BSc Civil Engineering

Towards a more natural and robust regional water system in an agriculture dominated area

Scenario analysis for the side watercourses of the Groenlose Slinge to increase water retention and decrease peak discharges

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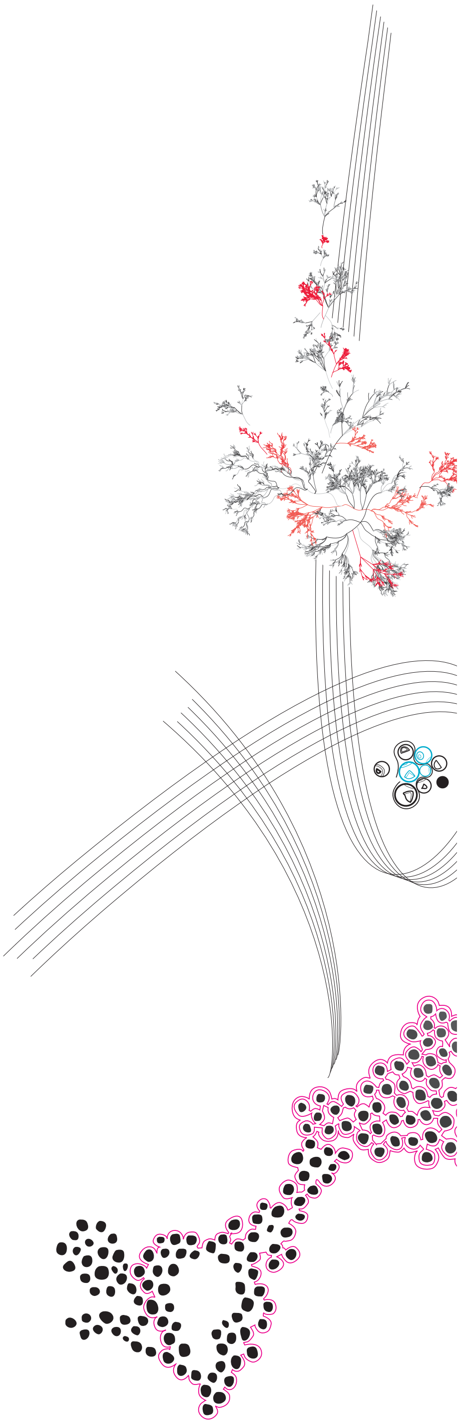

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UNIVERSITY OF TWENTE.

Waterschap Rijn en IJssel
WATERBEHEER: VEILIG EN OP MAAT

Preface

This research is the final product of my bachelor's degree in Civil Engineering at the University of Twente. Over the last years, it became apparent that the summers were consistently becoming dryer, which are the effect of climate change. These dry summers led to drought problems in the Netherlands regarding agriculture, groundwater levels, and many more problems.

During my bachelor my interest in drought problems grew over the years, finally, this put me to finding a bachelor's assignment that focuses on solving drought problems at Waterschap Rijn en IJssel (WRIJ). WRIJ manages the surface water and groundwater in multiple regions in the Netherlands, namely de Achterhoek, Liemers, and a small part of Overijssel. WRIJ desired to get a better insight into the problems of the side watercourses of the Groenlose Slinge and how to solve these problems. The Groenlose Slinge is a stream that emerges behind Winterswijk and flows in the direction of Groenlose and flows into to the Berkel. The current side watercourses of the Groenlose Slinge discharge water too fast which leads to drought, water coming into the area gets discharged too fast due to the current unnatural water system which leads to a high flow velocity. This assignment matched with what I was looking for and this report is the result of the collaboration.

This thesis is an in-depth study on a subarea of an already performed bachelor's thesis by Niek Klein Wolterink, (Wolterink, 2020). The bachelor's thesis of Niek is about water retention in the catchment of the Groenlose Slinge. Laurens Gerner, a hydrologist at WRIJ, already made an elaboration on two watercourses in the catchment area of the Groenlose Slinge. This elaboration contains, among other things, the water retaining program, this program focuses on every drop of water that seeps into the ground and achieving a more natural watercourse without stone coatings. This can be translated into the other watercourses in the subarea and to a more in-depth elaboration.

This thesis was written during the Covid-19 pandemic, which led to an unusual way of finishing my bachelor's degree. It was not possible to meet colleagues at the office, however, everyone at WRIJ was happy to help me with my research. Therefore, I want to thank everyone that from WRIJ that helped me with this research. First, I want to thank Karel Hesselink, my main supervisor at WRIJ, who provided me with his expert knowledge about the study area. Second, I want to thank Joep Schyns, my supervisor from the University of Twente, whose knowledge about research, reporting, and water systems helped me during the process of this research. Lastly, I want to thank Rutger Engelbertink and Dinja Bol from WRIJ, for joining the weekly meetings regularly and providing expert knowledge on modeling and the surface water system.

I hope you enjoy your reading.

Cas Pfeijffer

Enschede, July 12, 2021

Abstract

This research addresses the drought problems in the area of the Groenlose Slinge. The Groenlose Slinge is part of the Berkel located in the Eastern part of the Netherlands. To solve the drought problems in the area the water system of the Groenlose Slinge and the whole water system of the Berkel has to be changed. The dry summers cause the groundwater levels to decrease to critically low levels. However, the amount of the peak precipitation events increase during the winter. The necessity of solving these problems are in line with Kaderrichtlijn Water (KRW) criteria. The aim of this research is to design, model and evaluate various scenarios for the side watercourses of the Groenlose Slinge to achieve a more natural and robust water system.

To achieve the research aim, six interventions for the side watercourses of the Groenlose Slinge are identified and afterwards translated into three scenarios of which each contains one type of the following measures: *natural measures (scenario 1), water retention measures (scenario 2), and technical measures (scenario 3).* Scenario 1 aims to achieve a more natural and robust water system, scenario 2 aims to increase retention in the area and scenario 3 contains technical measures that are derived from current drought mitigation measures and are intensified. The designed scenarios will all be modelled in SOBEK Rural 2.13, compared with the modelled current situation and afterwards evaluated via a multi-criteria analysis. This will lead to the most suitable scenario for the study area. The difference in discharges, water levels, water depth, flow velocity, and freeboard levels compared to the current situation will be calculated. Afterwards, the scenarios are evaluated against each other based on flood safety, ecology, water retention, and required space.

The average freeboard levels next to the watercourses of the current situation is during the winter 45 centimeters and the summer around 48 centimeters. The freeboard levels of scenario 1 are comparable to the freeboard levels of the current situation. However, the freeboard decreases slightly during the dry months and increases slightly during wetter periods. Scenario 1, natural measures, retains 1.5% of the total discharge more than the current situation. The freeboard levels of scenario 2, retention area measures, are also similar to the current situation, the average freeboard during the spring and winter is increased by a maximum of 0.5 centimeters. The discharge during the summer is decreased by 3.3% and during the spring by 9.75%. This scenario also leads to an increase of groundwater levels of an average of 48 millimeters throughout the study area. The average freeboard of scenario 3 is decreased by 20 centimeters during the whole year. During the summer 3.8% of the discharge is retained in the area.

From the multi-criteria analysis, it follows that scenario 2 comes out as the best scenario for the area. In this scenario, the largest amount of water is retained in the area over the year while maintaining flood safety in the area. After carrying out an elaboration for a specific watercourse, it was found that this watercourse performs the best with the implementation of scenario 1. From this, it can be concluded that scenario 2 is the overall best scenario, although scenario 1 can be better for specific watercourses hence this has to be further researched.

The implementation locations of the various measures could have been expanded. In this research, the area was divided into three areas: valley, transition area and plateau. To get a better understanding of the effects of a scenario, the area should be divided

into more area types and more measurement locations need to be used. In this way, the effectiveness of a measure on a certain area type can be found. Next to this, more in-depth research to scenario 1, natural measures, should be performed. Scenario 1 has improvement opportunities and potential. The main potential of scenario 1 is in the way cross-sections are shaped and for which return periods the cross-sections are designed. By adjusting these two things scenario 1 can be fine-tuned. For follow-up research, the scenario preference of each watercourse should be researched. Each watercourse differs and every watercourse has a different optimal solution. This research discusses the approach to side watercourses of the Groenlose Slinge. Research should be performed to improve the current Groenlose Slinge into a more natural and robust water system.

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1 Introduction

The last few years, the summers in the Netherlands have been on average noticeably dryer. In 2020 there was a precipitation deficit of 253 mm, while in a median year the precipitation deficit is around 120 mm (KNMI, 2021b). The consequences of these dry summers are still felt. Mainly the agricultural sector is affected by the scarcity of water that leads to crop failures. Also, nature itself gets affected by the dry periods as groundwater levels descend, creeks run dry, accelerated breakdown of peat and local species lose their habitat (Stichting Landschappen NL, 2020).

The aforementioned example emphasizes the fact that the vision of water management has to be changed. Storing and retaining more water in the Netherlands is a possible solution to solve the drought problems. Currently, the vision of water management in the Netherlands is already changing. In 2020 the ministry of infrastructure and water management announced that 100 million extra euros would be invested in the fight against drought that year (Unie van Waterschappen [UVW], 2020). Storing the water in times of precipitation peaks will reduce the flood risk in the area, this leads to better flood safety which can be necessary because climate change causes the precipitation events to be more capricious (KNMI, 2012). Drought problems in the Netherlands mainly occur in the Eastern and Southern parts of the Netherlands, due to the sandy soils that appear at these locations.

The Groenlose Slinge, located in the East of the Netherlands, is an example of an agricultural area that faces drought-related impacts. The water gets discharged so fast that it does not get the chance to infiltrate into the ground to achieve the appropriate surface- and groundwater levels that are needed in dry periods by the agricultural sector. In the area, drought impacts arose due to droughts of previous years. Similarly to the rest of the Netherlands the groundwater level is not sufficient and if nothing is done about this in the upcoming years the area will only deteriorate.

In the spring of 2021, a lot of precipitation has fallen in the Netherlands. This made it possible for farmers to harvest two cuts of grass within a short amount of time. This led to farmers having enough cattle-fodder for the rest of the year. Among farmers this led to the belief that a wet area during dry periods is favourable thus that water has to be retained and stored more whenever it is possible.

1.1 Project history and problem description

After the flooding of August 2010, it was decided that the problems with the Groenlose Slinge had to be tackled (Nieuwe Oogst, 2012). Parcels could not discharge the water of the precipitation at the time and corn plots next to Groenlose Slinge flooded due to insufficient height of the stream banks. The discharge profile at the time was more than sufficient, however, due to a large amount of water coming from the ditches combined with a high precipitation event the flood occurred.

Climate change is one of the causes of the dry summers of previous years (Philip et al., 2020). The consequence of these dry periods is that crops can get damaged due to insufficient rainfall and low groundwater levels combined with the fact that it is not possible to irrigate the clay layers.

Waterschap Rijn en IJssel (WRIJ) plans on arranging the Groenlose Slinge in a more natural way to tackle the aforementioned problems (Nieuwe Oogst, 2012). A water storage of 9 hectares has been constructed in the area to store the water in extreme precipitation events and to use this stored water in dry periods (Vreemann, 2014). A high water channel was created to prevent floods in the area during wet period. Additionally, the banks of the stream were built up naturally to preserve the local ecosystem and local species. This rearrangement was also done to comply with European guidelines for more natural streams called the Kaderrichtlijn Water also referred to as KRW (Rijksinstituut voor Volksgezondheid en Milieu [RIVM], 2011). These rearrangements were performed to the north of Groenlo which is not within the study area of this project. In the study area itself, there is still a problem regarding non-compliance with the guidelines of KRW. The river bed of the Groenlose Slinge itself has too little dynamics in the stream. However, before the problems in the Groenlose Slinge can be tackled, the problems in the side watercourses first have to be solved.

Problem description

The current surface water system is designed in such a way that it discharges the water that comes into the system as efficiently and fast as possible. This is done to prevent floods such as the flood of August 2010. In the area, various side watercourses flow into the Groenlose Slinge. These side watercourses have a steep slope and cut relatively deep into the ground. Most of these side watercourses contain stone cladding to counteract erosion and these watercourses also contain multiple technical weirs. The high flow velocity and thus fast discharge of the water in the side watercourses make it difficult to retain water in the area.

Next to the main issue of the water getting discharged too fast, another issue is that WRIJ would like to replace the current stone coating on the stream bed with a less maintenance-intensive solution. If one of the stones of the coating comes loose, then a whirl at the bottom of the stream will occur and many more stones will come loose. It is a necessity to replace the stone coating to counteract the erosion of the side watercourses and this is an expensive business. WRIJ would like to see the stone coating disappear in the near future in and change the side watercourses into a more natural design. However, the main issue is to retain more water in the area. A more natural watercourse with a low flood probability that fosters water retention is ideal. Local ecology will get the chance to flourish and drought problems are tackled while keeping the area safe from floods.

1.2 Study area

The area of interest for the thesis is the plateau located to the East and the West of the Groenlose Slinge. The study area contains five catchments areas and the border of these combined catchments is the study area, in Figure B in Appendix 26 the sub-catchments within the study area can be seen. This area is located between Winterswijk, in specific the debouchment of the Beurzerbeek and Groenlo. The study area can be seen in Figure 1. The side watercourses of the Groenlose Slinge are also included in this study and are the main subject of this study. The side watercourses that will be included in this study are the watercourses that discharge water fast from higher grounds into the Groenlose Slinge, these side watercourses can be seen in Figure 2. As already explained in 1.1, the side watercourses currently contain multiple technical weirs. The current area contains

60 weirs, behind the weirs water is dammed to decrease the discharge to retain water for a longer period.

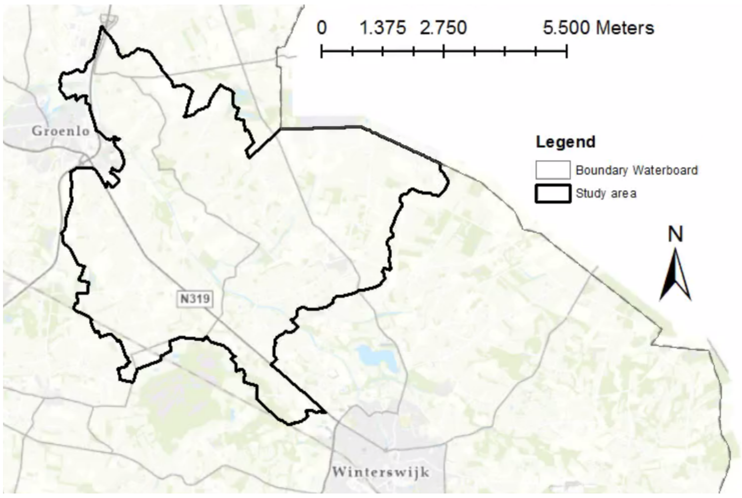

Figure 1: Study area. Source: Basisregistratie Grootschalige Topografie (2020)

The study area has an area of approximately 35 km^2. The watercourses follow the height differences throughout the area. In section 3.1.2 an in-depth analysis of the area can be found.

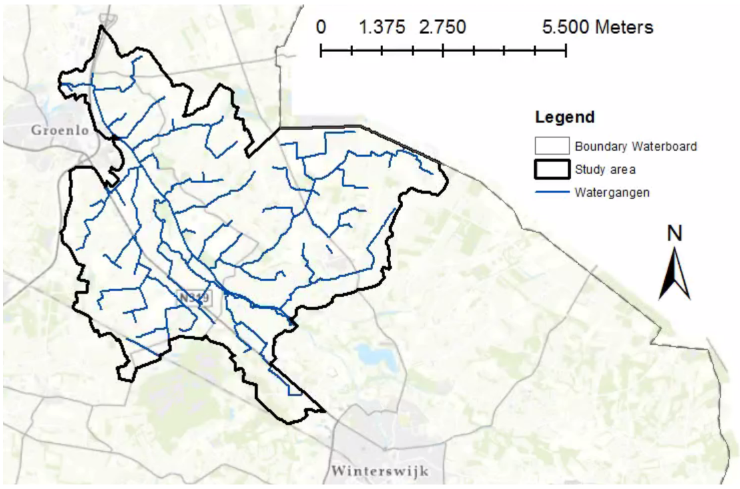

Figure 2: Study area of Groenlose Slinge inbetween Winterswijk and Groenlo. Source: WRIJ (2020)

1.3 Theoretical framework

In this section the possible interventions for the side watercourses of the Groenlose Slinge will be discussed. A previous research has been executed by Witteveen & Bos that was about promising measures that will increase the available water storage and decrease drought problems in the higher sand grounds in the East of the Netherlands (Phernambucq et al., 2019). The catchment area of the Groenlose Slinge falls within the study area of the research. Utilizing the most promising measures of the research of Phernambucq et al. (2019), the different interventions for the side watercourses of the Groenlose Slinge were determined. Also the research performed by Alterra, a research institute in Wageningen, was used to determine which interventions could be used for the side watercourses of the Groenlose Slinge. This research performed by Kwakernaak et al. (2000) described different measures to store and retain water in Gelderland. The Groenlose Slinge also falls within the study area of their research.

WRIJ has a preference for natural measures, natural measures are interventions that hamper ecology as little as possible and mainly natural resources are used for the implementation of the measures. To fulfill this request the measure of raising riverbeds is investigated. With the help of these two papers and the preference of WRIJ, six presumable effective measures for the side watercourses of the Groenlose Slinge were identified and will be further elaborated on. It is expected that not every side-watercourse will have the same preferred intervention, a combination of interventions can also be used for side watercourses. The six interventions will be classified into three different intervention classes that are: *natural stream interventions (scenario 1), retention area measures (scenario 2) and technical stream interventions (scenario 3).*

1.3.1 Natural stream interventions

Raising riverbeds (Shallow rivers and meandering)

The main focus of this intervention is to redesign the streams into a more natural system. This will be accomplished by meandering within the stream banks in combination with widening and heightening of the side watercourses. Meander within the banks will cause the streams to become wider and more shallow (Makaske & Maas, 2014). The widening of the streams takes up space that is currently mostly owned by farmers. This intervention can be adjusted in many ways during the design and after the completion of the project. For example, the more vegetation the banks of the meandering stream contains the smaller in width the stream has to be, due to erosion effects (Makaske & Maas, 2014). With this measure the clinkers at the bottom of the current streams will be removed. The clinkers also hamper vegetation, macrofauna and fish in the streams which has a negative effect on the ecology in the area. The vegetation on the bottom of the streams will cause more friction with the water than the clinkers currently do (Verschoren et al., 2016). This will reduce the flow velocity of the streams.

Improvement of soil structure
Another measure that can have a big impact on water retention in the area is the improvement of the soil structure. To improve the soil structure, the soil has to become less compact and the organic matter content has to be increased. By increasing the organic matter content of the soil in the area, the soil will become more permeable for water (Stichting Toegepast Onderzoek Waterbeheer [STOWA], 2019b). This will lead to more infiltration and retention of water into the ground in the area. The compaction of the soil counteracts the infiltration rate of water into the soil, thus if the soil compaction is reduced, the infiltration rate of the soil will improve (Handboek Bodem & Bemesting, 2020). Soil compaction also decreases the amount of water that can be stored in the soil.

1.3.2 Retention area measures

Spillway system

Another intervention to retain and store more water in the area while reducing the discharge of the streams is to add a spillway system. The streams will remain the same, however, during heavy precipitation events excess water is discharged to a savings basin. This spillway system can be seen as a parallel channel, it will run along the side watercourses like a trench. The trench itself will eventually end up into a savings basin. The trenches will be a natural system in which the flow velocity is reduced by vegetation and thus the spillway system manages its own erosion and watercourse (de Haas, 1991).

Percolation areas

Percolation areas is the second retention area measure. The percolation areas will be filled with water during peak precipitation periods and this water gets the chance to seep into the ground (van Leengoed, 2002). This intervention can both be combined with agriculture and with nature. In times when there is no retention necessary these percolation areas can be used by the agricultural sector as grassland. With weirs the inundation in the percolation areas can be managed (Kwakernaak et al., 2000). Another way of implementing the percolation areas is to design grasslands at such a height that water flows on them during peak precipitation periods. The percolation areas will decrease drought effects in the area due to extra retention of water and also ensures the flood risk in the area. During the times there is water in the percolation areas different vegetation types get the chance to flourish.

1.3.3 Technical stream solutions

Heightening current weirs

One of the technical solutions that can solve the drought problems in the area is by heightening the present weirs. Currently there are already 60 weirs in the area, by heightening these the discharge will be reduced further to increase the retention in the area. The retention will occur because the flow velocity will be decreased by the weirs and thus the water has more chance to seep into the ground thus the infiltration rate rises (Meijer et al., 2004). Presently, the overall precipitation amount increases over the years and the precipitation events are more intense. More and more water precipitates during events and this gets discharged immediately to prevent floods (de Gelderlander, 2020). By increasing the height of the current weirs the difference between the water level in the streams and the agricultural grasslands gets reduced. WRIJ uses the norm that at times of a base flow the freeboard is around 70 centimeters. Freeboard is the difference between the surface level and the water level of the closest stream. This norm is established to ensure the agricultural grasslands do not inundate regularly. The heightening of the current weirs would require to change the present policy to a smaller height difference between the water level and the agricultural grasslands.

Implementing extra weirs in the area

Another technical solution that is similar to the previous technical solution, is implementing extra weirs in the area. With the placement of extra weirs the height deficit within the area can be handled while maintaining a low flow velocity in the side watercourses. In Limburg, a southern province of the Netherlands, extra weirs are already placed to cope with the dry springs and summer (Waterschap Limburg, 2020). The extra weirs in the ditches and small streams will retain and store more water in the area during a surplus of water, which will help to supplement the groundwater. Due to the fact that the water gets dammed behind the weirs, only a part of the discharge can flow through the side watercourses resulting in more water retention. Due to the low flow velocity of the water the infiltration rate of water in the area will rise. The advantage of this technical solution is that the water levels in the side watercourses can be managed better than with the higher weirs. However, this intervention will hamper the nature even more due to extra non-natural constructions in the side watercourses.

1.4 Research framework

1.4.1 Research aim

"The aim of this research is to design, model and evaluate various scenarios for the side watercourses of the Groenlose Slinge to achieve a more natural and robust water system."

To accomplish this, various interventions will be presented to have the side watercourses of the Groenlose Slinge retain more water in the area. These interventions are possible solutions to change the Groenlose Slinge into a more natural and robust water system. To achieve this, the ecology in the area should get the chance to flourish and more water has to be retained during the spring and summer to accomplish this. The interventions are possible measures for the side watercourses to accomplish higher average water levels in the summer and in the spring. While also be able to cope with peak discharges that mostly occur during the winter. The peak discharges can be used to increase the water retention in the area. Thus, to achieve a more robust water system, excess water can be retained to increase groundwater levels during the summer. These interventions will result into three scenarios, which will be designed, modelled and evaluated.

1.4.2 Research scope

The research involves designing, modelling and evaluating scenarios for the side watercourses of the Groenlose Slinge on the plateau between Winterswijk and Groenlo. More specific, between the outfall of the Beurzerbeek and Winterswijk. Currently, this whole area is under the management of WRIJ regarding the water management.

1.4.3 Research questions

In this section the main research question with its sub-questions will be discussed.

Main-question

1. What is the preferred scenario of the designed scenarios to make the Groenlose Slinge a more natural and robust system?
The main question will be answered by answering the sub-questions. The outcome of the sub-questions will be the best suitable scenario for the area and the consequences for the area. The Groenlose Slinge is changed into a natural and robust system to achieve the set KRW-criteria. The robust system is also there to satisfy the local agriculture.

Sub-questions

1.1 How natural and robust is the current water system?

The answer to this sub-question will explain the current water system and how it stores and retain water in the area. A system analysis will be performed for the area. All the watercourses managed by WRIJ in the study-area will be shown, promising parts of the area for increasing the groundwater levels will be identified. Next to this a small analysis into the history of the Groenlose Slinge will be carried out. Parameters of the current system will be gathered to get information for a reference model. Afterwards the current situation is modelled.

1.2 What designs are possible to change the plateau between Winterswijk and Groenlo into a more natural and robust water system?

This sub-question will elaborate on the identified interventions in section 1.3. With the help of the system analysis, possible locations for these interventions will be recognized. The applicability of the interventions on parts of the area will be assessed and elaborated on to design various solutions for the area are .

1.3 How do the designed scenarios perform and score on various criteria compared to the current system?

The answer to this sub-question will explain the limits of the reference case and the limits of the three chosen scenarios. First, the three scenarios will be modelled and afterwards simulated. Second, the results of the reference case and the three scenarios will be gathered. After simulating the three scenarios the effects on the area can be seen. Last, the scenarios will be evaluated on their performance on different criteria compared to the current water system. With this evaluation the best performing scenario can be seen as the best solution for the study area.

2 Methodology

In this section, the methods and data are discussed that were used to achieve an answer to the main research question. In Figure 3, a conceptual diagram can be seen which shows the set-up of this research.

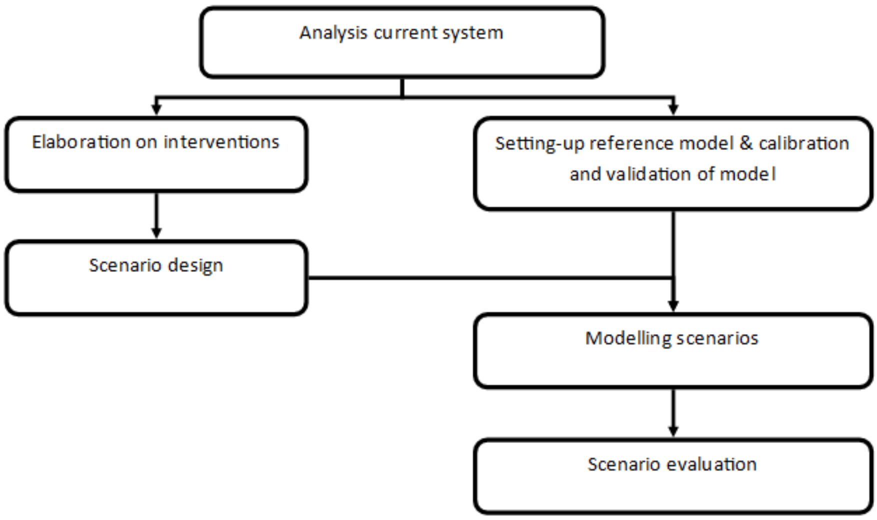

Figure 3: Conceptual diagram of method

2.1 Analysis current system

The research was started by performing a system analysis of the area to form a basis for the elaboration of the possible interventions in the area. To start off, all the watercourses in the area were defined with the help of ArcGIS maps that were available at WRIJ. More maps from WRIJ were used or adapted into useful maps for the research, when necessary these adaptations were done via ArcGIS. Via literature, more information about the area was discovered and with the help of previous studies, the history of the Groenlose Slinge was discovered and discussed. Next to that, every Monday, an expert meeting was held with two area experts who provided next to their conception of the area also literature. The maps that were used for the system analysis and the small history assessment can be found in Appendix A and B.

2.2 Elaboration interventions

Interventions were identified with the help of literature research. To elaborate on these interventions an in-depth study was performed on them, again via literature. Combining this literature research with the system analysis, suitable locations for the interventions in the area were found. The following six interventions were elaborated: *raising riverbeds, improving soil structure, spillway system, percolation areas, heightening weirs, and implementing extra weirs.*

2.3 Scenario design

With the help of the in-depth study during the intervention elaboration, three scenarios were designed. The choice was made to design scenarios because modelling the current situation and three scenarios would be less time-consuming than modelling each intervention. Each scenario contains two coherent interventions. The three scenarios contain the following measures successive: *natural measures, retention area measures, and technical measures.*

2.4 Set-up reference model & calibration and validation of model

The reference model for this research is set up in SOBEK Rural 2.13. The program called SOBEK is used by WRIJ to simulate the current water system and is used to analyse adjustments to the water systems and to simulate precipitation events. WRIJ had a model available in SOBEK for the whole Berkel water system. The available model contains the 2016/2017 water system of the Berkel. The first step to achieve the reference model was to clip the study area out of the whole Berkel water system. Afterwards, the amount of structures in the model were reviewed and verified with the current amount of structures in the study area, an example of the mentioned structures are weirs. This check was also done with the program called GeoWeb, this program contains up-to-date information about the current water system in the management area of WRIJ. After the structures were verified, the cross-sections of the side watercourses in the model were compared with the current cross-sections and if necessary adjusted. These cross-sections were also found on GeoWeb.

After the model check, information for the model calibration and validation was gathered. Within the study area, there was only one measuring location which closed in 2017. This led to the choice of calibrating the model with the month of June 2016 and validating the model with the month of July 2015. Via the program Wiski, water levels of a specific location in the Wissinkbeek were derived. These water levels were obtained from Wiski and put into Excel. Afterwards, precipitation events of the Koninklijk Nederlands Meteorologisch Instituut (KNMI) for the months June 2016 and July 2015 were downloaded from their website and transferred to an excel file. Precipitation events were extracted because SOBEK uses precipitation events as input. The precipitation events had to be translated into specific discharges since the model is calibrated in this way for WRIJ. In Appendix D, the gathered information can be found as well as the set-up of the reference scenario.

Afterwards, the needed information for the reference model was found and input values were gathered, the input for the SOBEK model was calibrated. The SOBEK model is calibrated with the gathered water levels from Wiski, these are compared to the simulated water levels in SOBEK. MatLab was used to create graphs for the calibration and validation. With MatLab, the Nash-Sutcliffe efficiency and the Relative Volume Error were calculated to assess in what manner a simulation approaches reality. Four calibrations were carried out, thereafter, the validation was performed. The calibration and validation of the input for the SOBEK model can be found in Appendix E. After the reference model was completed, an expert meeting was held with a hydrologist of WRIJ to verify the reference model.

2.5 Modelling scenarios

After the reference scenario was completed, the three scenarios were all modelled in SOBEK Rural 2.13. The required changes needed in SOBEK were identified and adapted to suit the specific scenario. Precipitation events of January 2020, July 2020, and October 2020 were used as input to test the three scenarios as well as the reference scenario.

The input data was gathered with the help of the data collected by KNMI. After the three scenarios were implemented another expert meeting was held with the same hydrologist of WRIJ to check if the scenarios were implemented properly.

The results of the model were collected in three points within the model, the measurement locations can be seen in Figure 4. The following variables were collected in each of the three points: water level, water depth, discharge, flow velocity, and freeboard. The freeboard values are measured directly next to the streams. The results were transferred to Excel in which they were summarised and clarified.

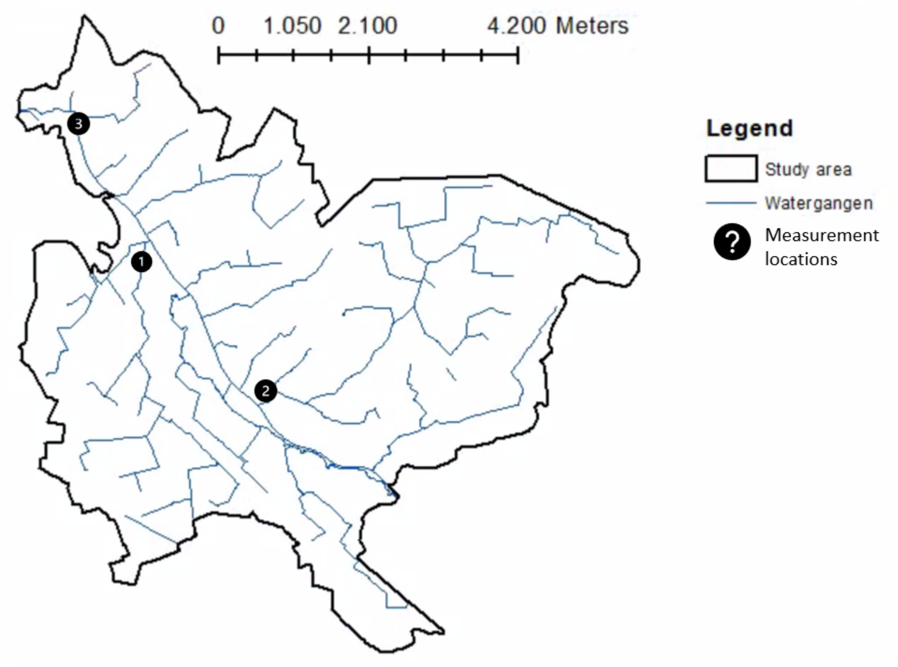

Figure 4: Measurement locations. Source: adapted from WRIJ (2020)

2.6 Scenario evaluation

After the scenarios were modelled and results were gathered from the simulations, the scenarios were evaluated. During the two expert meetings, the criteria on which the scenarios would be evaluated were identified. The results of the scenarios were shown to the expert, during the meeting each scenario was judged on the following four criteria: *flood safety, ecology, water retention and required space.* Each scenario got a score for each criteria and the criteria were determined with the following indicators:

Flood safety; the scores for flood safety are determined based on the minimal and average freeboard levels of a scenario.
Ecology; the scores for ecology are determined based on the flow velocity of a scenario and the expected ecological impact of the designed scenario based on literature.
Water retention; the scores for water retention are determined based on discharges, expected groundwater rise and scenario specific retention measures.
Required space; the scores for required space are determined based on the space that is required for the implementation of a scenario and in what way the used area can be given a multi-functional purpose.

A multi-criteria analysis was performed to evaluate the three scenarios, this was done in Excel. After the two meetings with the expert a weight is given to each criteria based on the judgement of the experts. A criteria weight matrix is created and normalized afterwards. Each scenario is scored on the criteria and utilizing the priority vector the best scenario was found. Afterwards, an elaboration on "de afwatering van Hulshof" was carried out to assess a specific watercourse. Through the scenario evaluation and the watercourse elaboration an advice was given to WRIJ on which scenario is the most suitable for the study area.

3 Results

In this section, the results of the research are discussed and elaborated upon. This system analysis is performed to get a better understanding of the current area. Firstly, a small analysis of the history of the study area is performed to get a better understanding of the historical water system why it is designed the way it currently is, and how this design developed over centuries. Second, in section 3.2, the results of the natural measures scenario are compared to the current water system. Third, in section 3.3, the results of the retention measures scenario are discussed and compared to the current water system. Fourth, in section 3.4, the results of the technical measures scenario are discussed and compared to the current situation. In each scenario section, the scenario corresponding interventions are further elaborated on. Afterwards, the designed scenario is discussed, thereafter the results for the scenario compared to the current situation are given. The results are given in percentages of multiple measurement locations combined, in Appendix G results of the research can be found in absolute values per measurement location. Last, an evaluation is performed to compare the scenarios to each other. In section 3.5, the scenarios are evaluated and the best scenario is identified.

3.1 Current water system

3.1.1 History water system

The water system between Winterwijk and Groenlo changed over the centuries. This paragraph is largely based upon the research of Derks, et al. (2006), the mentioned research is about the cultural-historic area description of Oost Gelre. The oldest known plan about the Groenlose Slinge dates from 1614 and was to make the stream navigable for ships. In 1830 the same plan arose, however, due to the big price tag this plan was never realised. To make the stream navigatable for ships, five sluices were needed which would have been a costly affair. Over many decennia the stream was improved to manage bigger discharges. In between 1921 and 1930 the Groenlose Slinge underwent a big improvement to increase the discharge capacity to 14 m^3/s (Derks et al., 2006). During the large-scale improvement of the Slinge during the 70s, many bridges were placed over the Groenlose Slinge that are still standing at this point. From the 19th century till far in the 20th century, peat extraction took place in the study area. Many smaller and bigger watercourses were created to extract the peat in the area and make large parts of the area suitable for agricultural purposes. At the beginning of the 20th century, large-scale channeling of streams began for the Slinge.

From multiple historical maps of the study area it can be seen that it has changed in multiple manners over the years. In 1880 the Groenlose Slinge had many more curves and was meandering, the stream used to have a more natural course. Figure 15 and Figure 16 in Appendix A, show the topography map of the study area in 1880-1890 and also a zoomed-in part of the study area with the current watercourses included. In 1930, the Groenlose Slinge was still meandering, although, to a lesser extent. When looking at the current topography, it can be seen that the stream meanders little to none. Figure 17 and Figure 18 in Appendix A, show the topography map of the study area in 1880-1890 and also a zoomed-in part of the study area with the current watercourses included. The cause of change in meandering over the years is presumably due to the demand for agricultural space. Meandering streams require a large amount of space and thus the Groenlose Slinge was diverted to fulfill the agricultural land demand. The current stream contains a bypass that only discharges a small portion of the total discharge, however, the full discharge of the Groenlose Slinge used to flow through this bypass. Between 1930 and current times a canal was dug where the current stream flows through. This was done to improve the water discharge in the area. In Appendix A, multiple historical maps of the study area can be seen.

3.1.2 System analysis

Surface system

The current water system that is included in the study contains watercourses that are managed by WRIJ. In the area itself, there are also smaller watercourses, however, these watercourses are ditches and trenches that are not managed by WRIJ. The ditches and trenches still have a big impact on the overall water system, because most of the water that ends up in the watercourses that are managed by WRIJ comes from these smaller streams. Figure 19 in Appendix B also shows watercourses outside of the study area. An important drought mitigation measure of the current water system is weirs. Weirs make it possible to control the water levels within the watercourses for WRIJ. In Figure 20 in Appendix B, the weirs within the study area can be seen. The streams follow the height differences in the area. In Figure 21 in Appendix B, the height map of the study area can be seen. The flow direction of the watercourses in the area follows the height differences logically. In Figure 22 in Appendix B, the flow directions of the managed watercourses by WRIJ are shown. Small differences can be seen between the natural water system and the current water system. Expansion of agricultural land and flood safety aspects caused the diversion of watercourses over the years, thus not all watercourses in the area still follow the natural water system. In Figure 23 and Figure 24 in Appendix B, the natural water system can be seen, and also the comparison to the current water system is visualized.

One of the problems in the area is that the streams discharge water too fast. Clinkers within the streams are a cause of this problem, however, these are put into the streams to counteract erosion. Around 75% of the side watercourses in the study area contain clinkers, on the Eastern side of the Groenlose Slinge 100% of the side watercourses contain clinkers. In Figure 5, a watercourse in the study area containing these clinkers can be seen. The clinkers have a flat surface compared to the dirt stream bottom, the flatter the surface the lower the friction in the stream. This lower friction causes a higher flow velocity thus a higher discharge. When the clinkers are removed, the discharge gets delayed and reduced thus more water can be retained in the area. However, the streams have to be designed in such a way that flood safety remains ensured while erosion is not be a problem. In Figure 25 in Appendix B, watercourses containing clinkers are visualized.

Figure 5: Watercourse in the study area containing clinkers. Source: own elaboration

The study area contains five sub-catchments, furthermore, most of the water within these sub-catchments end up in the Groenlose Slinge. In Figure 26 in Appendix B, the five sub-catchments can be seen. A sub-catchments shows from which locations the water flows to which stream in the area. At the transition between the plateaus and the valleys in the area, the slope percentage also tends to be high. These also apply for the plateaus themselves, the plateaus mainly occur in the North-Eastern part of the study area. Most problems regarding fast discharging streams occur at these locations. Figure 27 in Appendix B, shows the slope percentages in the study area.

Subsurface system

The subsurface system is equally as important because it can give information about which locations are promising for a scenario and which locations have to be avoided. In Figure 6, the soil map of the study area can be seen. The area mainly contains a podzol soil type, however, the area also contains gleisoil (Dutch: Beekeerdgronden) around the watercourses. The disadvantage of the podzol soil is that it has a low permeability, this comes from the fact that it is dense because this layer contains amorphous humous (Steur & Heijink, 1972). On the other hand, the gleisoils have better permeability than the podzol grounds, since generally the gleisoils are located at a lower elevation level than podzol grounds which does not give the amorphous humous the chance to develop into this (Massop & van der Gaast, 2005). The gleisoils generally contain a sandy subsoil which improves the permeability of the soil type.

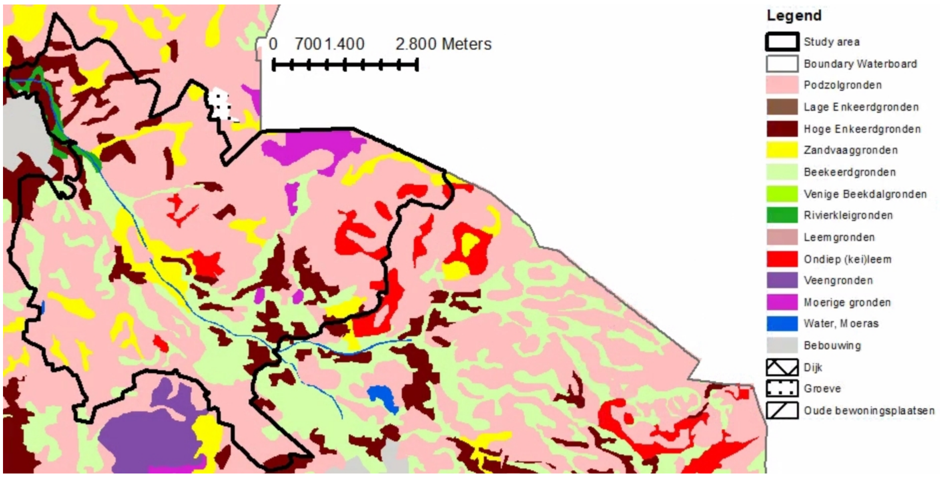

Figure 6: Soil map of the study area. Source: Alterra (2006)

The study area also contains shallow boulder clay, which is almost impermeable for water. This shallow boulder layer does not let water seep into the subsoil, so it has to be discharged via the surface which discharges it fast. Figure 28 in Appendix B, shows the shallow boulder clay locations within the study area. The combination of the shallow boulder clay layer and the steep slopes in the area makes the system react fast to precipitation events. The water coming into the area via precipitation is discharged fast via the streams thus the water can not be retained or stored in the area. During precipitation events streams are full of water, however, during dry times the streams contain little to no water. The streams on the shallow boulder clay areas are "fast-reacting streams" which is translated from the Dutch called "snel reagerende beken". It can be concluded that the shallow boulder clay areas within the study area are one of the causes of drought problems.

The area consists out of 80% agricultural land. Figure 29 in Appendix B, shows the land-use in the study area. Farmers enrich their lands with soil nutrients to improve their crop growth, which causes the land plots to rise by the accumulation of soil enrichment products. These elevated areas are not only visible on the height map but also the soil map. The mentioned areas are depicted as enk earth-soils (Dutch: Enkeerdgronden). In the agricultural department heavy machinery is used to work the lands, as well as cows that graze on the grasslands. This causes the soil to become more compact and dense. This densification of the soil causes it to be less permeable and able to store less water in the soil.

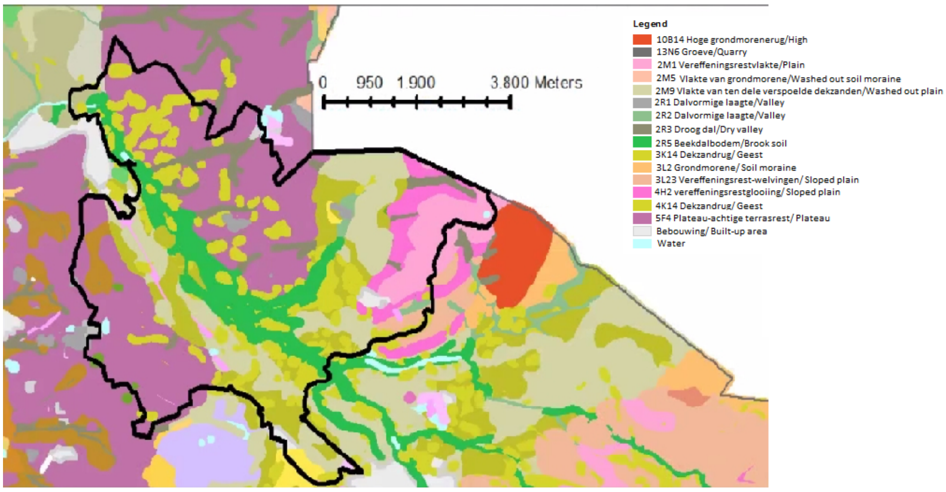

Figure 7: Geomorphological map of the study area. Source: Maas (2008)

The geomorphological map that can be seen in Figure 7 shows many different geomorphological features. A large part of the study area consists out of plateaus, on top of the plateaus multiple sand ridges can be seen that are created by the wind in the last ice age (Province Drenthe, 2020). In between the plateau and plain in the study area, the washed-out plains and sand ridges are mainly located. These are mainly located in a lower elevated area. The sand on the washed-out plains once belonged to the sand ridges in the lower elevated area which was flushed by water and blown by wind upon the washed-out plains (ten Cate & Maarleveld, 1977). The brook soil is located in the lower elevated part of the area, it can be seen that the watercourses follow this subsurface soil type. Not surprisingly, most of the natural watercourses are located in this part. However, some streams deviate from the natural water system and the brook soil. Streams were dug out to make the streams discharge more efficiently.

In Figure 8, the thickness of the top sand layer can be seen. The thickness of this sand layer extends from 0-1 meters to more than 20 meters thick. Underneath this top sand layer, there is generally an impermeable layer. As can be seen, on the plateau and plains itself the top sand layer tends to be shallow. In the valley in between the plateau and the plains, the top sand layer is thicker. Where the bigger watercourses run in the area the top sand layer tends to be thicker. The thicker the top sand layer is, the more water can be stored in this layer (Lenssen et al., 2018). The water can not infiltrate the impermeable layer and thus can not be stored here. The watercourses in the area tend to run along the sides of the thicker sand layers.

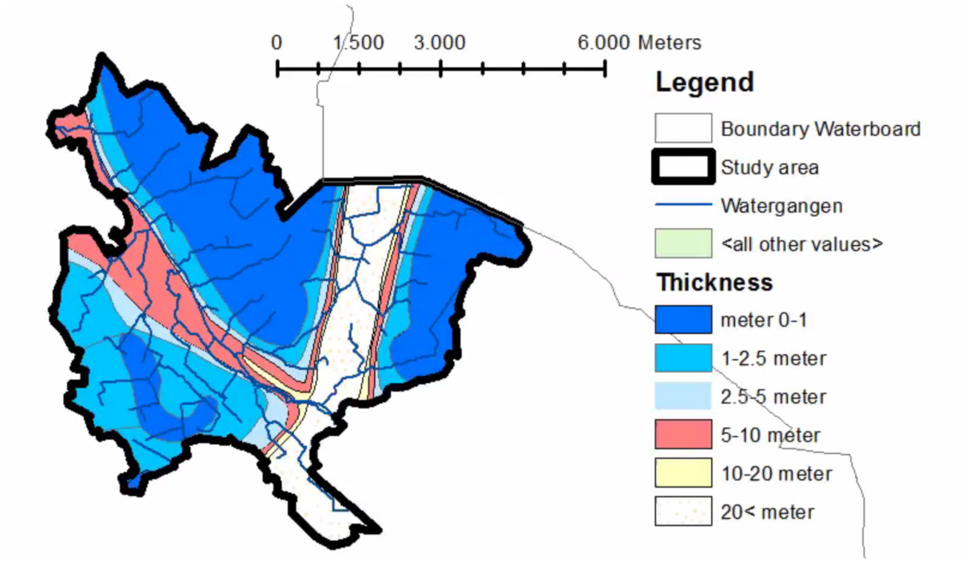

Figure 8: Thickness of the top sand-layer. Source: van den Bosch (1994)

In Figure 9, the freeboard (Dutch: drooglegging) in the area can be seen. The freeboard in the area is the height difference between a specific location and the water level to where this location discharges. As explained earlier, over the years farmers enriched their soil by using fertilizer on top of their soil. The accumulation of these products caused plots of land to rise, which leads to larger freeboard values. Next to this, the wish from the local agriculture were deep ditches and trenches to dewater their lands fast, furthermore, deeper and smaller trenches cost less agricultural land. The higher the freeboard in the area, the larger the hydraulic head. The larger the hydraulic head the more seepage occurs towards the watercourses thus water gets retained for a shorter period. The shorter retention period leads to drought problems. In Figure 30 in Appendix B, the most optimal freeboard levels in the study area are visualized.

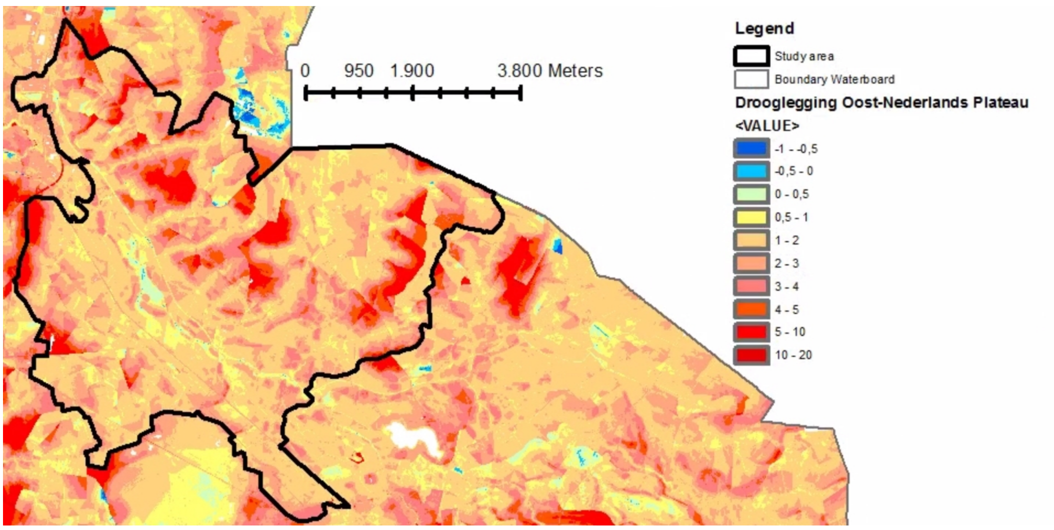

Figure 9: Freeboard, elevation level of location compared to water level where the location discharges into. Source: Engelbertink (2021)

Location indication in study area

In the following sections, locations within the study area are mentioned. In Figure 10, the mentioned locations within the following sections are visualized for the study area.

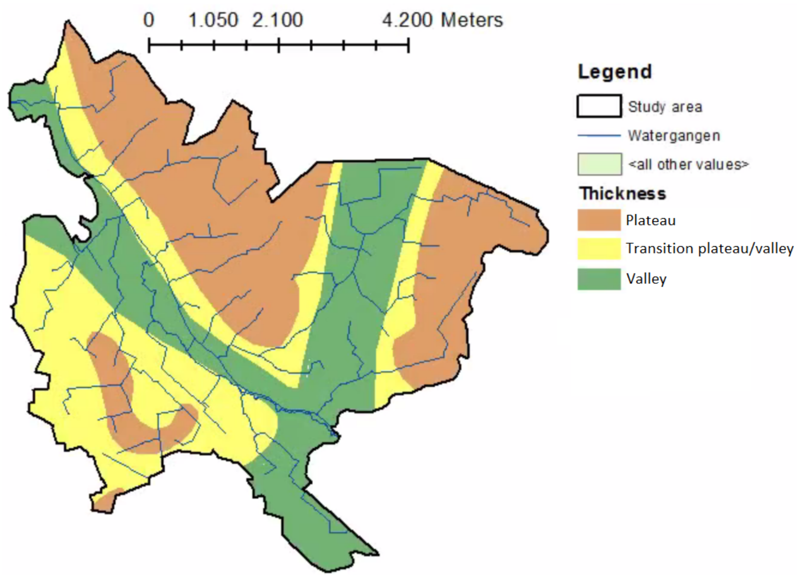

Figure 10: Designation of different sub-areas. Source: adapted from WRIJ (2020)

3.2 Scenario 1 - Natural measures

3.2.1 In depth analysis natural measures

Raising Riverbeds (Shallow rivers and meandering)

Raising the riverbeds and letting the side watercourses meander in its banks has many advantages, also its disadvantages. The watercourse will have the chance to develop bottom meandering itself. In Figure 11, the design for the Rijerinksgoot can be seen. The Rijerinksgoot is located within the study area and the idea for this side-watercourse is to let the stream meander within its banks, which can also be seen in the figure. The advantage of letting the watercourse meander and making the stream more shallow while increasing its width is that the flow velocity of the side watercourses get reduced drastically due to extra friction which leads to more water retention in the area. This measure also does not require clinkers on the bottom of the watercourses and mimics a natural stream, which is an ecological advantage. Streams that meander within its banks also maintain themselves, because the bends on the stream bottom vary over time due to erosion and sedimentation (Makaske & Maas, 2014). The meandering of streams causes the depletion of dissolved oxygen concentrations along hyperheic lateral flow paths which causes denitrification of the stream water (Kasahara & Hill, 2007). One of the biggest advantages of this measure is that the freeboard becomes lower due to the heightening of the riverbeds. The lower the freeboard the less the hydraulic head between the groundwater and the water within the streams, which leads to less seepage. The lower the hydraulic head, the less water gets extracted from the groundwater by the side watercourses.

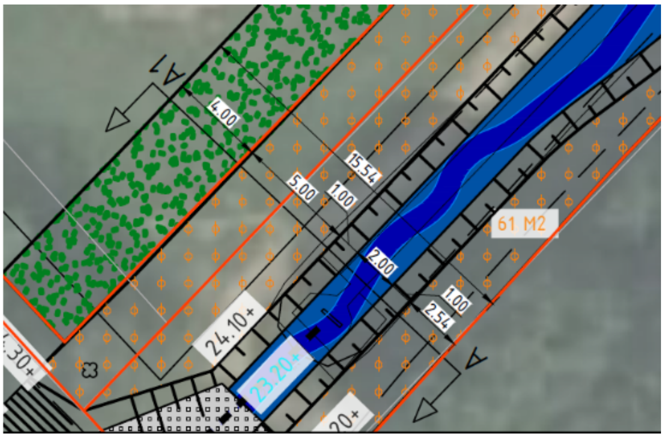

Figure 11: Design of Rijerinksgoot schematized. Source: WRIJ (2021)

The widening of the streams requires extra space mainly during the winter, however, if properly designed the watercourses require less space during the summer. New arrangements have to be made with the local farmers regarding wet periods and inundation. To change the cross-sections over the length of the side watercourses require a large investment has to be done. Next to this, the never-ending change of the meandering shape has to be checked regularly to see if it is still within the river banks (Makaske & Maas, 2014).

This measure would be effective in areas with a relatively large slope that also has a large freeboard and a thick aquifer. The flow velocity gets be drastically reduced in the sloped areas due to the extra friction. By decreasing the freeboard the hydraulic head gets reduced which beneficial for retaining water in the area. Areas with a thick aquifer can store more water in the ground. As assessed in section 3.1.2, the largest slope percentages occur at the transitions between the plateaus and valleys. At these places, the freeboard tends to be high too. However, the aquifer layer is not the thickest and ranges from 2.5 meters to 20 meters. Overall, the transition areas between the plateaus and valleys seem the most suitable for this measure. In essence, this measure can be implemented in the whole area and is expected to be beneficial regarding water retention.

Improving soil structure

The current soil structure can be denoted in organic matter content and soil compaction. In Figure 12, the organic matter content in the study area can be seen. Most of the area fluctuates between 2.5 to 8 percent of organic matter content, which can be improved in two main ways. First, organic matter which contains many nutrients can be used to enrich the soil. A disadvantage of this is that the soil is raised thus the freeboard is increased. Second, the organic matter content can be increased by not working the agricultural lands or using different management for the lands. The measure of not working the land or using different management takes multiple years to be effective.

The average soil compaction in the area is 30-45 percent. The area is prone to subsoil compaction, furthermore, the overall risk of soil compaction is large. If the soil compaction in the area is lowered, the soil can store more water and the infiltration rate of the soil improves. This can be improved in multiple ways, one way to prevent soil compaction is by not using agricultural vehicles on the agricultural fields at all. However, if the farmers decide to enter the agricultural fields with their equipment, proper tire pressure and tire choice can also prevent soil compaction. Using lighter machinery and tillage of the land during dry periods also prevent soil compaction (Handboek Bodem & Bemesting, 2020). Figure 32 and Figure 33 in Appendix C, show the soil compaction of the subsoil in the study area and also the risk of soil compaction within the study area.

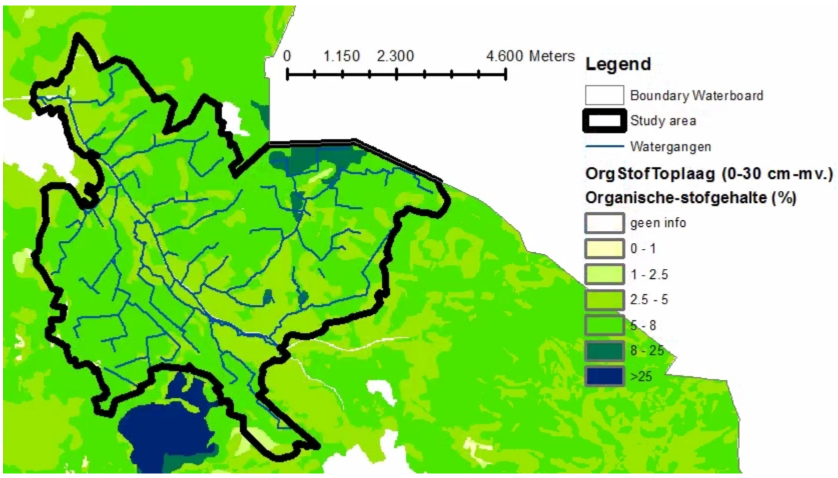

Figure 12: Organic matter content in study area. Source: van Tol-Leenders et al. (2018)

The improving soil structure measure can be well combined with other measures, it does not counteract or hamper one of the other measures and is most effective in the area with a thick aquifer because the thicker the aquifer the more water can be stored in the soil. However, in essence the improvement of the soil structure is effective over the whole area. This measure is focused on the infiltration of water into the ground, thus the thicker the aquifer the more water can be stored. The thick aquifer appears in the valley in between the plateaus. The area also contains a podzol soil type, 53% of the podzol in the area in compacted (Sietzema, 2016). The podzol grounds in the area also have an average organic matter content of 5.1%, this can also be increased. The valleys in which the main watercourses flow has the lowest organic matter content, with an average of 4.1%. These two soil types are the most promising for implementing this measure. The organic matter content is only be improved in the topsoil layer in these areas.

3.2.2 Designed scenario 1

The first scenario is a combination of the natural measures. The scenario contains the measures of raising the riverbeds and improving the soil structure. Both measures can be well combined with other measures and in practice, more measures can be implemented into this scenario if needed. As aforementioned, the raising riverbeds measure is most effective at the transition between the plateau and the valley also on the plateau itself. However, the measure is also effective in areas with a smaller slope. The typical cross-section in the area is heightened by 40%. The smaller slope mainly occurs in the valley thus is most effective in the valley area.

The raising riverbeds measure has been implemented by adjusting the cross-sections of the side watercourses, the cross-sections have been made wider and shallower. The meandering of the stream-bottom is not possible to implement in SOBEK combined with these measures.

The improvement of the soil structure has been implemented in an assumption-based way. No adjustments have been done to the model itself, only to the input of the model. The SOBEK model does not contain infiltration rates and thus the soil structure can not be adjusted in that way. The improvement of the soil structure leads to a higher infiltration rate, thus less water is discharged immediately via the streams. This measure leads to a longer retention period for water. Less water ends up in the streams during precipitation events, but more water is stored in the soil. The longer retention period of the water leads to a larger base flow during dry periods and a smaller base flow for wetter periods. To mimic this, the input for the model is changed for both dry periods and wet periods. The input precipitation events on the area remain the same, although the base flow as input for the model is increased for the spring and summer and decreased for the autumn and winter.

3.2.3 Results scenario 1

Table 1: Study area average change in variables in scenario 1 compared to the reference scenario

Scenario 1	*Water level*	*Water depth*	*Discharge*	*Flow velocity*	*Freeboard*
Summer	0.00%	0.03%	0.37%	0.38%	-0.03%
Spring	0.00%	0.03%	0.07%	0.07%	-0.03%
Winter	0.00%	-0.11%	-0.93%	-0.76%	0.15%

Table 2: Freeboard values scenario 1

Scenario 1	*Minimal freeboard (m)*	*Average freeboard (m)*
Summer	0.35	0.48
Spring	0.37	0.49
Winter	0.33	0.45

The results of scenario 1 are summarized in table 1 and table 2. The results are average values of three divergent points in the study area. From these tables, it can be concluded that the measures taken in scenario 1 have a small impact on the measured values in the model. It stands out that the discharge and flow velocity increases during the summer and spring, at first sight, this leads to increased drought problems in the area. However, due to the soil structure improvement, the base flow increased by 0.5% for the summer and 4.5% for the spring. This increase leads to an expected increase in discharge. Although, when these values are taken into the account, it can be determined that in general more water is retained in the area during the summer and spring. This small increase in discharge can also be derived from the larger water depth.

The freeboard values of scenario 1 are similar to the freeboard values of the current situation. This is presumably because while the riverbeds are heightened, they are also widened. Due to the widening, the water levels remain at a similar level. This means that the flood safety does not get decreased and remains sufficient because the flood safety of the current situation is also sufficient. The flow velocity values remain relatively the same as in the current situation, though due to the natural nature of the measures taken in this scenario, this scenario will be beneficial for the local ecology. Mainly since this scenario requires little to no weirs in the study area, current weirs can be changed into natural dam spillways that are currently used in fish passes in the area. In Figure 13, an example of a natural dam spillway can be seen. The local ecology gets the chance to flourish since this scenario decreases large fluctuations in discharge and water levels during the summer and spring, this leads to a larger diversity of species (Semmekrot et al., 1997).

Figure 13: Natural dam spillway, currently used in fish passes in the area. Source: own elaboration

3.3 Scenario 2 - Retention measures

3.3.1 In depth analysis retention measures

Spillway system

A spillway system in the area can be one of the most efficient ways to cope with the current drought problems. The trenches can be used to discharge excess water to a savings basin. The excess water is discharged via a secondary channel into a savings basin. The primary channels remain the same, however, the trenches are be designed in such a way that they can discharge at least a specified specific discharge. The trenches do not contain any weirs, because the purpose is to discharge the water into the savings basin, and thus free travel for animals within the secondary channel is created. This natural solution for the area encourages meandering and vegetation in the parallel stream (de Haas, 1991). The savings basin can be used for multiple purposes: irrigation, drinking water, industrial water supply, and water to supplement the groundwater (Waterwinningbedrijf Brabantse Biesbosch [WBB], 2021). In the study area, the savings basin will mainly be used to retain water and supplement the groundwater. On the other hand, the measure requires a large amount of space, compared to the aforementioned interventions it requires the most amount of space. The secondary channel can not be directly located next to discharging streams, the flow velocity is lower in the secondary channels and otherwise, the secondary channel gets drained by the discharging channel (Phernambucq et al., 2019). Thus, with the implementation of the secondary channels, the discharging streams have to be taken into account and distance has to be kept between the streams. Surface run-off is needed to fill up the secondary channel and the savings basin. Figure 31 in Appendix C, shows a parallel stream as clarification for this intervention.

As already mentioned, the secondary channels can not be located next to larger discharging streams. Surface run-off is also needed to fill up the secondary channel. The savings basin should be located at a low elevation point in the area. The lowest elevation points are near the Groenlose Slinge. In essence, the secondary channels can be located through the whole area as long as surface run-off is present at those locations. Surface run-off depends on the rate of rainfall and the rate of infiltration, the higher the rate of rainfall and the lower the rate of infiltration, the more surface runoff is present. Next to this, the land use and soil type also play a role in the infiltration rate. Surface run-off mainly occurs when the soil is saturated or in an area with a steep slope, thus the secondary channels is the most effective on the plateaus and in the transition between the plateaus and valley.

Percolation areas

Percolation areas are the second retention area measures that is implemented into scenario 2. This measure can be combined with multiple other measures, such as raising the riverbeds. A pro of this measure is that the water levels can be managed by either weirs or a specific field height. Percolation areas thus have a low flood risk (van Leengoed, 2002). Next to this, it is an ecology-friendly solution. Extra weirs are not necessary and current weirs can be removed if this measure is combined with another measure such as raising the riverbeds. However, this measure requires grasslands next to discharging streams that can function as percolation areas. It can be necessary to lower certain grasslands to make these fields suitable as percolation areas. Next to that, the grass fields should be allowed to be inundated, this has to be arranged with the local farmers.

To supplement the groundwater the best and to retain as much water in the area as possible, the percolation areas should be located in areas with a thick aquifer. The thick aquifer can be found in between the plateaus. The percolation areas can also be implemented in areas with a shallow aquifer to ensure flood risk in the area.

3.3.2 Designed scenario 2

The second scenario that is designed and that has been implemented into a SOBEK model is the combination of two retention area measures. The first retention area measure is a spillway system. As aforementioned, this measure is only effective if the secondary channels are located next to a small discharging stream and surface run-off is needed. The savings basins in this measure are located in the valley due to the thick aquifer. The second measure of this scenario is the percolation areas. These percolation areas are also mainly located in the valley due to the thick aquifer.

These measures were difficult to implement into the SOBEK model. The secondary channels of the spillway system were mimicked by adding reach segments to the model. These reach segments follow the low discharging side watercourses. Multiple inlets points have been implemented into the model by adding weir structures and setting weir heights according to the needed water levels in the primary channels. The savings basin has been created by adjusting the cross-section to a wide bin, the savings basin is shallow with an in ratio large width.

The percolation areas have been created similar to the savings basin. Grasslands are used to implement the percolation areas. The percolation areas have been mimicked by adding reach segments at the designated grassland locations or by adjusting the current reach segments. These reach segments have a similar cross-section as the savings basin in ratio, however, the width and length of the percolation area depend on the grasslands. The percolation areas can be seen as a buffer zone that comes into play during peak discharges.

3.3.3 Results scenario 2

Table 3: Study area average change in variables in scenario 2 compared to the reference scenario

Scenario 2	*Water level*	*Water depth*	*Discharge*	*Flow velocity*	*Freeboard*
Summer	0.00%	-0.19%	-3.30%	-12.67%	0.14%
Spring	-0.01%	-0.60%	-9.74%	-19.08%	0.72%
Winter	-0.02%	-0.63%	-5.23%	-14.72%	0.82%

Table 4: Freeboard values scenario 2

Scenario 2	*Minimal freeboard (m)*	*Average freeboard (m)*
Summer	0.36	0.48
Spring	0.38	0.49
Winter	0.35	0.45

As similar to the results of scenario 1, the results are average values of three divergent points in the study area. Compared to the results of scenario 1, the results of scenario 2 are more telling. From table 3 and table 4, it can be concluded that during the general discharge is reduced and that the flow velocity in the streams is also reduced. Normally, when the discharge decreases during the summer and spring, the discharge increases during the winter. Due to the construction of saving basins, the discharge decreases also during the winter because a portion of the discharge ends up in the savings basins. The general flow velocity in the streams also gets significantly reduced, this has a positive effect on the local ecology. A lower flow velocity leads to a larger habitat availability for species in the area (Semmekrot et al., 1997).
The changes in water level and water depth are minimal, this leads also to a small difference in freeboard. The freeboard values of scenario 2 are similar to the freeboard levels of the current situation. The percolation area measure increases the local flood safety.

The combination of all savings basins can store up to 60 millimeters for agricultural lands over the year. This comes from the fact that that three irrigation events of each 20 millimeters can be stored in the savings basin, (Phernambucq et al., 2019). For the whole area, this means that 48 millimeters of water used for irrigation purposes is not consulted from the groundwater during precipitation deficits. The average of 48 millimeters groundwater level increase in the areas comes from the fact that the area consists out of circa 80% agricultural lands.

3.4 Scenario 3 - Technical measures

3.4.1 In depth analysis technical measures

Heightening weirs
Heightening of the current weirs in the area is a similar measure as raising the riverbeds. Both measures decrease the flow velocity of the streams and slow down the discharge. The main difference between heightening weirs and raising riverbeds is that heightening the weirs has only a local effect on the surface water system and raising the riverbeds of the side watercourses affects the whole area. The main advantage of this measure is that it is cost-effective, the streams do not require large redesigns, little to no extra space is needed and the measure is easy to implement because the current weirs can be used. However, this intervention hampers the local wildlife, especially animals in the streams themselves. Even with fish passages, the biodiversity decreases in the area due to weirs (J. L. Spier & Bergsma, 2007). The local ecology will not deteriorate compared to the current situation, because in the current situation watercourses in the area are already stowed. Weirs do also not ensure flood safety in the area, due to the heightening of the weirs the water levels are higher and the overall risk of floods increase and thus has to be coped with.

As already explained, heightening weirs only has a local effect on the surface water system. The measure would thus be most effective in areas with a low slope. The lower the slope in the area, the more effective the heightening of the weir is. A lower slope means that water is dammed behind the weir for a longer distance, to create the same effect in areas with a larger slope more weirs are needed to achieve the same effect. In comparison to the raising riverbeds measure, this measure is more suitable for areas with a larger freeboard. With weirs, the water levels can be controlled better than with the raising riverbeds measure. The larger freeboard levels and lower slopes are located in between the plateaus in the area. The weirs would also be most effective here because the aquifer is the thickest in this area.

Implementing extra weirs in the area

The implementation of extra weirs in the area measure is similar to heightening the weirs measure. However, in an area with a larger slope, it is easier to manage the discharge, water levels, and flow velocity with the implementation of extra weirs (Waterschap Limburg, 2020). In comparison to the heightening weirs measure, this measure can deal better with low freeboard levels, because with more weirs it is easier to manage water levels in the area. This is a well-known measure for WRIJ and it is known for them how to implement it in the area. The measure has already proved to work because over the years this measure was the conventional solution to manage surface water (WRIJ, 2013). Like the heightening of the current weirs measure, this measure requires little extra space. However, due to the placement of extra weirs, this measure hampers the local wildlife drastically, especially animals in the streams themselves. Streams tend to fall dry at more locations, which leads to barely any fish in the streams. However, at locations where water is retained longer behind a weir, more biotope and macrofauna species occur. This measure is operative and maintenance intensive, small weirs have to be manually controlled in the field and the weirs have to be checked regularly to check if they still fulfill their purpose and dam the required discharge. In comparison to the heightening of the current weirs, this measure is less cost-effective.

The implementation of extra weirs can be implemented in the whole area. The extra weirs can be used to decrease the flow velocity in sloped areas, but the weirs function the best in lower sloped areas. In principle, this measure can be used in the whole study area, but the measure is most effective in retaining water in areas with a thick aquifer.

3.4.2 Designed scenario 3

The last scenario is a combination of two measures that are currently used to maintain water levels in the area. This scenario is not a natural and robust scenario like scenarios 1 and 2, however, this scenario is designed to show what happens when current drought measures are intensified. The first measure that is part of this scenario is the heightening of the current weirs. Heightening of the current weirs is most effective in areas with a low slope. This measure is thus implemented in the valley in between the plateaus. The second measure is the implementation of extra weirs in the area. This measure can be used in the whole study area and is thus also implemented through the whole area within the model. However, this measure appears more in the transition between the plateau and the valley and the plateaus itself, because the heightening of the weirs measure is not effective in this area.

The heightening of the current weirs was easily implemented into SOBEK. Current weirs located in an area with a low slope are heightened. The implementation of extra weirs in the SOBEK model is done by placing extra weir structures at the desired location. The number of extra weirs were placed according to the hydraulic gradient of the side-watercourse. Thus, the higher the hydraulic gradient of a side-watercourse the more extra weirs have been implemented.

3.4.3 Results scenario 3

Table 5: Study area average change in variables in scenario 3 compared to the reference scenario

Scenario 3	*Water level*	*Water depth*	*Discharge*	*Flow velocity*	*Freeboard*
Summer	0.82%	34.91%	-3.76%	-31.71%	-40.94%
Spring	0.83%	35.73%	-4.34%	-32.49%	-40.44%
Winter	0.80%	32.91%	-2.56%	-30.27%	-42.40%

Table 6: Freeboard values scenario 3

Scenario 3	*Minimal freeboard (m)*	*Average freeboard (m)*
Summer	0.07	0.28
Spring	0.09	0.29
Winter	0.06	0.26

Similar to scenarios 1 and 2, the results are average values of three divergent points in the study area. The results of scenario 3 are rather extreme compared to the results of scenarios 1 and 2. As can be seen in table 5 and table 6, the water depth has increased significantly, and thus also that the freeboard has significantly decreased. The decrease in flow velocity also stands out. However, these changes in parameter values were expected. Water is dammed behind the heightened weirs and extra implemented weirs. As a result, the water levels and water depths increase. Next to this, the flow velocity decreases drastically because the heightened weirs and extra weirs obviate the height differences in the area.

As explained before, a lower flow velocity improves the local ecology. The ecology behind the weirs will flourish, however, downstream from the weir the streams tend to run dry faster which leads to a decrease in biodiversity downstream of weirs. The overall discharge decreases and thus more water is retained in the area during the summer and spring.

The increased freeboard levels by scenario 3 can become problematic. The average freeboard levels decreased by approximately 40%. During larger discharges, the freeboard level tends to be at the surface level. This scenario makes the area prone to inundations and thus the flood safety for the agricultural fields decreases. However, the freeboard results of the model are only an indication of the change in freeboard. The freeboard results of the model are not precise enough to draw firm conclusions.

3.4.4 Overview results

In Figure 14, the spring results are visualized of measurement point 1 to make the results more clear. April 2020 was a dry month thus an overview of this month is given to give insight into how each scenarios reacts on a dry month.

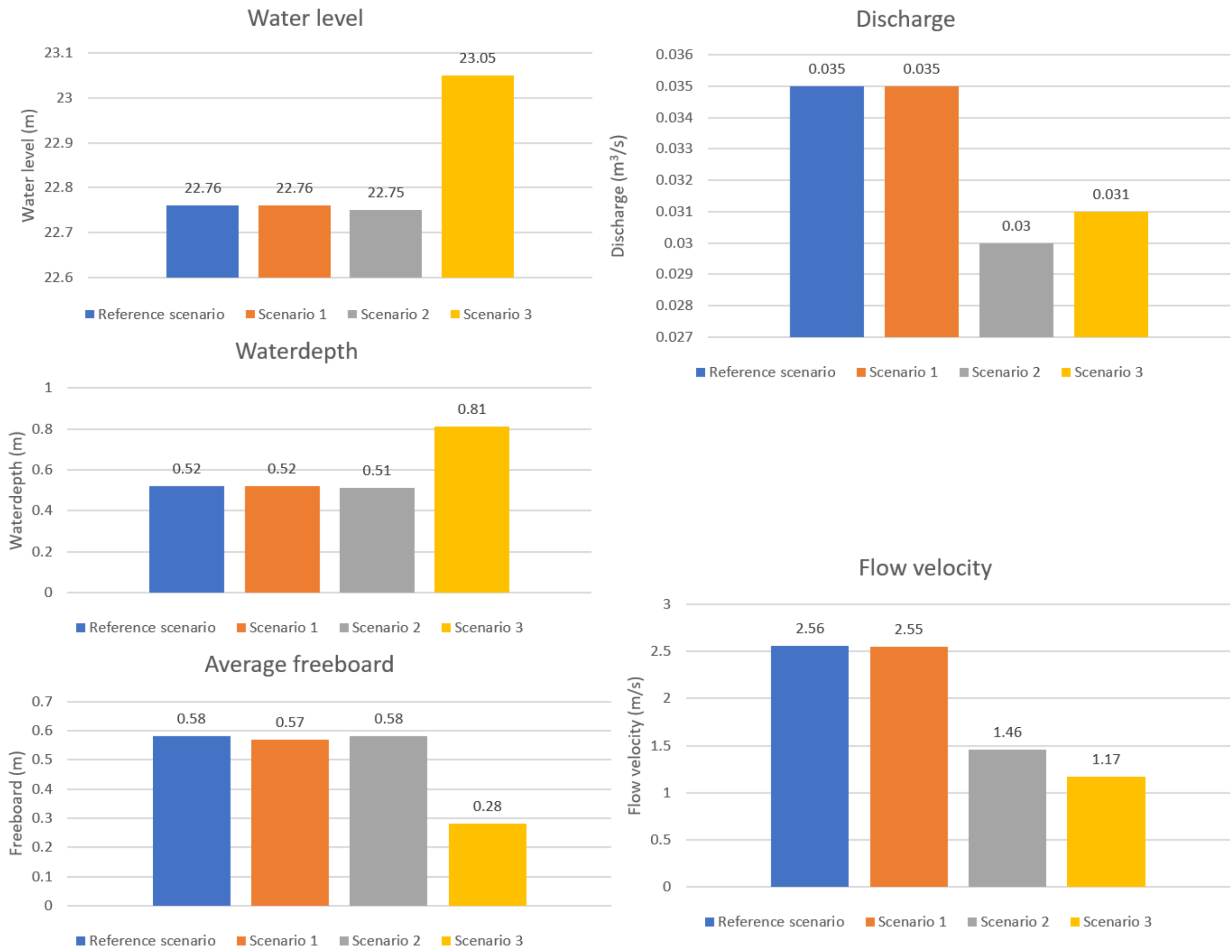

Figure 14: Spring results of measurement point 1 visualized in graphs

3.5 Scenario evaluation

After the simulation of the scenarios and discussion of the results, the scenarios were evaluated. The scenarios were evaluated based on four criteria. A scenario receives a score on criteria based on multiple variable values. Next to this, each criterion was given a different weight based on its importance. To start the multi-criteria analysis (MCA), each scenario received scores for each criterion as can be seen in table 7. Afterwards, each criteria was weighted based on its importance, as can be seen in table 8, this was done with the help of an expert during the two expert meetings. Last, the MCA was performed and the results of the MCA can be found in table 9. The full elaboration on the MCA can be found in Appendix H.

Table 7: Score matrix

Score	Scenario 1	Scenario 2	Scenario 3
Flood safety	4	5	1
Ecology	4	3	2
Water retention	3	5	4
Required space	3	1	5

Table 8: Criteria weight matrix

	Flood safety	**Ecology**	**Water retention**	**Required space**
Flood safety	1	1	0.5	2
Ecology	1	1	0.5	2
Water retention	2	2	1	3.00
Required space	0.5	0.5	0.33	1
Sum	4.5	4.5	2.333333333	8

Table 9: Weighted score matrix

Weighted score	**Scenario 1**	**Scenario 2**	**Scenario 3**
Flood safety	0.90873	1.1359127	0.22718254
Ecology	0.90873	0.6815476	0.45436508
Water retention	1.269345	2.1155754	1.69246032
Required space	0.36756	0.1225198	0.61259921
Sum	3.454365	4.0555556	2.98660714

Scenario 2, the retention measures, comes out the best in the evaluation. The retention measure scenario can retain a significant amount of water in the area while maintaining flood safety in the area. This can derived from the decreased discharge during the summer and the spring, during the summer more than 3% is retained more than the current situation and during the spring almost 10%.. The flood safety for agricultural fields can mainly be ensured by the percolation areas. The percolation areas make use of designated grasslands to inundate during large precipitation events, this causes other non-designated agricultural fields to remain free from inundation. Another main advantage of this scenario is that during precipitation deficits the water in the savings basins can be consulted to irrigate lands up to 60 mm with water during the dry periods.

Scenario 1, the natural measures, comes out second best in the evaluation. As can be concluded from the results is that the scenario does not have a significant effect on the tested parameter values. However, the scenario improves the ecology in the area the best out of all the scenarios. Compared to the other scenarios it retains the least amount of water in the area, however, it stills retains more water during dry periods than the current situation. Next to this, current weirs are unnecessary if this scenario is expanded and further worked out. This leads to even more advantages, scenario 1 has a lot of expansion possibilities that may eventually make scenario 1 better than scenario 2. The riverbeds can be heightened even more and this intervention can be combined with different scenarios. Scenario 3, the technical measures, comes out the worst in the evaluation. This is mainly because the scenario hampers the local ecology and makes the area more prone to floods. The low freeboard values make the area prone to floods mainly during the winter. Although, due to the stagnation of the water behind the weirs, this solution would be perfect for the agriculture because the local agriculture can use this stagnated water to irrigate their lands. However, the aim of this research is to achieve a more natural and robust water system, which this scenario achieves less than the other scenarios resulting from the MCA.

4 Discussion

This section describes the discussion of the research and recommendations on improving the research. The results of the report can be used to tell which scenario is the most effective for the area to retain water and have a larger water availability during dry periods. However, to come to these results choices had to be made. This section will discuss what choices were made and how this influenced the results.

The main choice that was made was that the scenarios were a combination of two interventions. This choice leads to achieving results that tell something about the combination of two measures together, though not about what results of a single measure would be. For example, one of the two measures could have an effect of 90% and the other measure of 10%, but with this scenario design, it can not be derived how effective a specific measure is. Next to this, more measures and thus more scenarios could be identified, designed, modelled and evaluated. However, due to time constraints, this was not possible. A similar choice that was made was dividing the area into a valley part, the transition between valley and plateau part, and a plateau. Measures were implemented at one or multiple of these parts. The research could have been more detailed if there were identified more different locations to implement the scenarios upon. This would have led to a more detailed elaboration for WRIJ where which measure is effective. This could have lead to, for example, scenario 1 being implemented in a larger part of the area and thus also scenario 1 being more effective. Again, due to time constraints, this was not carried out.

The model makes also use of multiple assumptions and the same applies to the input of the model. In this SOBEK model, the infiltration function was not used, but the infiltration was applied in the precipitation input of the model. This choice is applied to most of the SOBEK models of WRIJ. The model makes use of precipitation events as input, however, these precipitation inputs are derived from specific precipitation events that occur at certain times a year. The choice was made to translate the precipitation events of multiple months to input for the SOBEK model. Although, these precipitation events are no specific precipitation events and thus the input for the model had to be calibrated. The calibration was due to time constraints only performed for a summer month, however, the same input formula was used for spring and also a winter month. If the formula was also calibrated for a spring month and also a winter month, the results of the spring and winter months would be more reliable.

The first scenario, the natural measures, the choice was made to the only test with one type cross-section. If more time was available, multiple cross-sectional shapes could be tested and better results regarding water retention could be achieved with this scenario. The current models were simulated with trapezium-shaped cross-sections, however, watercourses could also have been shaped into cross-sections with summer and winter-bed. This would have led to even more friction within the watercourse and reducing the flow velocity even more and thus retaining more water in the area.

Multiple choices were also made for the result collection, it was chosen to collect data from three different points in the area. These measurement locations were spread over the whole area, however, to achieve more reliable results more measurement locations could have been chosen. Next to this, only one summer month, one spring month, and one winter month were modelled. To achieve more reliable results, more months of each season of different years could have been modelled and averages could have been taken. Both choices were made because of time constraints.

For the visualization of the results choices were also made. The choice was made to visualize all the results from the model into percentage differences compared to the current situation in the main report. This was done to keep the results clear and concise. This was also done because the measurement locations all had a different gradation of parameter values, one point had an average discharge of 2 m^3/s while another point had an average discharge of 0.3 m^3/s. The choice of displaying the results into percentages was a problem for the water levels. The water levels were denoted in m+NAP, in the study area the average water level height is around 25 meters. The change of a water level of 50 centimetres is a large difference, although if this is expressed in percentages it is around 2 per cent. Displaying the percentage change of water depth solved half of this problem. To elaborate on the results and to make them more clear, Appendix G was created to show absolute values per indicator per measurement location at the three simulated months.

4.1 Recommendations on improving the research

To improve the research, the measures of the scenarios could have been better distributed over the area if more location-types were identified. Currently, only three locations were identified: valley, transition valley and plateau and plateau. Scenarios could have been implemented more precise. The research could also have been improved if infiltration rates were used instead of implementing this into the input for the model, more scenarios could also have been tested if Dhydro suite was used instead of SOBEK Rural 2.13, this is since Dhydro suite works faster than SOBEK Rural 2.13.

The research can also be improved by identifying, designing, modelling and evaluating more scenarios and finding more suitable presumable effective measures for the area. Measures can also be tested solely to identify the effects of a single measure. Next to this, more combinations of different measures can be assessed and results of the combination of measures can be gathered.

5 Conclusion

This section describes the conclusion of the research and recommendations on follow-up research. This research was performed to answer the question: "What is the preferred scenario of the designed scenarios to make the Groenlose Slinge a more natural and robust system?". This question was answered by designing, modelling and evaluating three different scenarios. These scenarios were compared to the current situation.

The results of the research started with the system analysis. What became apparent with the system analysis is at which locations measures would be most effective. The area has a thick aquifer in the valley that can store a large amount of water and thus water retention would be most effective in this location. Next to this, the current freeboard was identified and locations were found to heighten the current riverbeds without the chance to inundate adjacent agricultural fields.

Three scenarios were modelled and simulated afterwards for a month during the summer, spring and winter. Scenario 1, natural measures, contained two interventions, namely raising and widening riverbeds and improving the soil structure in the study area. Scenario 2, retention area measures, contained also two interventions, namely implementing savings basins in the area and also implementing percolation areas in the study area. Scenario 3, technical measures, contained also two interventions, namely heightening the current weirs, but also implementing extra weirs in the study area.

Scenario 2, retention area measures, is evaluated as the best scenario for the area to achieve a more natural and robust water system. Scenario 2 retains a significant amount of water in the area during the year while ensuring flood safety. The flood safety maintains ensured because the freeboard values remain similar to the current situation and the current flood safety is classified as sufficient. The discharge during the summer is decreased by 3.3% and during the spring with 9.75%, which means that in these seasons these percentages of water are retained in the area instead of discharged. Water from the savings basins can be used to irrigate up to 60 millimetres of water each year on agricultural lands in the area. This leads to the preservation of groundwater levels of 48 millimetres throughout the whole area. Next to this, the average flow velocity is reduced by 15% throughout the year, the lower flow velocity has a positive impact on the number of species in the study area, this leads to an increase of biodiversity in the area.

Scenario 1, natural measures, was the second-best scenario following from the MCA. Out of the results followed little improvements compared to the current situation. However, the main advantage of scenario 1 is that the local ecology gets a chance to flourish while improving the current water system slightly. The freeboard levels of scenario 1 are similar to the freeboard levels of the current situation and can thus be classified as sufficient. Although scenario 1 does not turn out the best, the scenario can still be seen as a successful scenario and a scenario with a lot of potentials. Scenario 1 has a lot of improvement opportunities thus the potential to become a better scenario than scenario 2. Scenario 1 can be combined with other scenarios and the possibility to heighten the riverbeds even more.

According to the evaluation, scenario 3, technical measures, was the least favourable scenario. This scenario was used to show what happened when current drought mitigation measures are intensified. As can be concluded from the results, the flood safety in the area decreases drastically and can be questioned during larger precipitation events. As indication, the minimal freeboard in the measurement locations dropped from 0.33 meters to 0.06 meters which is alarming. The discharge in the summer dropped by 3.76% which can be identified as an increase in water retention in the area. However, the stagnation of the water behind weirs makes this scenario perfect for the local agriculture. Overall, it can be concluded that intensifying the current drought measures is not favourable to achieve a natural and robust water system.

5.1 Recommendations on follow-up research

Follow-up research can be performed to do an in-depth study of the current designed, modelled and evaluated scenarios, in specific scenario 1. Scenario 1, natural measures, has potential improvement possibilities. For scenario 1, different cross-sectional shapes can be tested with different discharge profiles. For example, instead of using a discharge profile for a precipitation event of once in 10 years, design the watercourses into a profile suitable for a precipitation event of once in 5 years. Designing streams into coping with different return periods will drastically change the current water system. This will decrease drought in the area, but the consequences regarding flood safety also have to be looked at. This follow-up research should be performed together with input from local farmers to take into account their opinion on the current water management and also their vision on the future water management.

The second recommendation on follow-up research is to research the effects on single side-watercourses, in this research the focus was on assessing the effects on the whole area. As can be seen from the elaboration on "de afwatering langs Hulshof", the outcome for this specific watercourse is different from the outcome of the research. This leads to the recommendation of researching watercourses solely and implement measures that are effective for that specific watercourse.

The last recommendation is to the extent the research to the Groenlose Slinge and implement measures on the Groenlose Slinge itself. With this research drought problems in the side watercourses are addressed and possible solutions are researched. From here it is the most logical step to research possible measures for the watercourse where the side watercourses discharge into.

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Appendices

A Historical Maps

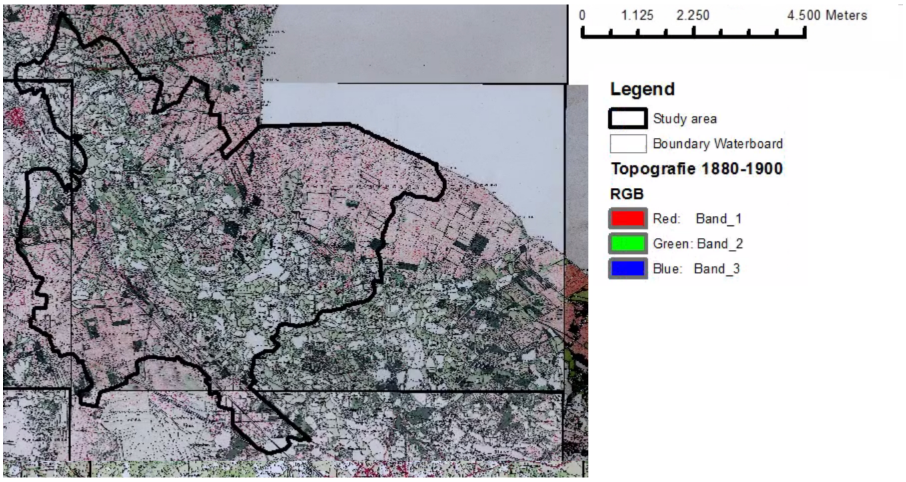

Figure 15: Topography map of the study area of 1880-1890. Source: WRIJ (2020)

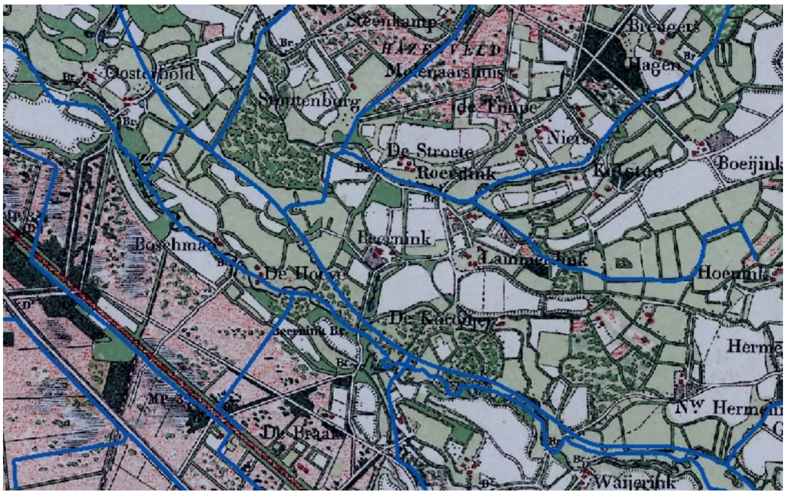

Figure 16: Zoomed-in part of topography map of the study area of 1880-1890 with current watercourses included. Source: WRIJ (2020)

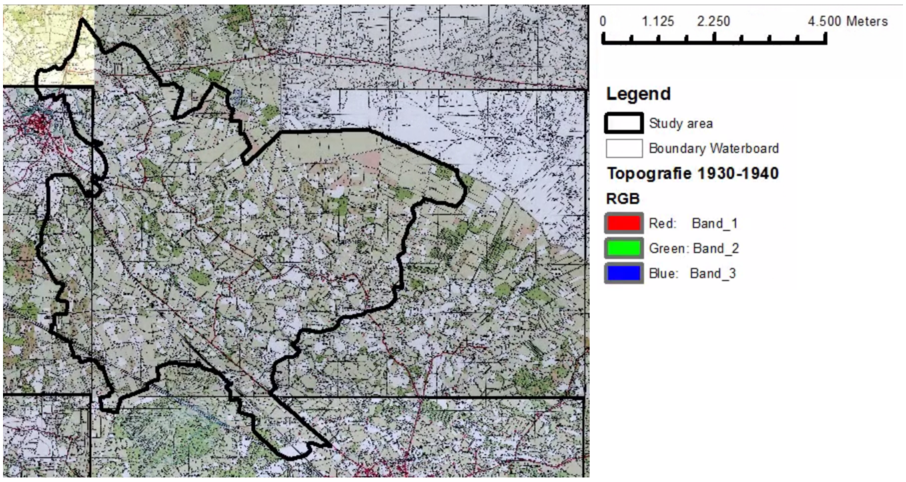

Figure 17: Topography map of the study area of 1930-1940. Source: WRIJ (2020)

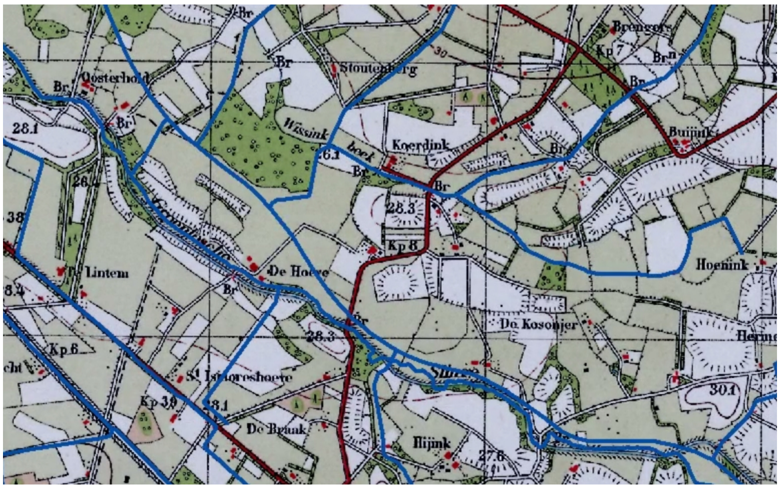

Figure 18: Zoomed-in part of topography map of the study area of 1930-1940 with current watercourses included. Source: WRIJ (2020)

B System analysis maps

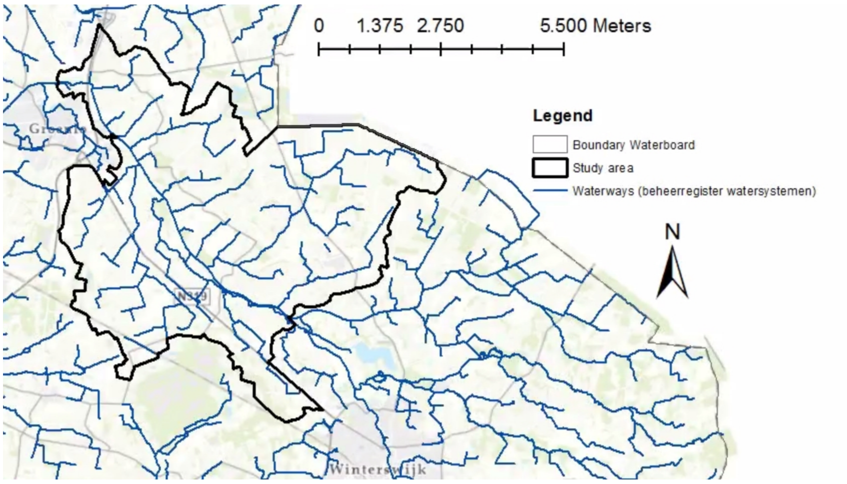

Figure 19: Watersystem, watercourses outside of study area included. Source: WRIJ (2020)

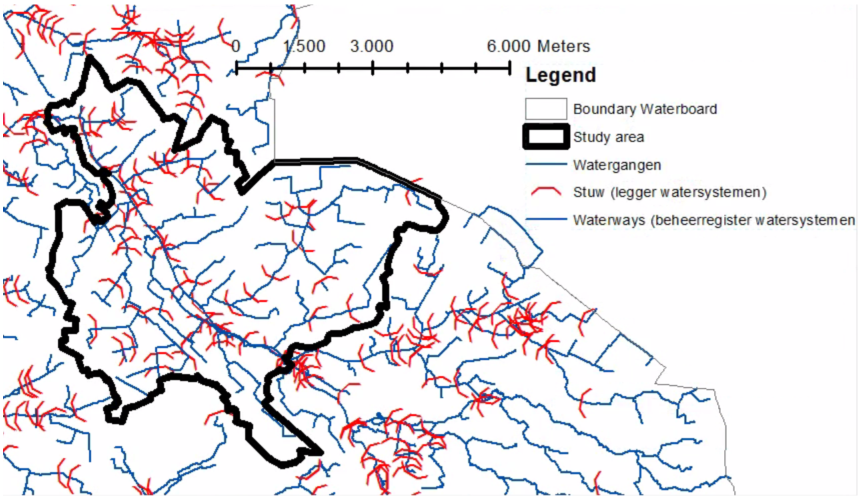

Figure 20: Weirs in the study area. Source: WRIJ (2020)

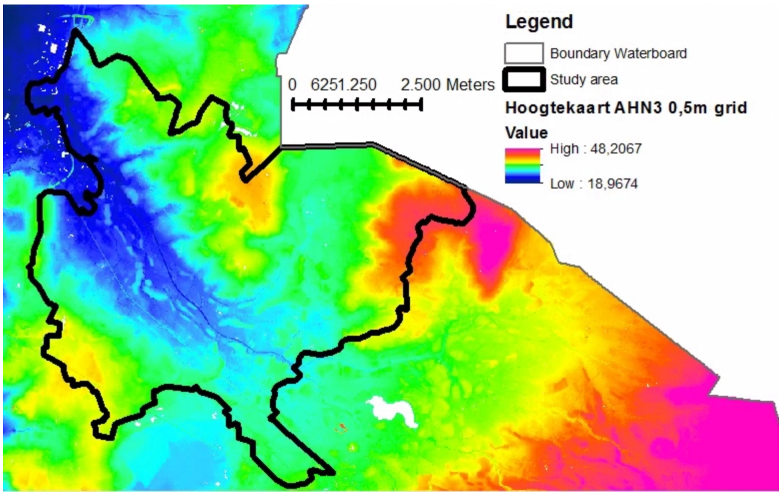

Figure 21: Height map of the study area. Source: AHN (2014)

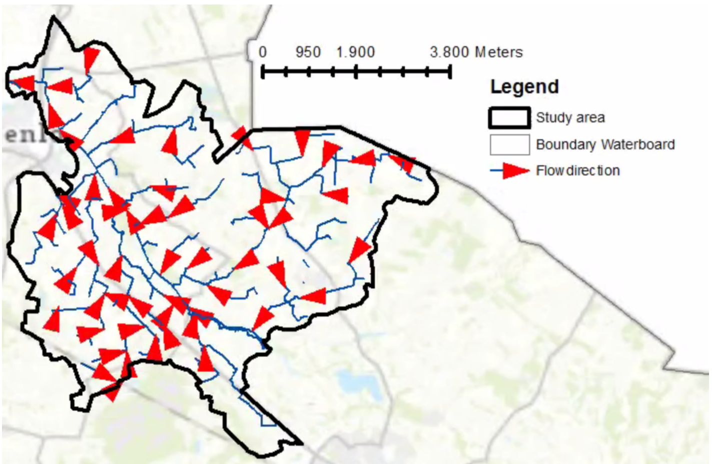

Figure 22: Flow directions in watercourses. Source: WRIJ (2020)

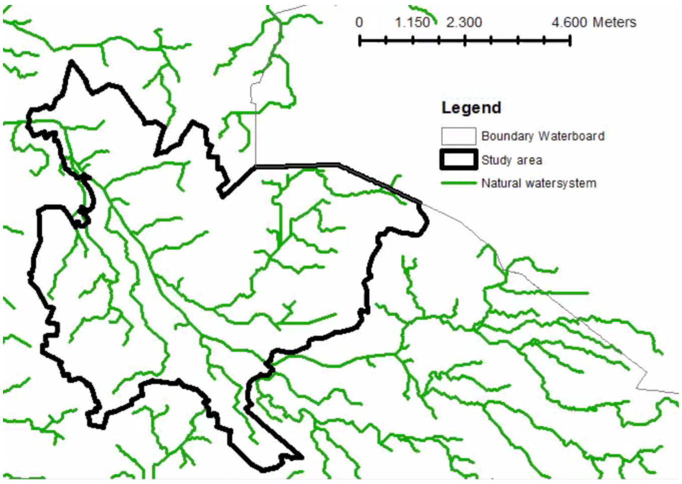

Figure 23: Natural water system based on height map. Source: WRIJ (2020)

The natural water system is determined via the elevation map, from this it can be derived how the watercourses would run if humans did not adjust the water system.

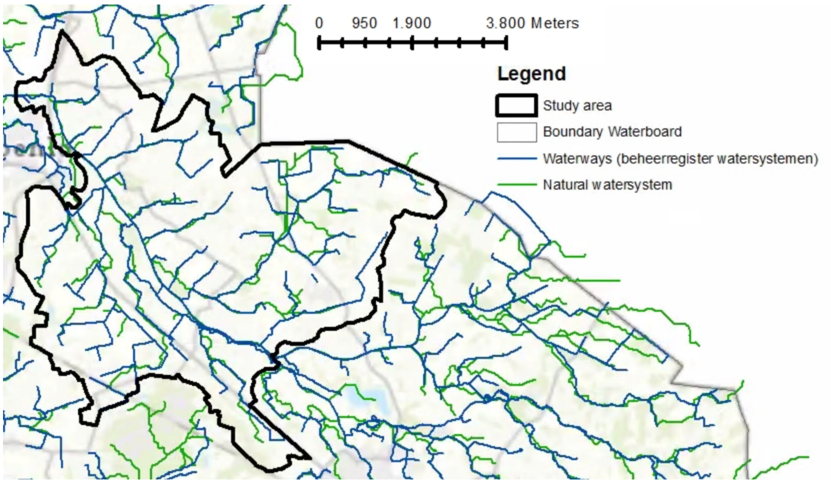

Figure 24: Natural water system and actual water system. Source: WRIJ (2020)

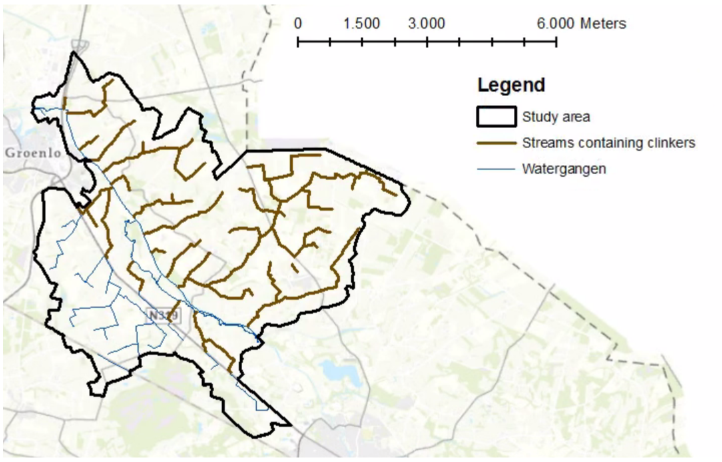

Figure 25: Streams in the area containing clinkers. Source: adapted from WRIJ (2020)

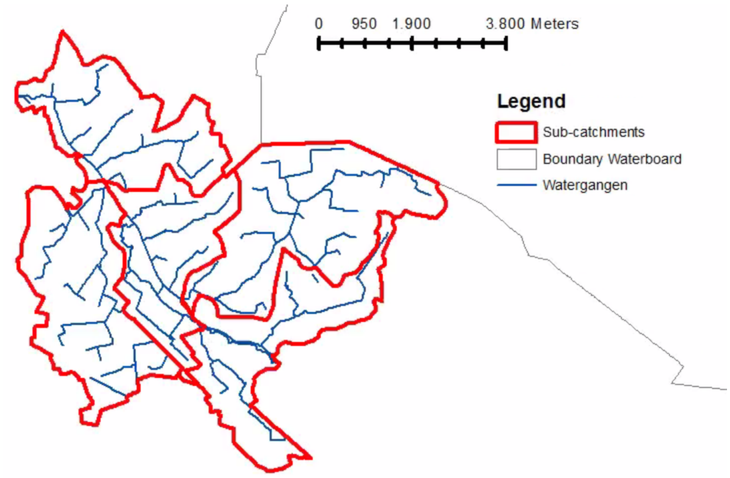

Figure 26: Catchments in the study area. Source: WRIJ (2020)

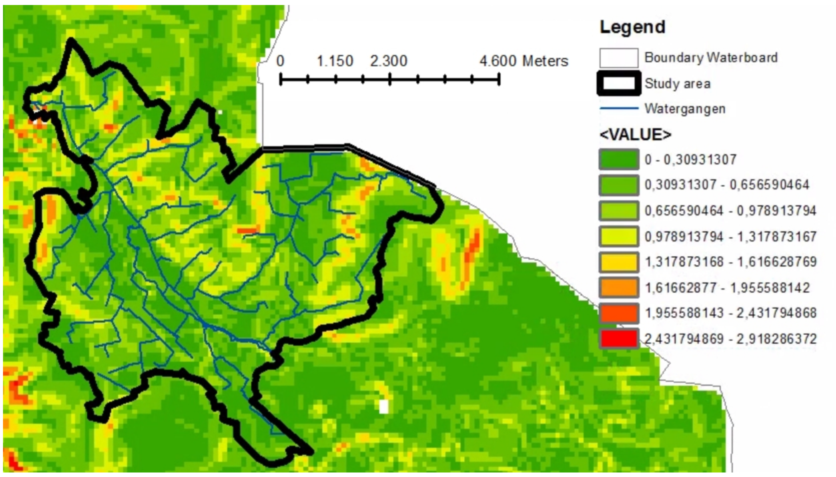

Figure 27: Slope map of the study area in percentages (Created with spatial analyst tool ArcMap, based on height map. Source: AHN (2014))

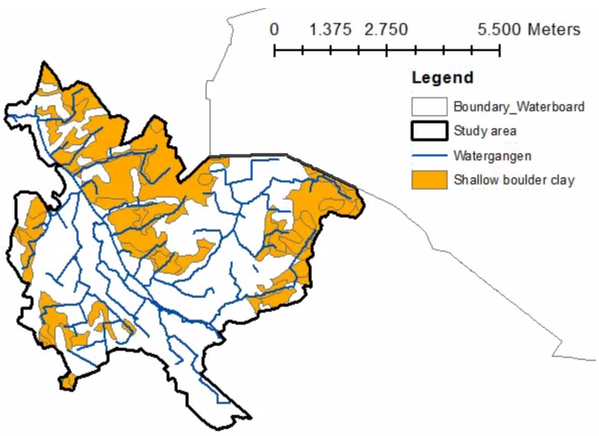

Figure 28: Shallow boulder clay in the area. Source: WRIJ (2020)

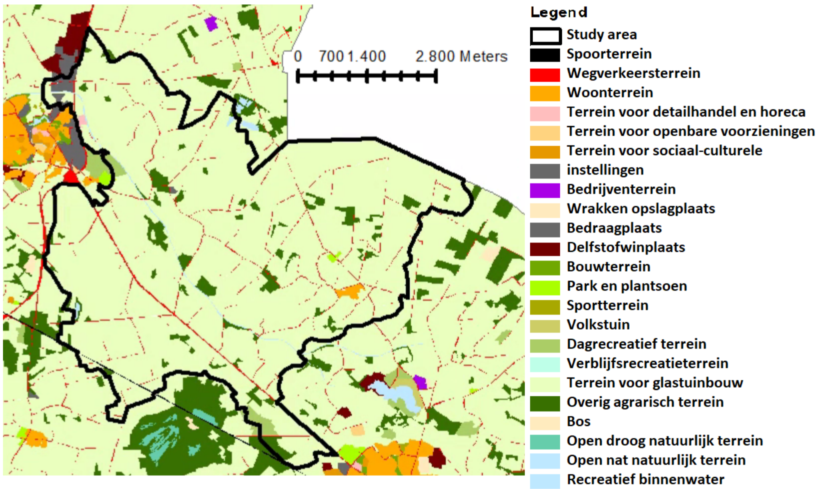

Figure 29: Land-use in the study area. Source: CBS (2003)

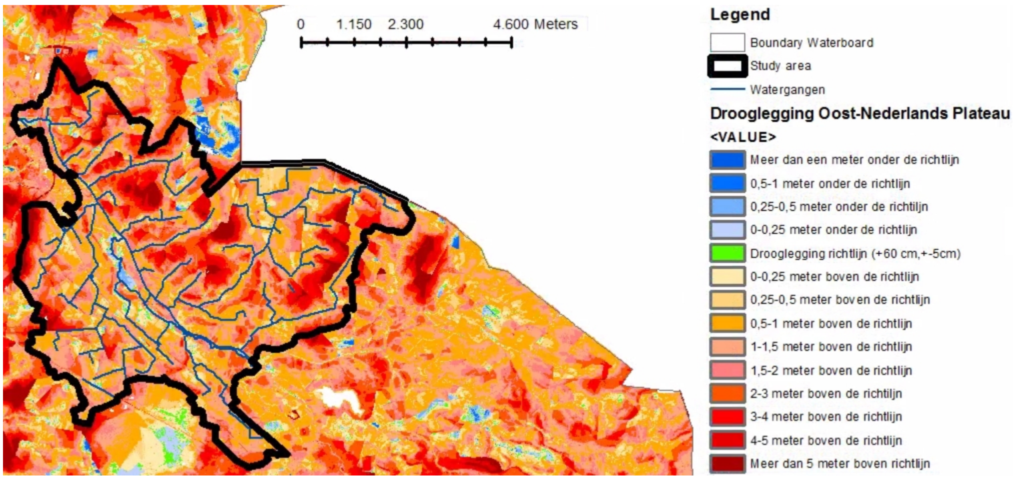

Figure 30: Optimal freeboard. Source: Engelbertink (2021)

C Intervention figures

Figure 31: Spillway system visualized with a parallel stream. Source: Waterschap Vechtstromen (2016)

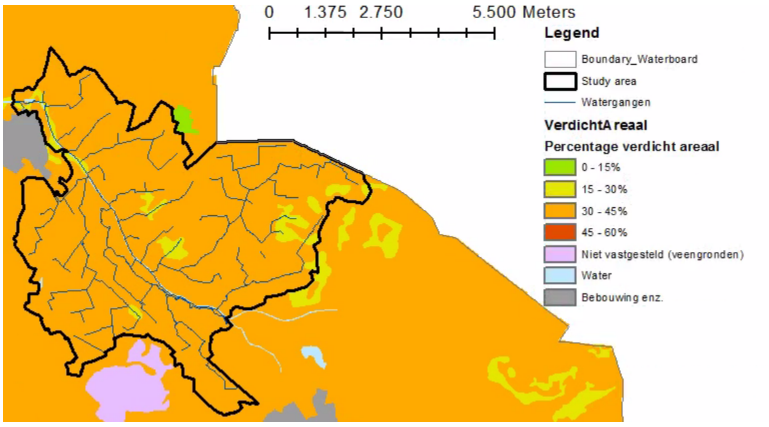

Figure 32: Compaction of the subsoil in study area. Source: RLI (2018)

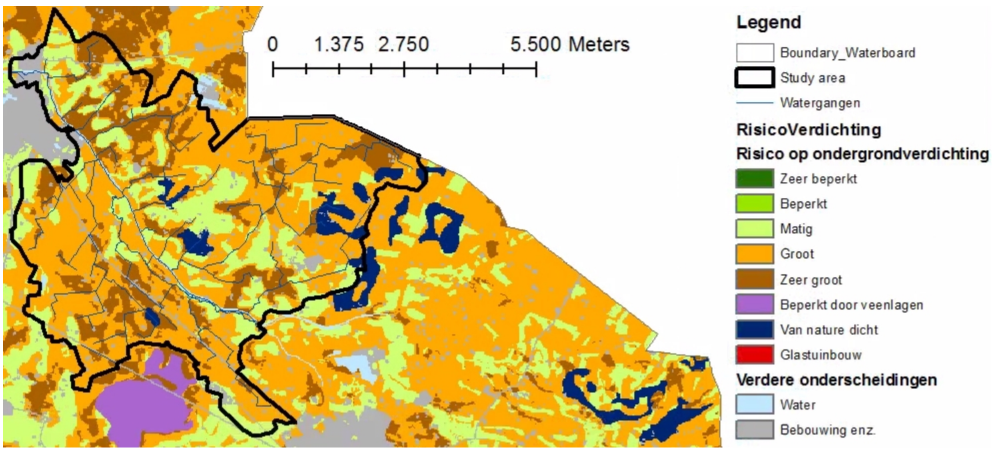

Figure 33: Risk of compaction of the subsoil. Source: Alterra (2012)

D Set-up reference scenario

Gathered information for reference scenario

The study area contains only one measuring point to calibrate the reference scenario with. The measuring point was also stopped measuring at the end of 2017. Thus the reference scenario has to be calibrated with the water levels from 2016-2017 and with precipitation events of 2016-2017. The water levels that will be used for the calibration can be found in Figure 35. The location of the measuring point is indicated on a map in Figure 36. The average precipitation that will be used as an input for the reference scenario can be seen in Figure 37. As can be seen, when comparing the precipitation figure and the water level figure, it can be seen that the precipitation peaks in the summer do not immediately mean an extremely high water level. The thick sand layer in the area can store a large amount of water and during dry times this happens, because it is not saturated during dry times. The highest precipitation peak occurs in the summer but does not translate into the highest water level of the year at the location. The highest water level is measured in the winter during multiple larger precipitation events.

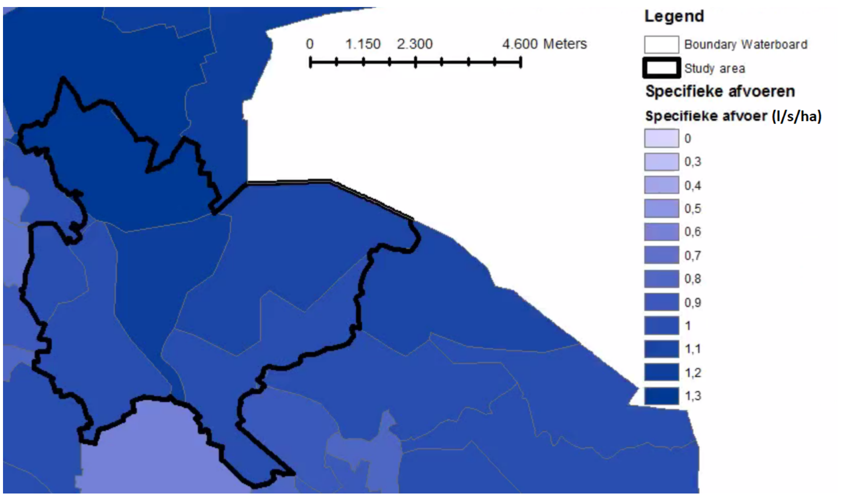

Figure 34: Used discharges per location in the study area. Source: WRIJ (2020)

In Figure 34, the specific discharge can be seen for the study area. The specific discharge is the discharge per area with an exceeding frequency included (Commissie voor hydrologisch onderzoek TNO, 1986). The area has an average of 1 l/s/ha as discharge during the yearly peak discharge.

Reference scenario model check

To match the reference scenario with the real life situation multiple steps were taken. At first the structures in the model were checked with the real life situation that could be found in the database of WRIJ. The most important structure that influences the model and reference scenario are the weirs in the area. In the database of WRIJ there were in total 60 weirs in the study area, the reference scenario of the model also stated that there were 60 weirs in the area. Next to the weirs in the area there are also 4 bridges in the area that are also present in the model. Bridges causes differences in friction regarding the water flowing through streams and thus this is also modelled in SOBEK.

In the area the cross section shape of a trapezium is used for the watercourses. This cross section shape is used to maximize the discharging efficiency of the watercourses. Cross sections modelled in SOBEK were checked with the real life situation. What stood out was that the designed cross sections by WRIJ were almost perfectly modelled in SOBEK, the modelled cross sections in SOBEK only differed in centimeters to the designed situation. However, due to erosion the shape of most cross sections deviated from the designed cross sections. The deviation is small so the cross sections in the reference model will not be adjusted, if more time was available this could have been done to improve the model slightly. A measured cross section of the Groenlose Slinge can be seen in Figure 38, the designed cross section of this part of the Groenlose Slinge can be seen in Figure 39 and the modelled cross section can be seen in Figure 40.

After the structures and the cross sections of the model were checked, the input for the model was calibrated and validated. Multiple simulations were performed to simulate the real life situation the best and with the help of the Nash Sutcliffe model efficiency coefficient and the Relative Volume Error as a measure of precision the models were used to quantify how well the simulation predicted the real life situation. In Appendix E, the elaboration of the calibration and validation of the input of the model can be found. The input of the model was calibrated, because SOBEK makes use specific discharge. These specific discharges can be translated into a precipitation event, however, these precipitation event differ from real life precipitation events and thus this difference has to be approached and calibrated. The input for the model will be calibrated with the month July of 2016, afterwards the input for the model will be validated with the month July of 2015.

Input reference model

Figure 35: Waterlevels of Zandvang Wissinkbeek over a year time. Source: WRIJ (2017)

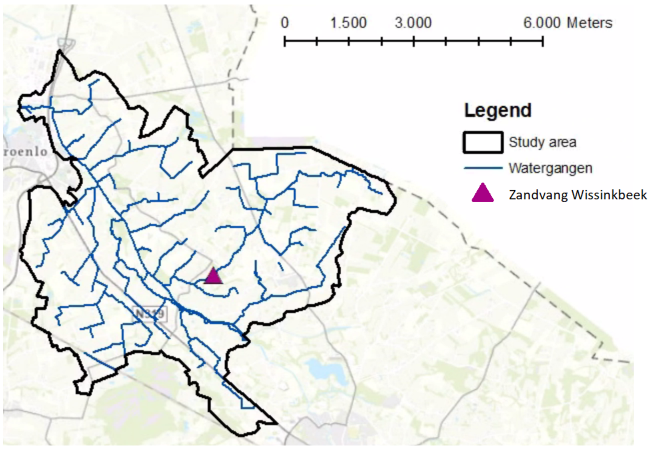

Figure 36: Location of measuring point Zandvang Wissinkbeek. Source: adapted from WRIJ (2020)

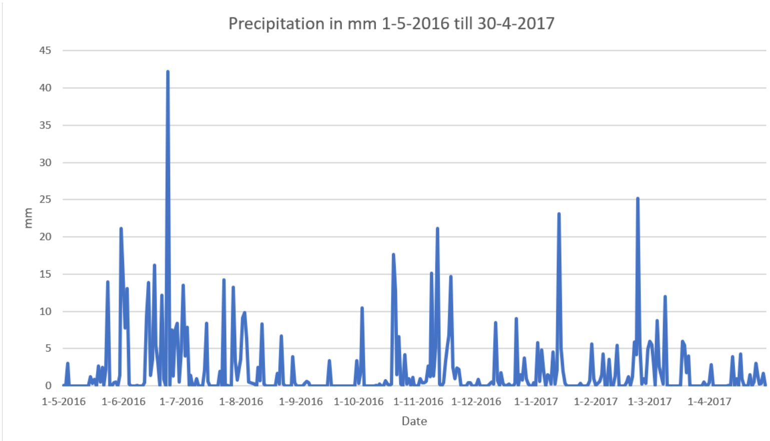

Figure 37: Precipitation Winterswijk 1-5-2016 till 30-4-2017. Source: KNMI (2021a)

As can be seen in Figure 34 in section D, the specific discharge over the area varies. The specific discharge of an area is the combination of the condition of the groundwater, soil type, ground-level slope and vegetation in the watercourse (van den Houten, 2006). A precipitation event gives a different specific discharge if it occurs during the summer on an area with shallow boulder clay and large slopes than on flat sandy soil during the winter. At WRIJ stochastic testing to determine the occurrence of specific discharge in the area.

The model uses an input of mm/day, so the specific discharge has to be translated to mm/day. The following steps explain how l/s/ha is translated into mm/day.

- 1 liter = 0.001 m^3
- 1 hectare = 10000 m^2
- 1 day = 86400 seconds
- 1 m = 10^3 mm

$$l/s/ha = (0.001m^3)/s/(10000m^2) = 10^{-7}m/s \tag{1}$$

$$1l/s/ha = 10^{-7}m/s = (10^3 * 10^{-7})/(1/86400)mm/day = 8.64mm/day \tag{2}$$

The above calculated specific discharge is the specific discharge for (T=1) which means that this specific discharge occurs on average once a year. The specific discharge for once a year is also indicated as Q_{T1}. The area also has a base flow, as a rule of thumb this base flow for the summer is $0.05Q_{T1}$, which is 0.432 mm/day. The base flow, for the winter, is $0.1Q_{T1}$ which is 0.864 mm/day. The base flow in the winter is higher due to higher groundwater levels and due to the occurrence of more precipitation events in the winter season (Deltares, 2012).

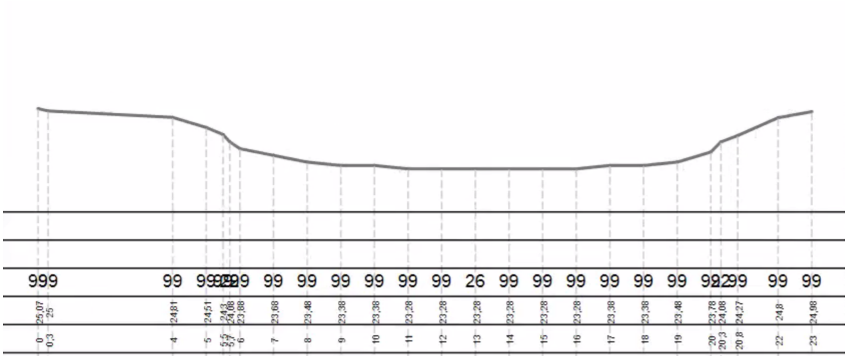

Figure 38: Measured cross section of the Groenlose Slinge. Source: WRIJ (2020)

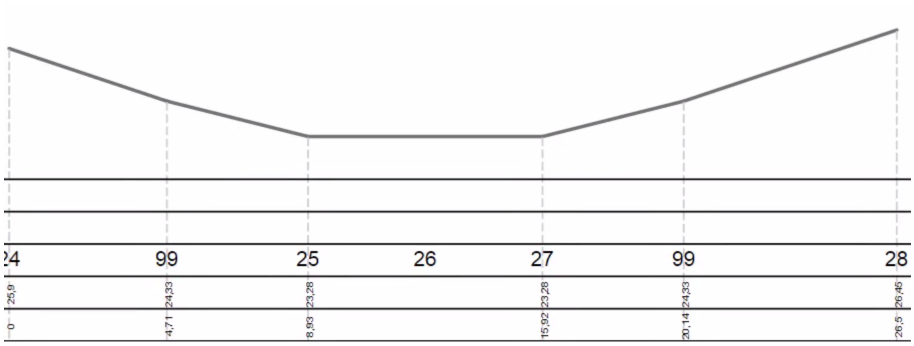

Figure 39: Designed cross section of the Groenlose Slinge. Source: WRIJ (2020)

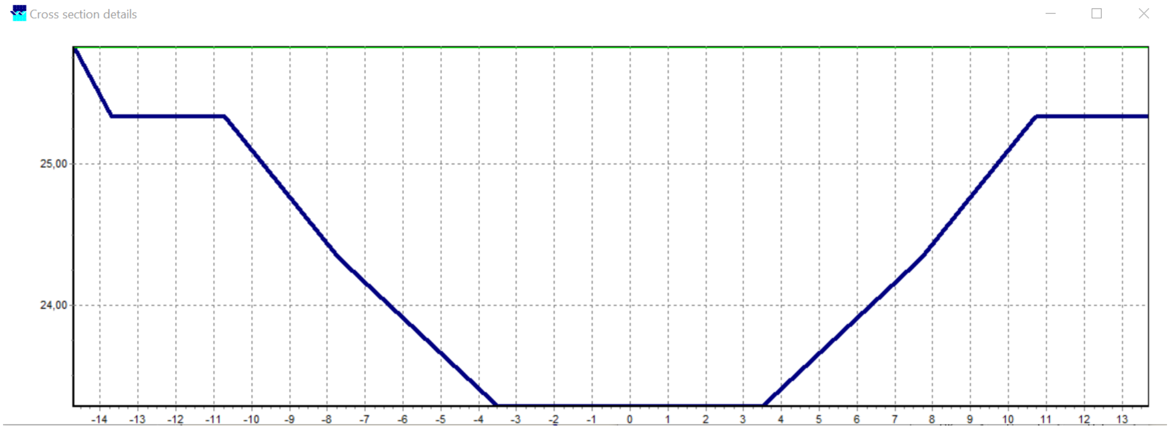

Figure 40: Modelled cross section in SOBEK

E Model calibration and validation

To calibrate and validate the model, multiple steps were taken. First, the happened precipitation events (KNMI, 2021a) of 1 May 2016 till 30 April 2017 were exported to an excel file. Within the excel file, the happened precipitation events of July 2016 were filtered. Afterwards, the input for the precipitation events in the model itself had to be determined. As explained before, the model makes use of specific discharges and thus the happened precipitation events can not be copied into the model. The input has to be calibrated to fit the model, at WRIJ 8.64 mm/dag as input is used for a precipitation event that occurs once every year (T=1). A precipitation event of 36.8 mm in a day recurs on average each year, derived from data between 1906 and 1977 (STOWA, 2019a). With the help of these 2 values, the input for the model is derived. Each simulation will use different assumptions to determine the input for the model.

The first simulation will use equation 3 to determine the input for the model. In the equation, the specific discharge (T=1) is always 8.64 mm/day and the T=1 precipitation event is 36.8 mm. The output of the equation has a unity of mm/day, this can be directly used as input for the SOBEK model. The following equation will be performed for each day of July 2016.

$$Input = \frac{Measured\ precipitation * specific\ discharge(T=1)}{(T=1)\ precipitation\ event} \tag{3}$$

The second simulation will use the same equation as the first simulation, equation 3. However, for each value lower than 0.432 mm/day, the base flow will be used as input $Q_0.05$ which is equal to the aforementioned 0.432 mm/day. This will be done because watercourses in real life will always have a base flow due to long-term water storage. Thus, if for example, the daily precipitation is 0 mm/day then the input for the model will use the base flow.

The third simulation will use equation 4 to determine the input for the model. As in equation 3, the specific discharge is always 8.64 mm/day and the T=1 precipitation event is 36.8 mm. The base flow is always 0.432 mm/day. The output of this equation will also have the unity of mm/day.

$$Input = \frac{Measured\ precipitation * specific\ discharge(T=1)}{(T=1)\ precipitation\ event} + Base\ flow(Q_{0.05}) \tag{4}$$

At first, only three simulations were performed, however, after validating the model it seemed that it could be calibrated better. Thus, a first simulation was performed. The fourth simulation uses equation 5 to determine the input for the model. As in equation 3, the specific discharge is always 8.64 mm/day and the T=1 precipitation event is 36.8 mm. The base flow is always 0.432 mm/day. The output of this equation will also have the unity of mm/day.

$$Input = \frac{Measured\ precipitation * specific\ discharge(T=1)}{(T=1)\ precipitation\ event\ -\ Base\ flow(Q_{0.05})} + Base\ flow(Q_{0.05}) \tag{5}$$

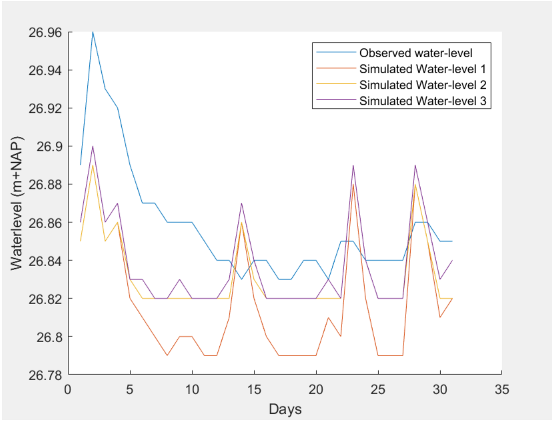

Figure 41: Observed and simulated water levels, graph created in MatLab

Table 10: Nash Sutcliffe and Relative Volume Error values of the four simulations calculated with MatLab

	Nash Sutcliffe (NS)	Relative Volume Error (RVE)
Simulation 1	-1.63	-0.15
Simulation 2	-0.41	-0.09
Simulation 3	-0.16	-0.07
Simulation 4	-0.18	-0.08

The closer a Nash Sufcliffe value is to 1 the better and the closer the Relative Volume Error is to 0 the better (Muthuwatta et al., 2009). From this can be concluded that the 3rd simulation is the best for the model, as can be seen in Table 10 in Appendix E. However, after the validation, a fourth simulation was performed to approach reality better. The problem with simulation three was that too much precipitation was put into the model, the base flow was an extra input, but in simulation 4 addition of the base flow input was compensated.

As can be seen in Figure 41, the water levels of the simulations tend to be lower on average than the measured water levels. However, the model tends to react heavier on precipitation events. Bigger precipitation events translate into the model to peak water levels, while the measured water levels remained lower. This can have multiple explanations, however, the exact cause of this can not be tracked. A possible cause for the water levels to remain low in the measured water levels can be that the soil is dryer than assumed in the model and thus has an increased infiltration rate, a dry soil tend to have a higher infiltration rate than wet soil (United States Department of Agriculture, 2014).

As can be seen in Figure 42, the measured cross-section (denoted in black) differs from the designed cross-section (denoted in green). The designed cross-section is implemented into the model, it can be seen that the actual stream bottom is located lower than the designed cross-section. The cause for this is erosion, but the stream width itself is thinner. This thinner stream width is the expected cause for the on average higher water level in the measured situation.

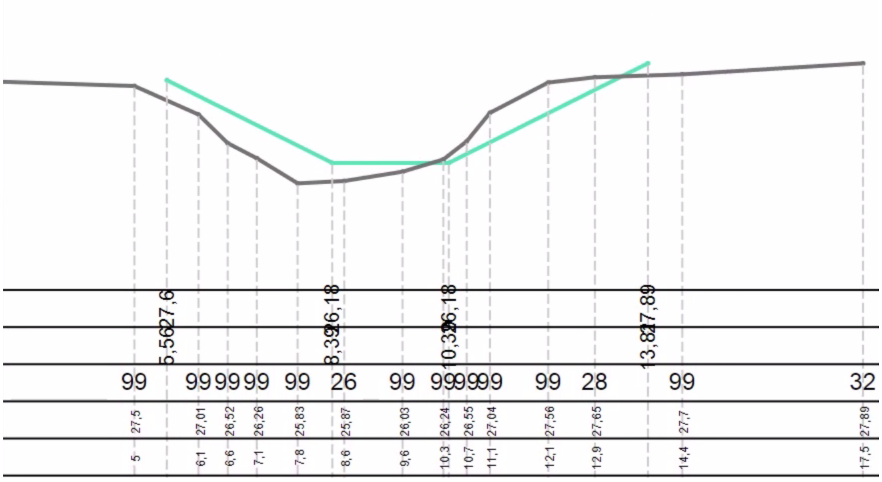

Figure 42: Designed and actual cross section at calibration location. Source: WRIJ (2020)

Validation

As explained before, the model will be validated by assessing a different month. First, the precipitation events of the month July 2015 were collected (KNMI, 2021a). Afterwards, the same formula was used for the best simulation of the calibration part, which was equation 4 to determine the input values for the model. In Figure 43, the simulated discharge is depicted against the measured water levels. The same location for the collection of the water levels was used as in the calibration part. After the first simulation, the formula of equation 5 was used as input for the second validation simulation.

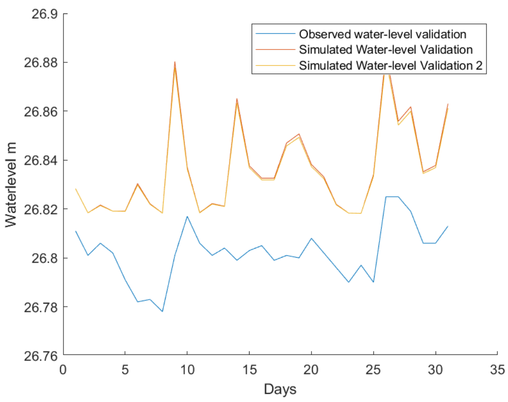

Figure 43: Simulated and observed water level for the validation month (1 July 2015 - 31 July 2015)

To assess if the validation was successful, the Nash-Sutcliffe efficiency and Relative Volume Error was used. In Table 11, the results of this assessment can be found. From the Relative Volume Error, it can be concluded that the validation was successful. The RVE comes out to be low value, however, the Nash-Sutcliffe value is far off. This is since the average of the simulated water levels is way lower than the measured water levels. When the measured water levels peak, the simulated water levels also peak which is a good thing. The simulation of validation 2 turns out to be the best.

Table 11: Nash Sutcliffe and Relative Volume Error values of the validation simulation calculated with MatLab

	Nash Sutcliffe (NS)	**Relative Volume Error (RVE)**
Validation simulation	-10.79	0.13
Validation simulation 2	-10.13	0.12

F Input interventions

Raising riverbeds (Shallow rivers and meandering)

The current cross-sections of the side watercourses in the area all have a trapezoid shape that discharges the water as efficiently as possible. To ensure flood safety in the area, the freeboard at the base discharge has to be at least 70 centimetres and to avoid drought problems the maximum allowed freeboard is 120 centimetres. These freeboard numbers are decided on by WRIJ for the catchments of the Berkel and thus the Groenlose Slinge. To achieve a shallow river, the riverbeds of the current side watercourses will be raised, depending on the space available at both sides of the stream and depending on the freeboard. The average freeboard near the side watercourses is between 1-2 meters, however, at some points, the freeboard is between 0.5-1 meters and at some locations even 2-4 meters near the side watercourses. The cross-sections of the side watercourses have a depth of 1-1.5 meters, to ensure flood safety by taking into account the freeboard and the size of the cross-sectional area, the riverbeds can be raised by 65% in maximum. So the riverbeds will be raised depending on the current freeboard and available space from 0-65%, the width of the cross-section will be increased to achieve the same previous cross-sectional area of the streams. On a typical cross-section in the area, the depth of the streams will be decreased by 40 centimetres which are also 40% of the stream depth. The freeboard will remain the same as the current situation as much as possible to ensure local flood safety Due to the width of the streams, stream bottom meandering will be possible. The cross-sections will be adjusted through the whole area in SOBEK.

Improving soil structure

The improvement of the soil structure leads to more water that can be retained in the soil. During dry periods, this leads to later sprinkling of the lands, because there is longer sufficient water for vegetation. By increasing the organic content matter in an area by 3 per cent, the moist deficiency can be lowered by 11 mm each year (Phernambucq et al., 2019). Combining this with decreasing compaction in the area by not working available land, the organic matter content is increased by 1%-2% in the area between the plateaus. In the previous research conducted by N. K. Wolterink (Wolterink, 2020), this increase of organic matter content leads to an increase of the discharge in the summer and spring, but a decrease in discharge during the winter and autumn.

As can be seen in Table 12, the base flow of the spring and summer increases. The spring has to largest increase, this is mostly because during the winter the most water can be stored in the soil, due to groundwater seepage this will end up in the base flow of the spring. The valley in which the organic matter content will be increased is having an area of around 40% of the total study area.

Table 12: Change in discharge caused by soil improvement. Source: Wolterink (2020)

	Change in base flow
Spring	4.5%
Summer	0.5 %
Autumn	-2.5%
Winter	-3%

The base flow of the spring months will be increased by 4.5% in the SOBEK model. Sequential, the base flow of the summer months will be increased by 0.5% in the SOBEK model. Next to the increase during the spring and summer, the base flow of the autumn and winter will be decreased. The base flow of the autumn will be decreased by 2.5% and the base flow of the winter by -3%.

During the winter and the autumn, the base flow is double the base flow of the spring and summer. This is because during the autumn and winter more precipitation events occur and on average more water precipitates during those periods. Thus, for testing the winter and autumn months, WRIJ uses a base flow of 0.864 mm/day. This substantiated assumption will thus also be used in this research.

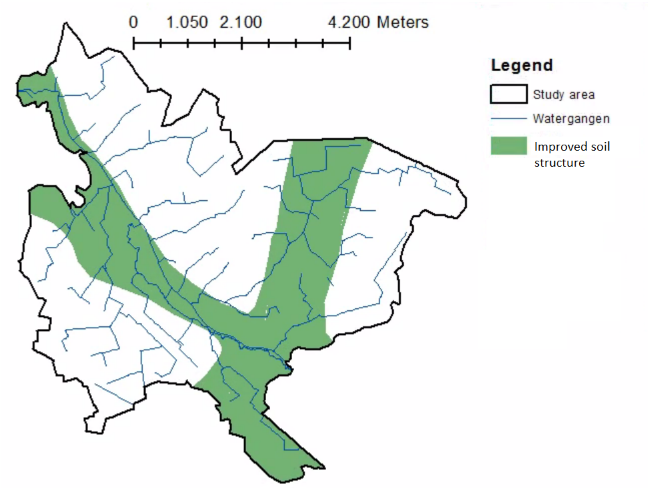

Figure 44: Improved soil structure in the study area. Source: adapted from WRIJ (2020)

In Figure 44, the improved soil structure over the area can be seen. However, 80% of the overall area is agricultural land, thus of the green denoted area 80% of the soil is improved.

Percolation areas

The current watercourses in the area are designed to discharge the precipitation event that occurs once every 10 years (T=10). A precipitation event of 63 millimetres occurs in one day (STOWA, 2019a). However, with this intervention the side watercourses next to the percolation areas will be changed to a discharge capacity of T=0.5, T=0.5 appears on average 14 days a year. It is not possible to change all watercourses into a T=0.5 design, due to possible local flooding that can occur. The reoccurring precipitation event twice every year (T=0.5) precipitates 30.4 mm in a day over the area (STOWA, 2019a). To keep the overall system safe and retain more water in the area, percolation areas are created that household the excess water and while it is in the percolation area it has more chance to be retained in the area. The percolation areas will have an average depth of 0.5 meters. For each catchment, the needed percolation space is calculated and can be found in Table 13. In Figure 45, the catchments with the named number can be found to clarify which catchment is calculated for. The cross-sectional area of the side watercourses will be made smaller by 50% to achieve watercourses that are set to T=0.5. In total 10 percolation areas are created within the study area, in Figure 46 the designed locations for the percolation areas can be seen.

Not everything that precipitates on the area gets discharged via the streams, only a portion of the precipitation gets discharged. From the stochastic testing performed by WRIJ, (van den Houten, 2006), it can be concluded that 16 mm/day gets discharged via the streams during a T=10 precipitation event. For the T=0.5 precipitation event, it is found that 4.32 mm/day on average gets discharged via the stream.

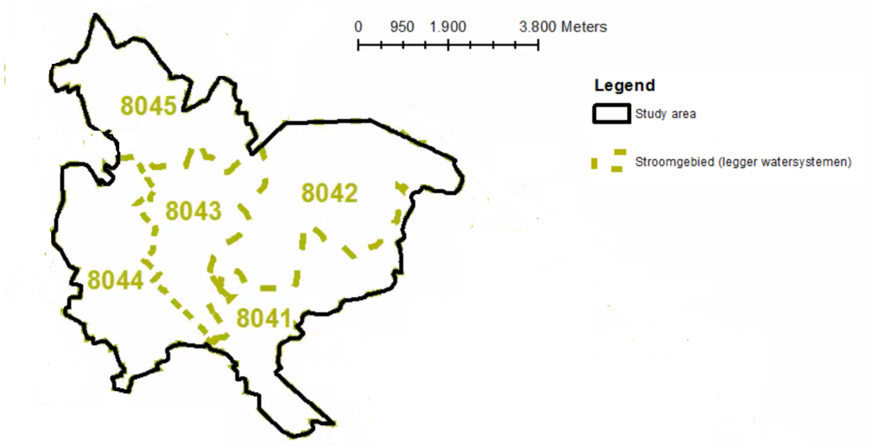

Figure 45: Catchments with naming numbers. Source: WRIJ (2020)

Table 13: Results of needed area for percolation

Sub-catchment number	**Area** (km^2)	**Current T=10 discharge capacity per day** (m^3)	**Designed T=0.5 discharge capacity per day** (m^3)	**Needed percolation volume per sub-catchment** (m^3)	**Needed percolation area per sub-catchment** (m^2)
8041	7.025	112400	30348	82052	164105
8042	10.120	161920	43719	118201	236402
8043	5.955	95280	25726	69554	139108
8044	8.254	132064	35657	96407	192814
8045	7.050	112800	30456	82344	164688

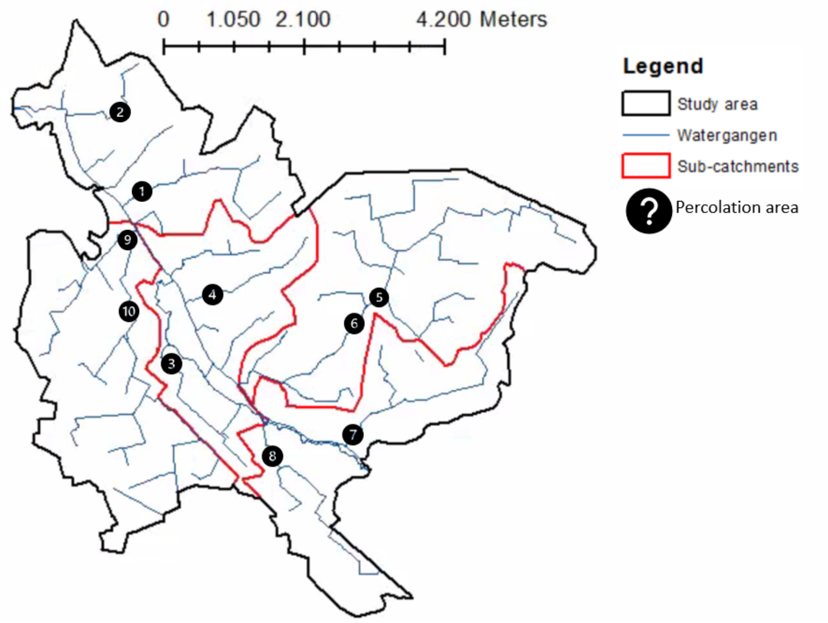

Figure 46: Locations designed percolation areas. Source: adapted from WRIJ (2020)

Table 14: Surface area per percolation area

Percolation area number	**Designed surface area (m^2)**
1	114,900
2	57,800
3	78,400
4	64,800
5	140,625
6	79,200
7	98,900
8	59,800
9	120,000
10	73,125

Spillway system

The trenches of the spillway will mostly be filled by surface run-off, during heavy precipitation events the trenches can also get filled by excess water from the primary channel. Excess water of the primary channels will be discharged to the trenches via weirs. The current channels will not be decreased in size, however, it can be decided that water flows into the trenches at a specific discharge. The weirs will be set up to discharge excess water during precipitation events of T=0.5 or higher. The cross-sections of the trenches will be 50% smaller than the primary channels to be able to discharge at least a T=0.5 solely through the trench.

In total there will be placed five savings basins, one saving basin per sub-catchment. In Figure 47, the designed locations of the savings basins within the study area can be seen. Three savings basins will be placed at the eastern side of the Groenlose Slinge because part of the system has the largest area. The overall area of the study area is

38.4 km^2, of this area around 80% is agricultural land. Each of the savings basins will store water from an area of around 7.7 km^2. The savings basin will mainly be used by farmers to irrigate their lands, reasoned from three irrigation gifts of 20 millimetres each (Phernambucq et al., 2019), the five savings basins should household 1,843,200 m^3 of water. This translates into around 368,640 m^3 storage per basin. For this research the depth of the savings basins is set at 2 meters, however, this can be easily adapted if needed to avoid eutrophication. This leads to a needed area of 184800 m^2 per basin per catchment. The savings basis can be made deeper to decrease the amount of area needed.

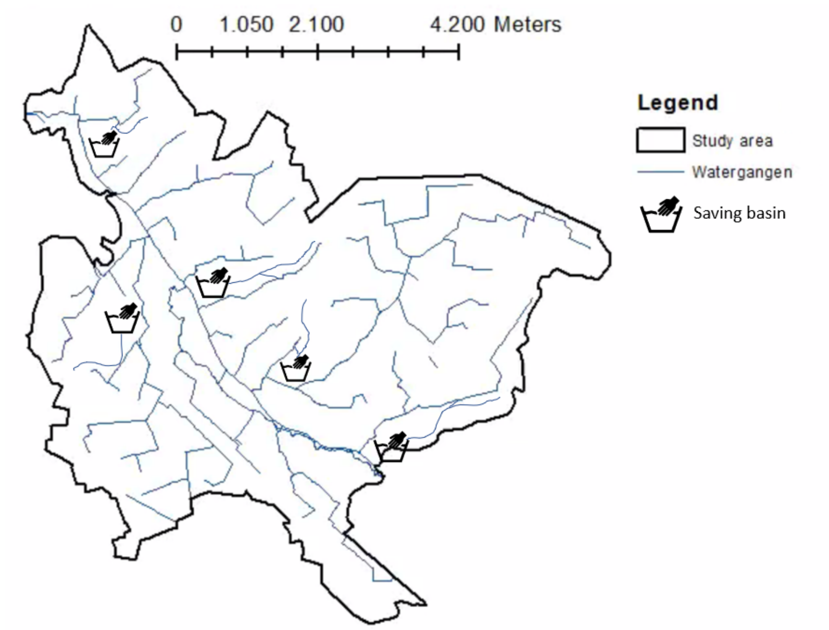

Figure 47: Locations saving basins and secondary streams. Source: adapted from WRIJ (2020)

Heightening weirs

Compared to the other interventions, this intervention can be easily implemented into the SOBEK model. In the previous study about the study area carried out by N. K. Wolterink (Wolterink, 2020), raising the weir levels by 30 centimetres was researched and approached in a theoretical manner. In this research, the current weirs will also thus be raised by 30 centimetres and will be approached more practically. The current weirs in the valley area and on the plateaus will be adjusted in SOBEK and heightened by 30 centimeters.

Implementing extra weirs

The amount of extra weirs in the transition between the plateau and the valley depends on the slope. For example, a weir of 10 cm high has to be placed in an area with a slope of 0.1% every 100 meters. In the transition, the slope is on average 0.8%, derived from ArcMap. Every 100 meters a weir of 80 cm would be needed, or every 60 meters a weir of 60 cm would be needed. With this information, the extra weirs can be implemented into the SOBEK model. In Figure 48, the extra implemented weirs in the study area for these interventions can be seen.

SOBEK uses equation 6 to calculate the discharge at a weir when there is a free flow in the stream. When a stream has a submerged flow, SOBEK uses equation 7. A channel has a submerged flow if $h_2/h_1 \geq 2/3$, this will be calculated within the SOBEK model. The average discharge coefficient in the area is 1.3, thus this value will be used for the extra implemented weirs. Other values mentioned in the following equations than the crest level of the weir and the discharge coefficient are already known by the SOBEK model.

$$q = C_d \sqrt{g} \, (\frac{2}{3})^{3/2} \, h_1^{3/2} \tag{6}$$

$$q = C_d \, h_2 \sqrt{2g \, (h_1 - h2)} \tag{7}$$

q Discharge per width unit (m^2/s)

C_d Discharge coefficient (-)

h_1 Upstream water level relative to crest height (m)

h_2 Downstream water level relative to crest height (m)

g Gravitational acceleration (m/s^2)

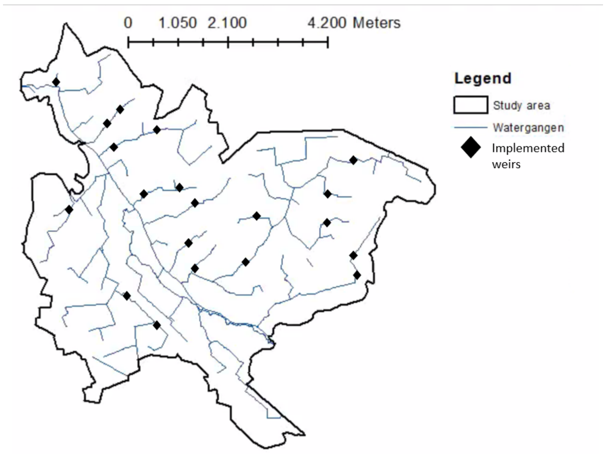

Figure 48: Extra implemented weirs in the area. Source: adapted from WRIJ (2020)

G Absolute results measurement points

Table 15, table 16 and table 17, show the absolute monthly average simulated values of each measurement location. In Figure 4 in section 2.5, a map with the location of each measurement point can be found.

Table 15: Absolute results of measurement location 1

Monthly average values measurement location 1		**Water Level (m+NAP)**	**Water Depth (m)**	**Discharge (m^3/s)**	**Flow Velocity (cm/s)**	**Freeboard (m)**
Summer	*Reference Scenario*	22.77	0.53	0.050	3.49	0.58
Summer	*Scenario 1*	22.77	0.53	0.050	3.51	0.57
Summer	*Scenario 2*	22.76	0.52	0.043	1.99	0.58
Summer	*Scenario 3*	23.06	0.82	0.044	1.65	0.28
Spring	*Reference Scenario*	22.76	0.52	0.035	2.56	0.58
Spring	*Scenario 1*	22.76	0.52	0.035	2.55	0.58
Spring	*Scenario 2*	22.75	0.51	0.030	1.46	0.59
Spring	*Scenario 3*	23.05	0.81	0.031	1.17	0.29
Winter	*Reference Scenario*	22.79	0.55	0.083	5.59	0.55
Winter	*Scenario 1*	22.79	0.55	0.082	5.52	0.55
Winter	*Scenario 2*	22.78	0.54	0.076	3.39	0.56
Winter	*Scenario 3*	23.08	0.84	0.077	2.82	0.26

Table 16: Absolute results of measurement location 2

Monthly average values measurement location 2		**Water Level (m+NAP)**	**Water Depth (m)**	**Discharge (m^3/s)**	**Flow Velocity (cm/s)**	**Freeboard (m)**
Summer	*Reference Scenario*	24.85	0.59	0.087	4.22	0.41
Summer	*Scenario 1*	24.85	0.59	0.087	4.23	0.41
Summer	*Scenario 2*	24.86	0.60	0.091	4.44	0.40
Summer	*Scenario 3*	25.15	0.89	0.087	2.43	0.11
Spring	*Reference Scenario*	24.84	0.59	0.064	3.21	0.41
Spring	*Scenario 1*	24.84	0.59	0.065	3.24	0.41
Spring	*Scenario 2*	24.84	0.58	0.055	2.79	0.42
Spring	*Scenario 3*	25.14	0.88	0.064	1.83	0.12
Winter	*Reference Scenario*	24.88	0.62	0.152	7.02	0.38
Winter	*Scenario 1*	24.88	0.62	0.150	6.95	0.38
Winter	*Scenario 2*	24.88	0.62	0.144	6.73	0.38
Winter	*Scenario 3*	25.17	0.91	0.152	4.15	0.09

Table 17: Absolute results of measurement location 3

Monthly average values measurement location 3		**Water Level (m+NAP)**	**Water Depth (m)**	**Discharge (m^3/s)**	**Flow Velocity (cm/s)**	**Freeboard (m)**
Summer	*Reference Scenario*	21.43	0.55	1.509	25.74	0.45
Summer	*Scenario 1*	21.43	0.55	1.510	25.75	0.45
Summer	*Scenario 2*	21.43	0.55	1.501	25.70	0.45
Summer	*Scenario 3*	21.43	0.55	1.500	25.67	0.45
Spring	*Reference Scenario*	21.42	0.54	1.424	25.03	0.46
Spring	*Scenario 1*	21.42	0.54	1.426	25.04	0.46
Spring	*Scenario 2*	21.42	0.54	1.402	24.83	0.46
Spring	*Scenario 3*	21.42	0.54	1.419	24.98	0.46
Winter	*Reference Scenario*	21.47	0.59	1.732	27.56	0.41
Winter	*Scenario 1*	21.47	0.59	1.726	27.52	0.41
Winter	*Scenario 2*	21.46	0.58	1.704	27.35	0.42
Winter	*Scenario 3*	21.46	0.58	1.721	27.48	0.42

H Scenario evaluation

Each criterion has a specific weight based on its importance. In table 18, the weights of each criterion can be seen. The lower the sum score, the more important the criteria is. The lower score makes criteria more important because the weights are normalized and a priority vector is created for each criterion, this can be seen in table 19.

Table 18: Criteria weight matrix

	Flood safety	**Ecology**	**Water retention**	**Required space**
Flood safety	1	1	0.5	2
Ecology	1	1	0.5	2
Water retention	2	2	1	3.00
Required space	0.5	0.5	0.33	1
Sum	4.5	4.5	2.333333333	8

Table 19: Normalized criteria weightage matrix

	Flood safety	**Ecology**	**Water retention**	**Required space**	*Priority vector*
Flood safety	0.22222222	0.22222222	0.214285714	0.25	0.22718254
Ecology	0.22222222	0.22222222	0.214285714	0.25	0.22718254
Water retention	0.44444444	0.44444444	0.428571429	0.375	0.423115079
Required space	0.11111111	0.11111111	0.142857143	0.125	0.122519841
Sum	1	1	1	1	

In table 20, the total weighted sum of a criteria can be seen. The values within the table are determined by multiplying the priority vector with criteria weight matrix.

Table 20: Weighted sum

	Flood safety	**Ecology**	**Water retention**	**Required space**	*Total*	*Weight / Priority*
Flood safety	0.22718254	0.22718254	0.21155754	0.245039683	0.910962302	4.009825328
Ecology	0.22718254	0.22718254	0.21155754	0.245039683	0.910962302	4.009825328
Water retention	0.45436508	0.45436508	0.423115079	0.367559524	1.699404762	4.016412661
Required space	0.11359127	0.11359127	0.14103836	0.122519841	0.490740741	4.005398111
Average						4.010365357

Consistency Index, CI: 0.003455119
Consistency Ratio, CR: 0.003839021

Less than 0.1 therefore grading is sufficiently consistent

$$CI = \frac{Average\ weight\ per\ priority - n}{n - 1} \tag{8}$$

n: number of criteria

$$CR = CI/0.9 \tag{9}$$

The consistency index and consistency ratio are calculated to make sure the set judgments are consistent enough to be reliable. As long as the consistency index and consistency ratio are below 0.1, the judgments are consistent enough.

In table 21, the scores for each scenario on each criteria can be seen.

Table 21: Score matrix

Score	**Scenario 1**	**Scenario 2**	**Scenario 3**
Flood safety	4	5	1
Ecology	4	3	2
Water retention	3	5	4
Required space	3	1	5

Table 22: Weighted score matrix

Weighted score	**Scenario 1**	**Scenario 2**	**Scenario 3**
Flood safety	0.90873	1.1359127	0.22718254
Ecology	0.90873	0.6815476	0.45436508
Water retention	1.269345	2.1155754	1.69246032
Required space	0.36756	0.1225198	0.61259921
Sum	3.454365	4.0555556	2.98660714

I Elaboration afwatering langs Hulshof

In Figure 49, the adjustments of the measures of scenario 1 and scenario 2 are combined in one figure. In essence, the scenario can complement each other, however, in this elaboration the scenarios are tested separately. In Figure 50, the exact location of the afwatering van Hulshof in the study area can be seen. The "de afwatering van Hulshof" has medium to low average discharge compared to other side watercourses in the study area. The elaboration for "de afwatering langs Hulshof" has been performed with the help of the precipitation events of July 2020. It was chosen to only analyse the summer month for the elaboration because most drought problems occur during the summer.

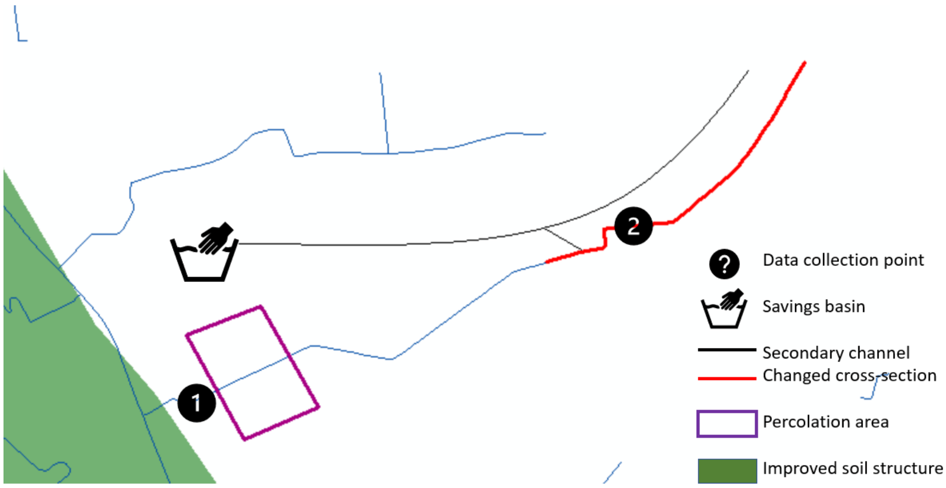

Figure 49: Scenario adjustments on the afwatering langs Hulshof. Source: adapted from WRIJ (2020)

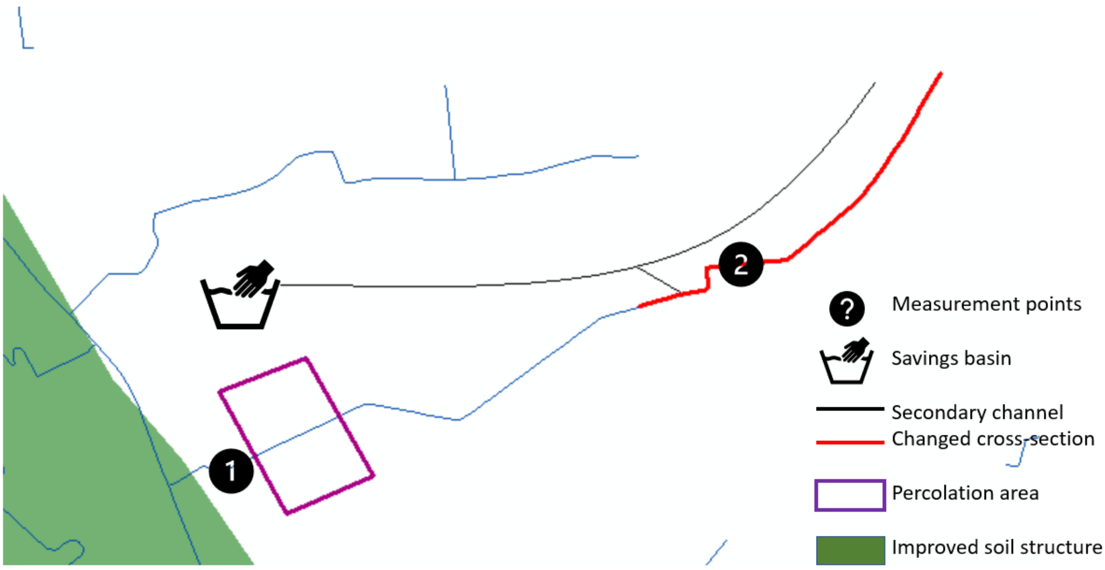

Figure 50: Location of afwatering langs Hulshof. Source: adapted from WRIJ (2020)

Scenario 1 implementation afwatering van Hulshof, natural measures

In Figure 51, the change in cross-section for the afwatering langs Hulshof can be seen. In Figure 49, it can be seen that the cross-section was only adjusted partially in the stream. Only parts in streams with large height deficits were adjusted, thus only the cross-sections in the top part of the stream were adjusted. Around the stream, little to no soil structure is improved.

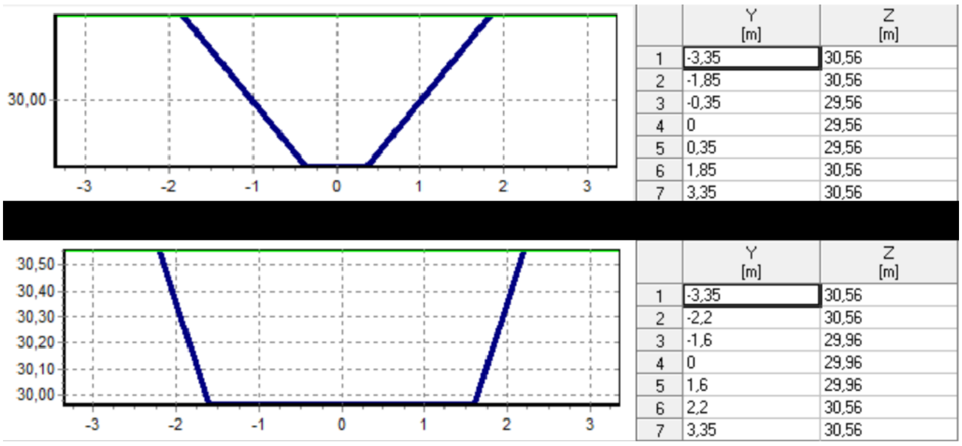

Figure 51: Change in cross-section, old cross-section visualized in top part of figure, new cross-section visualized in lower part of figure

Scenario 2 implementation afwatering van Hulshof, retention measures

In Figure 49, the locations of the percolation area and the savings basin can be seen. The secondary channel next to the stream will discharge water into the savings basin. In Figure 52, the cross-section of the secondary stream can be seen. The cross-sectional area of the secondary stream is small compared to the primary stream, the secondary streams are designed to be able to discharge precipitation events of T=0.5 solely.

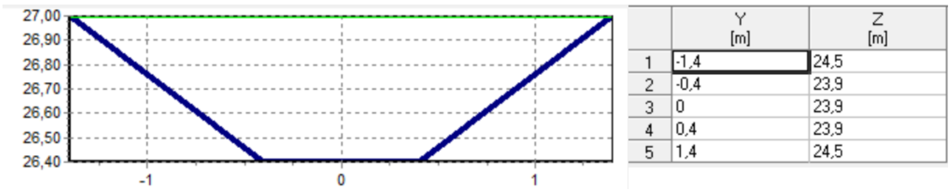

Figure 52: Cross-section secondary channel

The percolation area will have an area of 64,800 m^2, the percolation area is located on grasslands. The maximum capacity of the percolation area will be 32,400 m^3.

The savings basin will have a capacity of 368,640 m^3. The savings basin will have a depth of 2 meters, this leads to a needed area of 184,320 m^2. The depth of the savings basin can be varied.

Results elaboration afwatering langs Hulshof

In the following tables, the results of the elaboration on the afwatering langs Hulshof can be seen. Results were collected at two different points in the stream. The measurement locations can be seen in Figure 49.

The numbers in the tables are average values of the month July 2020.

Table 23: Results in percentages measurement location 1, afwatering langs Hulshof

Point 1	**Water level**	**Water depth**	**Discharge**	**Flow velocity**	**Freeboard**
Scenario 1	1.12%	149.11%	0.58%	-81.50%	-32.02%
Scenario 2	0.00%	0.06%	0.51%	0.39%	-0.01%

Table 24: Results data measurement location 1, afwatering langs Hulshof

Point 1	**Water level (m)**	**Water depth (m)**	**Discharge** (m^3/s)	**Flow velocity (m/s)**	**Minimal Freeboard (m)**	**Average freeboard (m)**
Scenario 1	23.94	0.44	0.0087	0.02	0.51	0.56
Scenario 2	23.67	0.18	0.0086	0.11	0.79	0.83
Reference scenario	23.67	0.18	0.0086	0.11	0.79	0.83

Table 25: Results in percentages measurement location 2, afwatering langs Hulshof

Point 2	**Water level**	**Water depth**	**Discharge**	**Flow velocity**	**Freeboard**
Scenario 1	0.65%	288.64%	0.42%	-38.26%	-25.86%
Scenario 2	0.00%	0.00%	0.00%	0.00%	0.00%

Table 26: Results measurement location 2, afwatering langs Hulshof

Point 2	**Water level (m)**	**Water depth (m)**	**Discharge** (m^3/s)	**Flow velocity (m/s)**	**Minimal Freeboard (m)**	**Average freeboard (m)**
Scenario 1	30.64	0.26	0.0026	0.04	0.55	0.57
Scenario 2	30.44	0.07	0.0026	0.06	0.75	0.77
Reference scenario	30.44	0.07	0.0026	0.06	0.75	0.77

In the tables it can be seen that both scenarios do not decrease the water discharge in the stream. However, the precipitation events onto the area in scenario 1 is increased by 1.8% to implement the soil structure improvement measure. The average discharge is in both points around 0.5%, but when taken into account the 1.8% it leads to a decrease in discharge of 1.3%. All in all, this means that scenario 1 thus retains more water in the area than the current situation.

Scenario 2 does not improve the current water system for a summer month. Regarding drought problems, scenario 2 is not recommended for "de afwatering langs Hulshof".