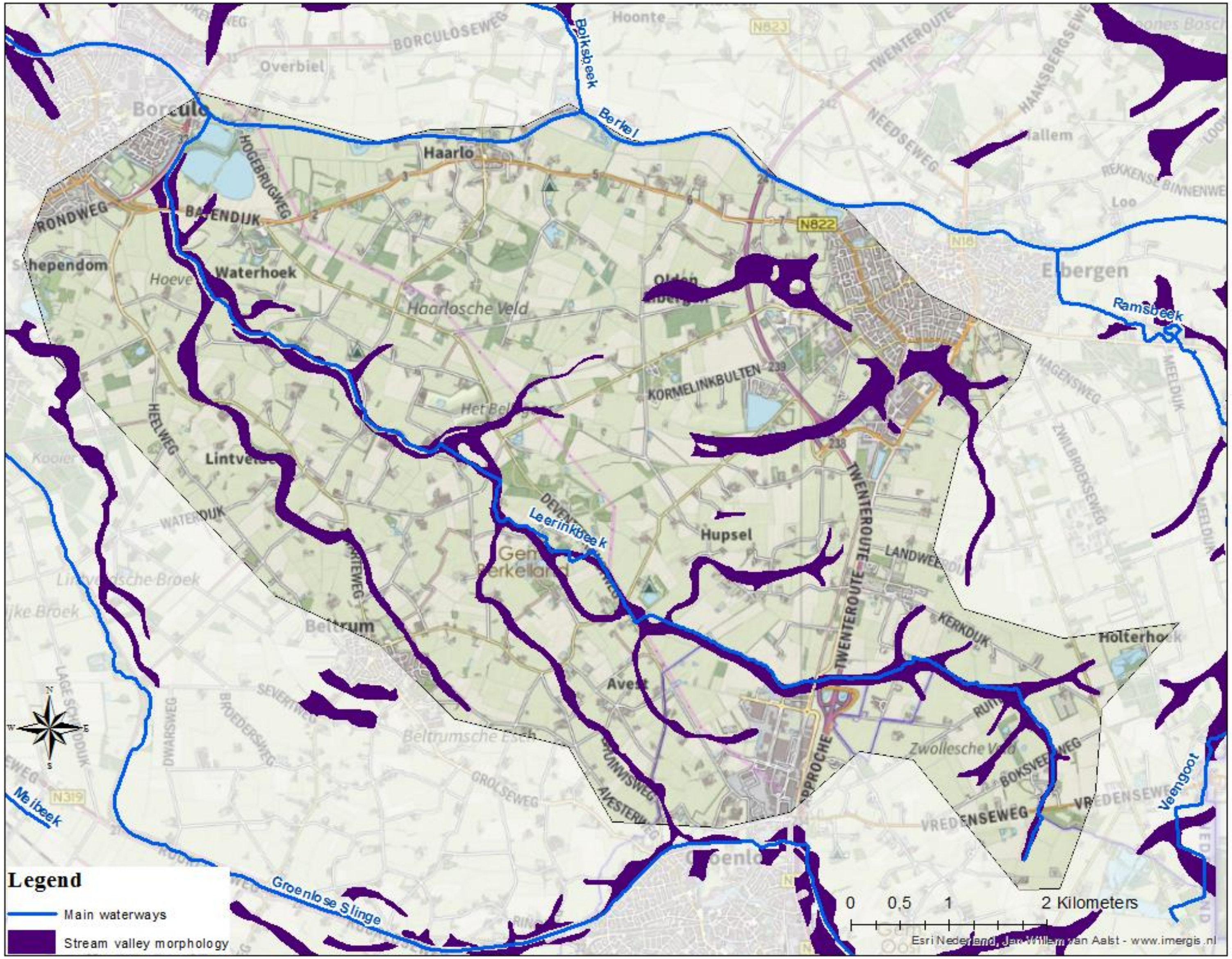

Figure A-5 Stream valley morphology in the area.

APPENDIX J – Wetter locations in the area

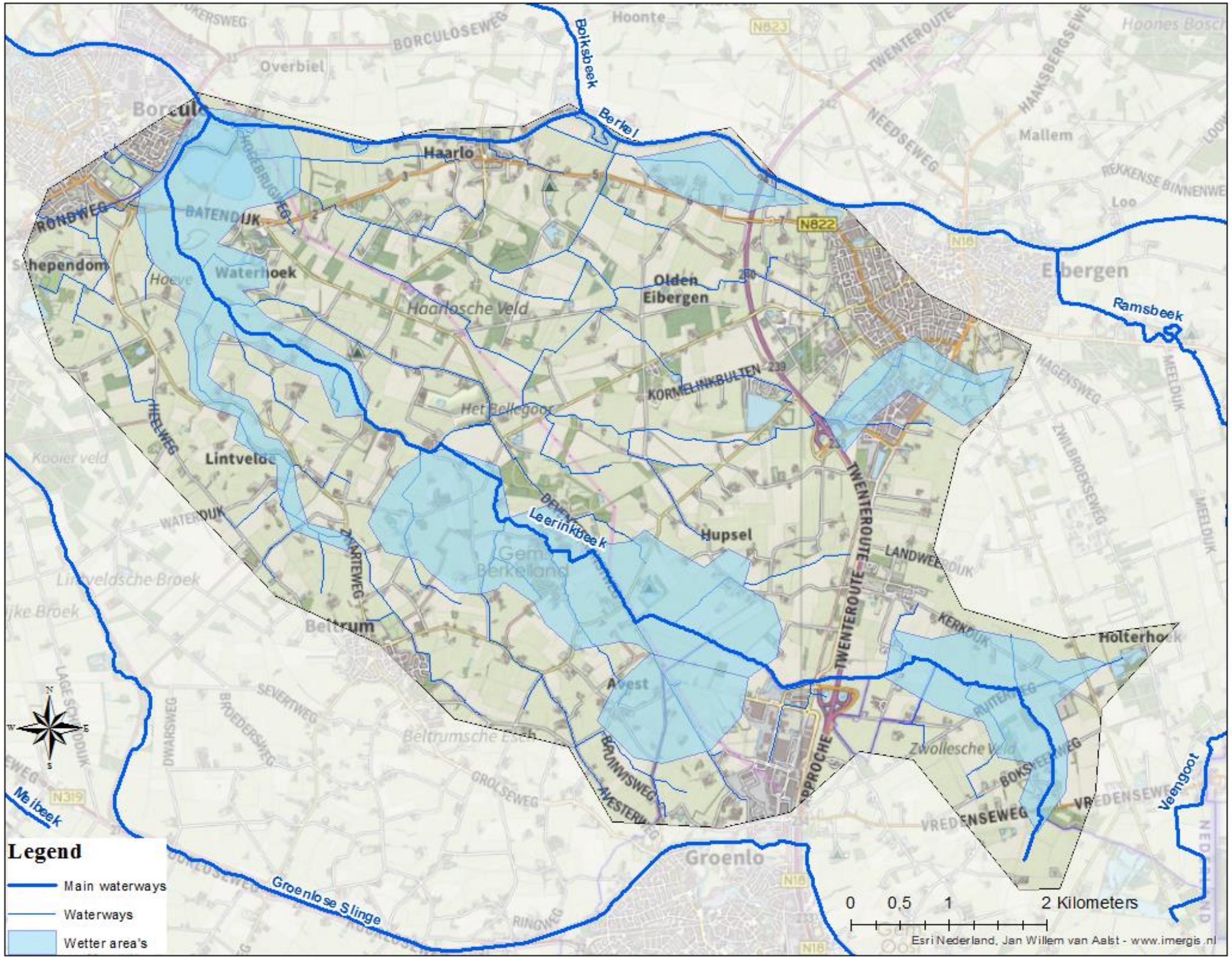

Figure A-6 Wetter locations in the area.