Bachelor Thesis

The influence of pinch culverts on the water system of the Glanerbeek in a historical and future climate

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Summary

The climate is changing. The last few summers have been very dry and showers have simultaneously been getting more extreme. These trends are expected to increasingly continue in the future (Verweij et al., 2010), which is likely to cause problems.

The region Twente, located in the east of the Netherlands, is relatively elevated and the ground exists mostly of thin and sandy water-permeable layers. This set of characteristics causes water to be discharged relatively fast and this can result in dry water channels during dry periods. The organisation responsible for water management in the area, waterboard Vechtstromen, counters this effect with the use of weirs and culverts. These existing structures are however not considered to be flexible enough to cope with the extremes climate change will bring. Vechtstromen is therefore interested in pinch weirs and pinch culverts and the extent to which they can influence water systems.

This study investigates the influence pinch culverts can have on the management area of Vechtstromen in the current and future climate. Glanerbeek, an representative area for a significant part of Twente, is chosen as a study area for this research. An existing Sobek 2.14 model of this area is used to calculate the flows through Glanerbeek. This model is combined with a previously made and area-specific Walrus model (Attema, 2020), which calculates the rainfall runoff and gives more detailed input for the Sobek model.

The results from the study show that pinch culverts do have a significant influence on the discharge from the study area: peak discharges are reduced by 38% compared to the current situation and pinch culverts are having an influence in 240 days per year. This influence is even larger for the future climate. The study also shows that pinch culverts with 50% of the original culverts diameter have virtually no influence, while pinch culverts with 25% of the original diameter tend to cause flooding at multiple locations in the study area. It can be concluded that pinch culverts do have a valuable influence on the water systems, especially for future climates, but that attention to their dimensions is required.

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1. Preface

This is the final report of my bachelor thesis 'The influence of pinch culverts on the water system of the Glanerbeek in a historical and future climate'. This research forms the completion of the main part of my bachelor studies Civil Engineering at the University of Twente and is executed in cooperation with waterboard Vechtstromen.

Doing this research and writing this report has not been an easy journey. It turned out that doing a bachelor assignment completely from home is quite a challenge, as working on an individual project with little to no social contacts sometimes made it hard to find motivation. Several technical and ICT-related problems also caused more time to solve than the original planning accounted for. Therefore I have not been able to do everything I originally planned to do. I do however still think that the research has given some valuable and interesting insights in the effects of 'pinching' water. The process has been, although hard at times, very educational for myself.

I am greatful Vechtstromen gave me the opportunity to do this research, even during these unsecure times. Special thanks go to my supervisors from the waterboard, Bas en Jeroen, for their patience, advices and the feeling of really being 'at work'. Also to Mr. Booij, my internal supervisor, for the often more in-depth feedback, that helped me to align all small details to turn this research into a logical whole. Lastly to my parents and friends for the support in the form of relaxation, which turned out to be just as important in the process.

Sjoerd Gabriëls

Enschede, February 9, 2021

2. Introduction

This chapter will give in introduction to the project. First, the problem context in Section 2.1 introduces the problem. Subsequently, in Section 2.2, the problem is explained and a summary of previously performed research is given to provide further insight into the problem. This concludes in a research gap, on which this research is based. The aim of the study and research questions are described in Section 2.3. The chapter concludes with an outline of this report in Section 2.4.

2.1. Problem context

Climate variability is a natural effect that is caused by a variety of reasons, such as variabilities in ocean dynamics, volcanic activities and the amount of atmospheric gasses (Rind and Overpeck, 1993). Since the start of the industrial era the latter category, to which we now often refer to as *greenhouse gasses*, has changed significantly. This human-induced effect is called climate change. It has resulted in worldwide changes in weather patterns, such as increases in temperatures and extreme weather events (IPCC, 2013). In 2017, the global average temperature had increased with approximately 1°C compared to the pre-industrial average and is expected to increase further with 0.2°C per decade. (IPCC, 2018)

This effect has been stronger in the Netherlands. Due to warmer western winds coming from the North Sea during winter and more solar radiation during summer, temperatures are increasing at double the speed of the global average (Verweij et al., 2010; Ligtvoet et al., 2013), with in 2019 an increase of 2.1°C compared to 1907 (Compendium voor de Leefomgeving, 2020). The amount of precipitation increased as well: from on average 720 per year in 1910 to 850 per year in 2013. It must be noted that this increase almost completely comes from winter precipitation. The number of days with precipitation ($>$0.1mm) did not change, but from observations we learned that precipitation mostly increases during extreme showers (KNMI, nd).

Based on several reports of the IPCC, the Dutch Meteorological Institute (KNMI) has made four scenarios for future climate developments, which were updated for the last time in 2014 (KNMI, 2015). A summary of the differences between the four scenarios and compared to the reference situation 1981-2010 is given in Table 1. The two base scenarios are $\mathrm{G_L}$ and $\mathrm{W_L}$, where *G* stands for moderate (gemiddeld) and *W* for warm. In both scenarios, increases in temperature, precipiation and evaporation are expected. The other two scenarios, $\mathrm{G_H}$ and $\mathrm{W_H}$ do contain a

Table 1: Summary of the KNMI climate scenarios. (KNMI, 2015)

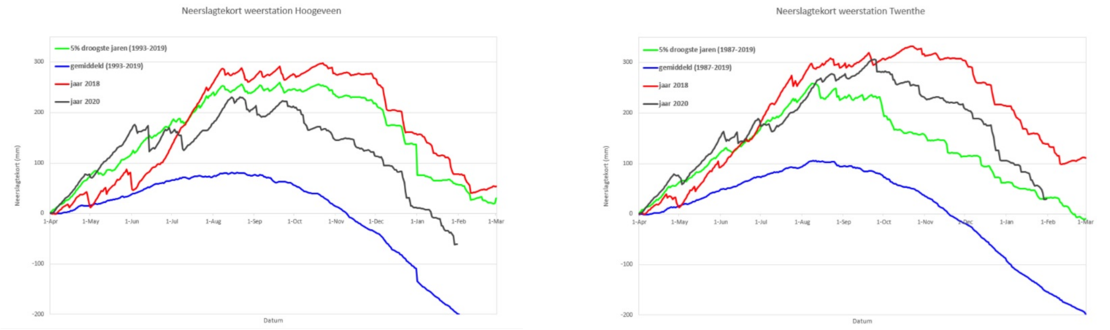
	1981-2010	**G_L**	**G_H**	**W_L**	**W_H**
Average temperature	10.1 °C	+1 °C	+1.4 °C	+2 °C	+2.3 °C
Precipitation	851 mm	+4%	+2.5%	+5.5%	+5%
Potential evaporation	559 mm	+3%	+5%	+4%	+7%

difference in airflow patterns, which will cause even higher temperatures and potential evaportation, but less increase in precipitation compared to the base scenarios (KNMI, 2015). Following the rapid temperature increase in the Netherlands, either scenario W_L or W_H is likely to occur in the future (Verweij et al., 2010).

The increase in temperature is already causing problems regarding drought. Between 1958 and 2013, the potential evaporation increased by 12% according to KNMI (nd) and this can be expected to increase further as global temperatures rise. Together with the predicted increase in precipitation intensity and the possible decrease in overall precipitation, this can lead to an increase in water shortages.

This problem has become apparent in the Netherlands the last few summers. This is illustrated by the average precipitation deficit over the last few years compared to the historical averages, as can be seen in Figure 1 (Waterschap Vechtstromen, 2020b). In general, the last few years have been consistently dryer than the average (measured since 1987) and often also dryer than the 5% driest years (Waterschap Vechtstromen, 2020a).

Drought is more apparent in Twente and other parts of the Netherlands, such as the Achterhoek and parts of Noord-Brabant, due to the soil composition and altitude. In Twente, most of the soil is higher sandy soil, where the surface ground layers exist of mostly sand. Next to that, the water-permeable layers (acquifers) are very thin, which makes that relatively little water can be stored in the ground. So, the soil becomes saturated quickly and excess water is discharged quickly, due to the elevated position of Twente compared to the rest of the Netherlands (Hasselerharm, 2020).



(a) Hoogeveen

(b) Twenthe

Figure 1: Precipitation deficits at weather stations Hoogeveen and Twenthe (Waterschap Vechtstromen, 2020b).

2.2. Problem description

Waterboard Vechtstromen, the governmental organisation responsible for water management in Twente, is searching for methods that can counteract this problem. In large parts of the area, there is no active water management, so water is currently free to flow. At other locations water is regulated by using weirs and culverts. Vechtstromen's water management distinguishes two different weir levels: a summer and a winter level. This means that during summer, when it is often dry, weirs are set high to retain as much water as possible. During winter, weirs are usually set to a lower level to discharge excess water quickly (Waterschap Vechtstromen, 2020b). Contrary to weirs, culverts do not have a regulating function, but allow water to keep flowing if the natural channel is obstructed. Because these measures are already present, Vechstromen is interested in the influence weirs and culverts could have on the water retention capacity of a water system during droughts. In other words: to what extent are the current methods useful for water management and nature preservation?

According to Mioduszwekski et al. (2014), damming devices like weirs do have the potential to limit water deficits during drought. The study clarifies that this is not only due to weirs simply limiting the amount of water discharging from a catchment, but also due to weirs causing lower downstream flow rates. This helps in the infiltration process and makes it easier to retain water downstream. In addition, these measures can have positive influences on the environment. As they improve or restore the water balance in water systems, they can lead to increases in the biodiversity and variety of ecosystems (Global Water Partnership Central and Eastern Europe, 2014).

Three studies have been done for waterboard Vechtstromen and specifically looked into a part of their management area called Glanerbeek, which soil characteristics are representative for a significant part of Twente. By modelling the water system of the Glanerbeek in Sobek, Hehenkamp (2019) came to similar results as Mioduszwekski et al. (2014). Next to that, he also discovered that the number and locations of weirs and culverts has a stronger effect on the water retention capacity than different types of measures. A study by Attema (2020) went into the influence of climate change on discharge regimes in Twente. By the use of a Walrus hydrological model, Attema showed that an increase in precipitation does have a direct influence on the discharges in Glanerbeek. He did also notice that seepage seemed to have a very large impact on the discharge process, but did not do any further research into this factor. This made it hard to distinguish the influences of seepage and climate change. A third study by Wiebing (2020) found that weirs and culverts do have a positive influence on the amount of groundwater conservation.

It can be concluded that weirs and culverts do have a positive influence on water retention in the management area of Vechtstromen. However, information regarding the influence of these measures during long (at least 10 years) and dry (below average precipitation) periods is still missing. A second research gap exists concerning climate change, as the influence of pinch weirs and culverts in a future climate scenario is yet unknown.

2.3. Research aim and questions

This study adds to the findings from the three previous studies to give the waterboard full understanding of the effects and possibilities pinch weirs and pinch culverts can have on water systems. The aim of this study is to get insight in the influence of pinch culverts over ten years on a water system, with special attention to the influence during dry periods and during future climate. This is be done by means of answering three research questions.

1. What are the actual hydrological characteristics of the water system?
2. What is the influence of pinch culverts on the water system in the current climate?
3. What is the influence of pinch culverts on the water system in a future climate scenario?

This study is focussed on the area Glanerbeek. Due to the soil properties and the large amount of (smaller) water streams, Glanerbeek is representative for a larger part of Twente. It is therefore expected that the results from this study will be applicable to a large part of the management area of Vechtstromen. More areas with similar (soil) characteristics to which this study might apply can be found in the east and south of the Netherlands (OBN, nd).

In this study, the influence of pinch culverts on groundwater is left out of consideration. Next to that, there are no tests with different types of (pinch) weirs and (pinch) culverts, as Hehenkamp (2019) already showed that this has little influence on the water system's characteristics.

2.4. Report outline

This chapter has introduced the research by explaining a problem and giving background information on previously performed studies into the subject. The next chapter will provide more general information on the models, data and study area used throughout the study. In Chapter 4, a more specific explanation of the models used in the study is given, together with a description of methods used to answer the research questions. The results of this are presented in Chapter 5. A discussion of the results and the research is given in Chapter 6. Finally, the report concludes with conclusions and recommendations in Chapter 7.

3. Study area, models and data

In this chapter, some background information that may be needed to understand the rest of the report. First, the difference between weirs and culverts and their pinching variants will be explained. After that, the used modelling programs are introduced briefly. The study area is introduced as well, with a brief description of the existing watersystem. At the end of the chapter, the data used in this study is discussed.

3.1. Differences between weirs and culverts and pinching structures

A weir is a damming device that is often used to retain water. Th goal of this is to either influence groundwater to prevent water deficits, to prevent flooding and waterlogging or to increase the water supply throughout dry periods (van Bakel et al., 2019). Weirs can be used in both urban and rural areas, but because of the scope of this study, we focus on rural areas here. Currently, the most common type of weir used in Dutch agriculture is the LOP (Landbouw OntwikkelingsPlan, in English Agricultural Development Plan) weir. LOP weirs exist of seperate planks that can be removed or added to the weir to change the effective height. This has the advantage that the owners, often farmers, can change the weir height depending on the precipitation situation. However, many farmers decide to leave the weir on a constant average height (Watercommunicatie B.V., 2009). This makes that the full water-retaining potential of a LOP-weir often is not used.

A pinch weir is different from a LOP-weir because pinch weirs have a hole in them. This hole is located at the average water height in the stream. In dry situations, the weir has a retaining function, just like a LOP-weir. In wet situations, part of the water flows through, while the majority of water is temporarily retained behind the weir (van Bakel et al., 2013). In extremely wet situations, water flows over the top of the weir. This makes a pinch weir very flexible and practical: any adjustment of the weir height is not required after installation and the pinch weir is able to both temporarily retain and drain water. Compared to a LOP weir, a pinch weir also drains water more gradually, which helps dividing water more evenly (Watercommunicatie B.V., 2009).

A culvert is a tube that connects multiple waters. Culverts are mostly located underground, allowing water to freely flow from one side to another without being obstructed by, for example, a dam or a road. Installing a culvert therefore allows

(a) A LOP weir
(b) A pinch weir (Bruins, 2018)
(c) A culvert (Hehenkamp, 2019)

Figure 2: Comparison between a LOP weir, pinch weir and a culvert.

water to flow through an area, thus increasing the discharge. A pinch culvert is similar to a culvert, except for the fact that a pinch culcert is designed to not drain all water during very wet scenarios. This makes that more water is retained behind the culvert.

3.2. Sobek

Sobek is a software package for water management developed by Deltares (Deltares, 2019). It enables engineers and modellers to model water systems in detail, to observe the behaviour of different linked systems and use the results to make water management decisions. This all happens in a structured way: the model itself can not be created before simulation settings and input data are set. Similarly, a simulation can only be run after the model is saved and the results of a previous simulation are not available anymore after the model gets changed. This keeps the modelling process structured. There are three main product lines of Sobek: Rural, Urban and River, that are each specialized in a certain environment. Sobek Rural is used for this study.

Sobek Rural specializes in water systems often found in rural areas, such as iirgation systems of natural streams. Models are made by adding nodes to a new or existing system and connecting those by links. Several types of nodes exist, such as weirs, channel cross-sections or inflow points, which enables the modeller to model a system into great detail. Sobek can then easily calculate the flows in the water system and give (dynamic visual) results at locations throughout the model. The RR-module gives even more details to the simulations. This module allows for modelling of the rainfall run-off (RR) process via different types of nodes for different circumstances and calculation methods.

3.3. Walrus

The Walrus-model, which stands for 'Wageningen Lowland Runoff Simulator' is a rainfall runoff model developed at the Wageningen University in 2013 (Brauer et al., 2017). It is specialised for flat, lowland areas with shallow groundwater. Walrus is a water balance model with three main reservoirs: the soil reservoir, the quickflow reservoir and surface water reservoir, with several flows and fluxes connecting them. Figure 3 gives a schematical overview of the model structure in which the reservoirs can be distinguished. The reservoirs are split in six parts, which are briefly described in the list below. For more information, the Walrus manual (Brauer et al., 2017) can be consulted.

1. Land surface: water is added to the system by precipitation P, soil water, which is then divided over the surface water, and quick flow. At the same time, water is removed from the system by evapotransporation ET.
2. Vadose zone: this zone is the part of the soil reservoir from the land surface to the groundwater table. The vadose zone controls the reduction in transevaporation and the wetness index W, which determines which part of the water from the land surface goes into the soil.
3. Groundwater zone: this zone is the part of the soil reservoir below the groundwater table. Togeher with the surface level water, the groundwater zone determines the drainage of surface water.
4. Quickflow reservoir: this reservoir represents all water that flows to the surface water without passing the soil reservoir, like water in residential ponds, drainpipes or surface runoff.
5. Surface water: the general surface water like ditches, rivers and lakes.
6. External fluxes: fluxes that add or remove water from the soil and surface water reservoirs, like seepage and extraction.

3.4. Study area Glanerbeek

The study area is the water system of the Glanerbeek, a small river in the far east of the Netherlands. It is located in the south east of the management area of Vechtstromen, to the east of the city of Enschede and south of the city of Glanerburg. The area has a size of 800 hecteres, of which 50% has an agricultural purpose. The other half is a natural reserved and exists of forests and small lakes (Hehenkamp, 2019). In general, the study area is suitable for water retention during wet periods, while it also is in need of water during dryer times.

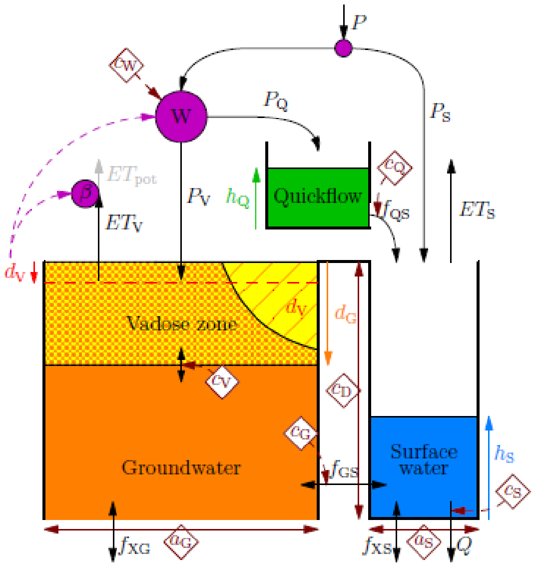


Figure 3: Schematisation of the Walrus model (Brauer et al., 2017)

The hyrdological system of the study area is relatively isolated from its surroundings, which makes the area suitable for research due to less external factors that could have a potential impact. The entire study area is located on a slope, with the west side being higher than the east side, which separates the area from more western parts of the Netherlands. There is also a slight decline from the south to the north of the area, which explains the natural flow of the Glanerbeek (towards the north). The eastern side of the area is bordered by the Dutch-German border and there is little interaction between channels from both sides of the border. A residential area is located to the north of the area. Finally, there is a measuring station located at the north side, where the Glanerbeek exits the study area, of which data can be used in the research.

3.5. Data

The model used in this study uses hourly historical data for the variables precipitation and evaporation. The data used has to meet three requirements: it should span a time period of 10 years, it should include at least one dry period and the data should be available for both the current climate and climate scenario W_H. The time period chosen is from January 1st 2000 to January 1st 2011, which meets the three requirements and is the most recent time period that does so. Data for the current climate and precipitation data for climate scenario W_H is provided by

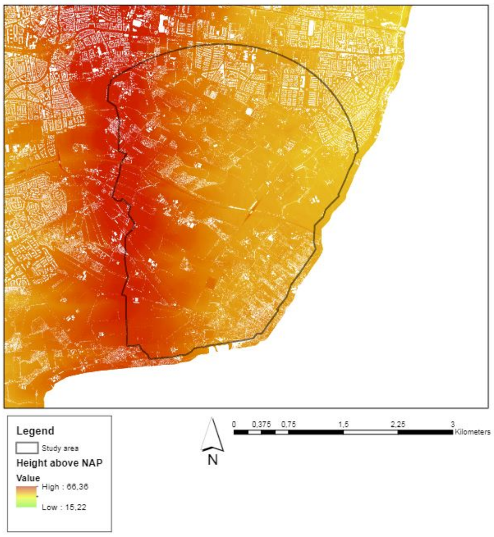


Figure 4: Height profile of the study area (Hehenkamp, 2019).

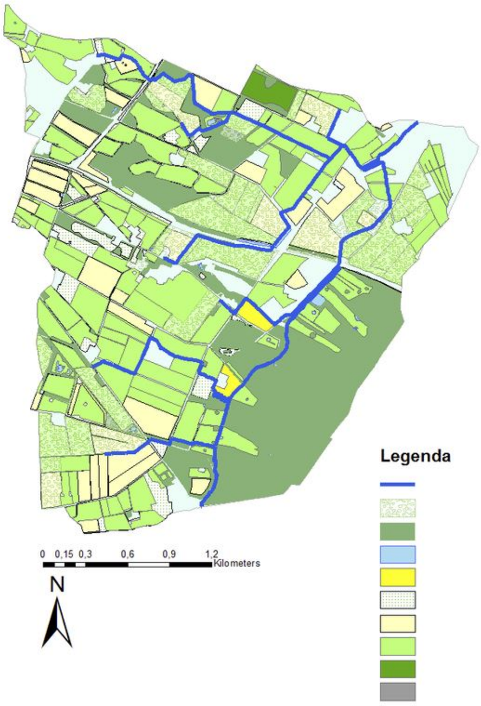


Figure 5: Land use in the study area and the main water system (Attema, 2020).

Meteobase (WIWB, nd). Evaporation data for the climate scenario are retrieved from the KNMI transformation program (KNMI, 2015). All data used is collected at meteo station De Bilt, as this is the only station for which climate-transformed data is available.

For the validation of the model, other historical data is used due to an inconsistency in the progress of the research. This data is collected at measuring station Melodiestraat, located at the end of the study areas water system (see Figure 8), and provided by the water board. As the goal of the validation is to check whether the combination of both models yields similar results compared to both original models, 2017, a time period used by the original models, is used for this. The used data is discharge data, as that is the main output of the model.

4. Methodology and modelling

This chapter gives a description of the methods used to answer the research questions as stated in Section 2.3. These methods are used for all the research questions, to make the results (visually) comparable. The modelling process of the model used to calculate all research is explained first. Subsequently, an overview of the different model scenarios is given. Finally, the methods to measure discharge and high and low water levels are explained.

4.1. Modelling

4.1.1. Implementing the Walrus model into Sobek

The model used for this study is composed from two existing but seperate models. One is a Sobek model available at the waterboard that contains all main watercourses in the study area. The other is a Walrus model made by (Attema, 2020). Because Walrus is specialized in areas like Glanerbeek, it is expected that combining this model with the Sobek model of the area will yield more accurate results.

The original Sobek model works with a number of different areas, on each of which falls a constant amount of rain. Part of this rain evaporates, but the majority flows into the water network. Walrus refines this process: for every part of the area, a RR-node is made and the Walrus parameters as calibrated by (Attema, 2020) are added to these nodes. With any given time series of precipitation and evaporation, the nodes then calculate the amount of water that flows from the land into the water channels by using the Walrus equations.

The Walrus RR-nodes are not a part of the distributed version of Sobek. The code for these nodes therefore has to be placed into the Sobek code first, after which they can be used within the model. Although Deltares has provided information on how to use the Walrus RR-nodes once they are in the model (Deltares, 2019), there is no information on how to add them to the code. Appendix C therefore gives an explanation on how this is to be done.

4.1.2. Calibration

The original Sobek model is a standard model available at the waterboard and has already been calibrated. The parameters of the original Walrus model have also been calibrated by Attema (2020) (see also Appendix B). In the combined model, the Walrus component runs first and then Sobek works with the results of the

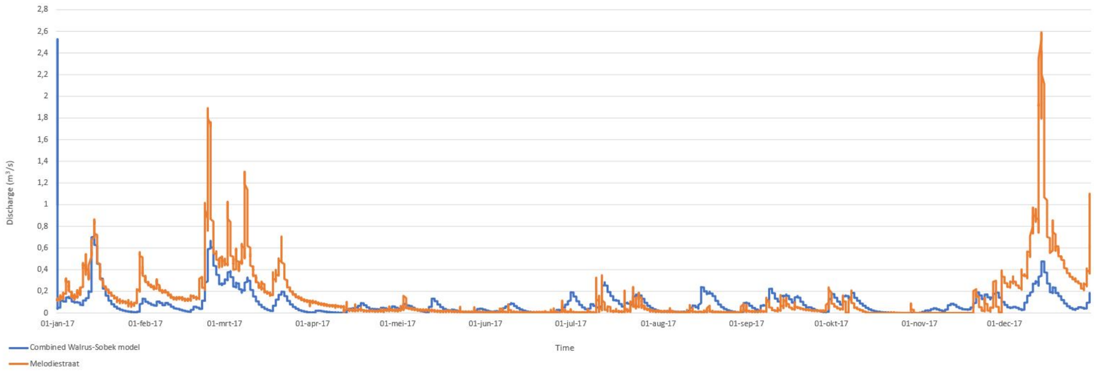


Figure 6: Comparison between modelled and measured discharges from the study area in 2017.

Walrus component. So the Walrus results influence the sobek model, but this it is not expected to also work the other way around. Therefore it is expected that the models can run seperately and that a calibration of the combined model is not required any more.

4.1.3. Validation

To still check whether the combination of the two models does not yield unexpected results, the model is validated by comparing the modelled discharge from the study area to the measured discharges at measuring station Melodiestraat (see Figure 8). Because the study area is only 53% of the area of which the discharge is measured at Melodiestraat, the collected data is corrected for this difference. Here, it is assumed that the discharge is spread evenly over the entire area. Comparing the modelled and measured discharge, it appears that the model follows the pattern of the measured data, but consistently underestimates the peaks (see also Figure 6. This can be explained by the fact that the modelled discharge from the Walrus model (Attema, 2020) was also consistently lower than the measured data. This once again is visible in the Root Mean Square value of the deviation between the modelled and measured discharge, which has a value of 0.207 m^3/s. This is relatively high compared to the model made by Hehenkamp (2019), which had an Root Mean Square of 0.031 m^3/s.

4.1.4. Warm-up period

As can be seen in Figure 7, the modelled discharge spikes early at the start of the simulation. This is caused by the fact that a Sobek model can not start empty

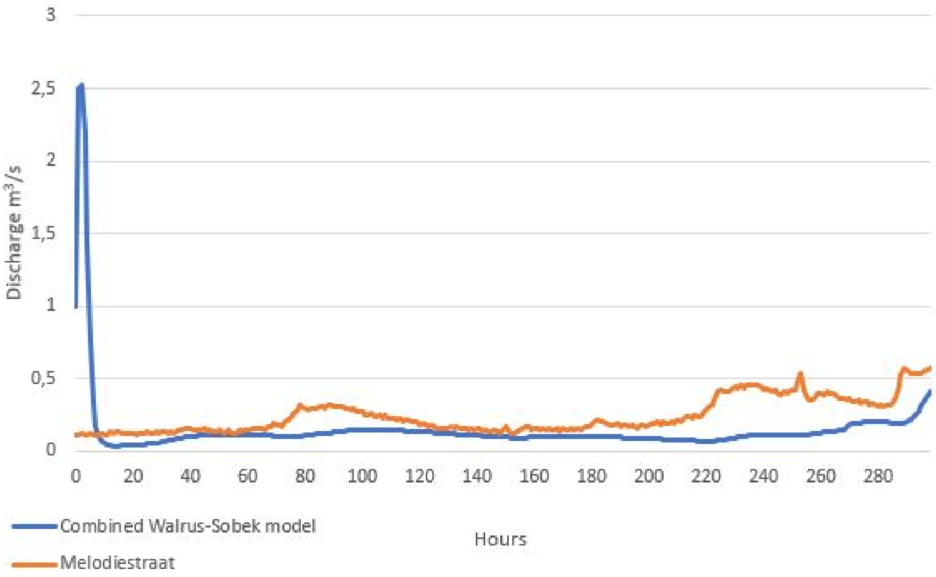


Figure 7: Comparison of the modelled and measured discharge for the first 300 hours of 2017.

and has therefore an initial water level for all trenches. Upon visual inspection of Figure 7, the initial spike disappears after 10 hours. To make the processing of data more convenient, it is therefore decided to take a warm-up period of 24 hours into account.

4.1.5. Other alterations to the model

During test runs, it became apparent that the model would crash when running scenarios BWH and SWH. Because of numerical instability, the water levels at node CONN9467 became too low to keep the model running. Therefore, a constant discharge of 0.01 m^3/s was added at this node in all scenarios to prevent crashes.

4.2. Scenarios

In order to examine the influence of pinching structures and/or climate change on the water system, four scenarios are made. Each scenario uses the same model with relatice changes to the diameters of culverts and changes in climate scenarios. An overview of the scenarios and the similarities and differences between them is given in Table 2.

Table 2: Overview of the different scenarios.

Code	**Culverts**	**Climate**
B	Original diameter	Current climate
S50	50% of the original diameter	Current climate
S25	25% of the original diameter	Current climate
BWH	Original diameter	Climate scenario W_H
SWH	25% of the original diameter	Climate scenario W_H

Culverts can be placed at any location in a water system. Because of time constraints, it was chosen to only look at placing pinch culverts at the locations of the existing culverts. By reducing the diameters of the culverts, they are turned into pinch culverts. After the firsts tests with a 50% reduction of culvert diameters, it became clear that this does not have a significant influence on the behaviour of the water system. Therefore, it was decided to continue modelling with culvert diameters of 25% of the original value.

4.3. Calculating discharge

The goal of placing pinch culverts is water retention during dry periods. This effect is mostly visible in the discharge of the water system. The discharge is therefore measured at the most downstream point of the modelled water system.

4.4. Calculating water levels

Implementation of pinch culverts does also have problems on water levels in the water system. Extreme water levels could cause problems in the form of dry water channels or flooding. It is therefore needed to pay attention to both extremely low and extremely high levels.

Very low levels is measured in the amount of simulated hours that a channel is completely dry. Because it is not possible to model a water depth of 0 in Sobek, water depths of lower than 0.01 meters are be classified as completely dry. Data for this is collected at four different locations throughout the model: at the end

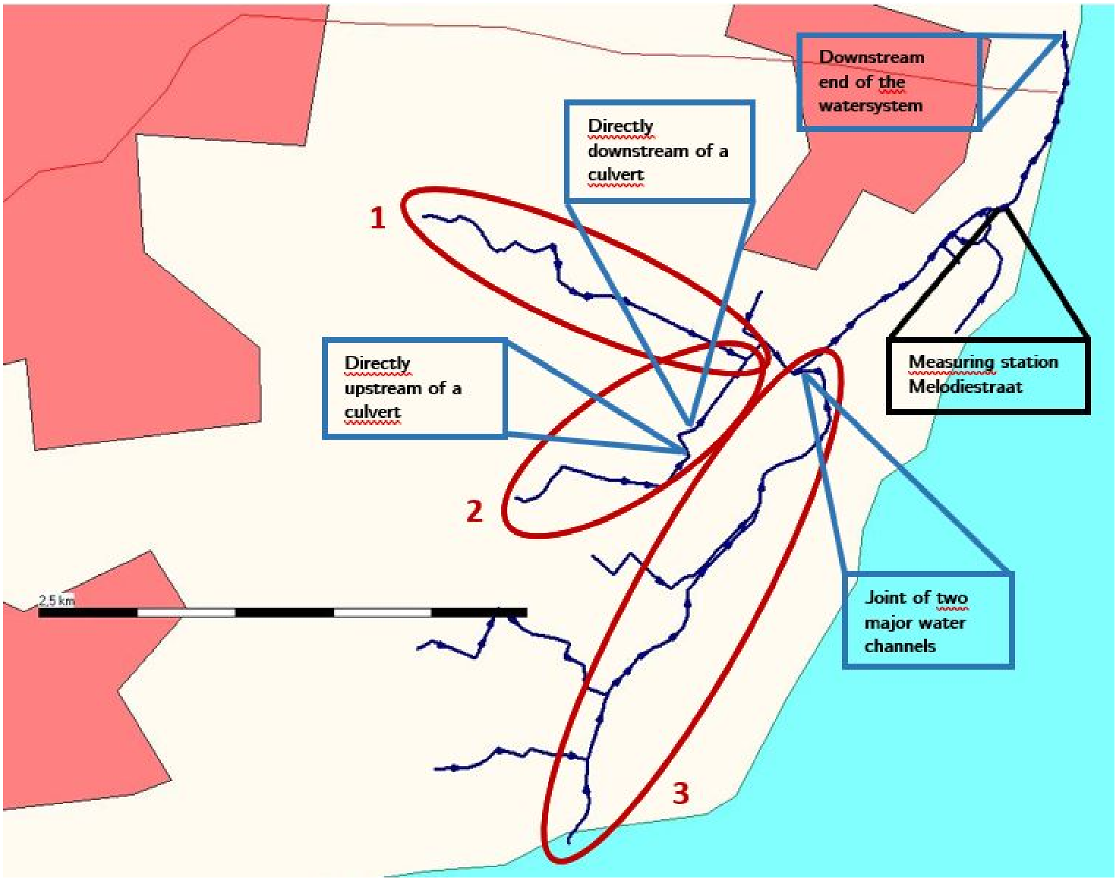


Figure 8: Overview of the model. Locations where low discharges are measured are indicated in blue. Branches of which longitudinal profiles with maximum water levels are made are indicated in red. Measuring station Melodiestraat is indicated in black.

of the water system, at a major joint of two channels and directly upstream and downstream of a culvert. These locations are indicated in blue in Figure 8.

Maximum water levels are measured by looking at the longitudinal profiles generated by Sobek. Longitudinal profiles of three different branches of the water system are made, in which the maximal water heights are depicted together with the surface level. If the water level is above surface level, it will result in flooding. The three branches of which longitudinal profiles are made are indicated in red in Figure 8.

5. Results

In this Chapter, the results of the experiments are visualised and illustrated. The results are presented per scenario, starting with the actual water system. Then, the results from the waterystem with pinch culverts are installed, followed by the scenarios with a future climate both with and without pinch culverts installed. The chapter concludes with a general comparison between the two scenarios.

5.1. Actual characteristics of the watersystem of the Glanerbeek

The simulated discharges for the actual water system are shown with the red line in Figure 9. The highest discharge happens in March 2000 and has a peak of 0.8 m^3/s. During the rest of the simulation period, the discharge does not exceed 0.7 m^3/s and the average peak has a magnitude between 0.3 and 0.4 m^3/s. The average discharge over the simulated 10 years is 0.1 m^3/s.

The maximum water levels are shown in Figure 10 with the continuous red lines. It is visible that the maximum water level is below surface level most of the times, with the exception of halfway the eastern branch of the water system, where the surface level is exceeded (Figure 10c). With the exception of this one location, the size of the existing channels does not cause any major flooding.

Water depths are generally above the threshold of 0.01 meters as visible in Figure 11. The only exception here is at location 2, directly behind a culvert. The water depth dips below the threshold during 883 of the total simulation time of 96412 hours. As this is only 0.9 % of the simulation time, this is not considered to be a problem.

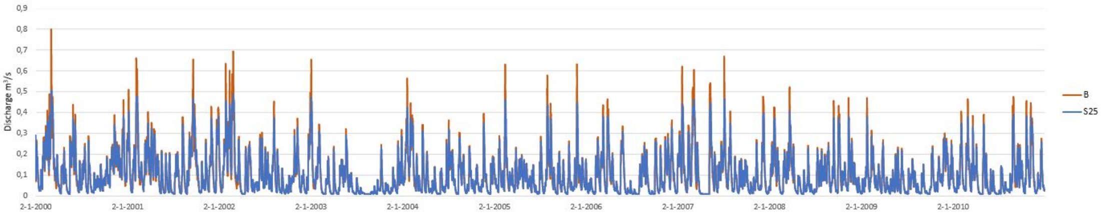
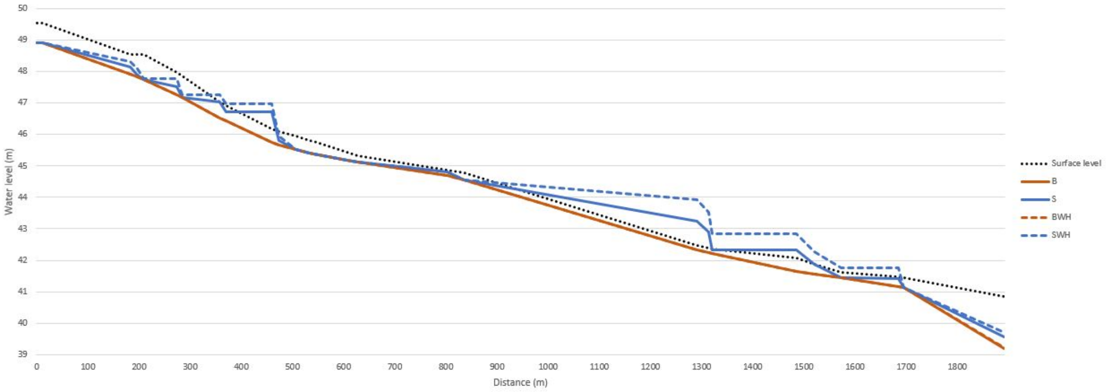
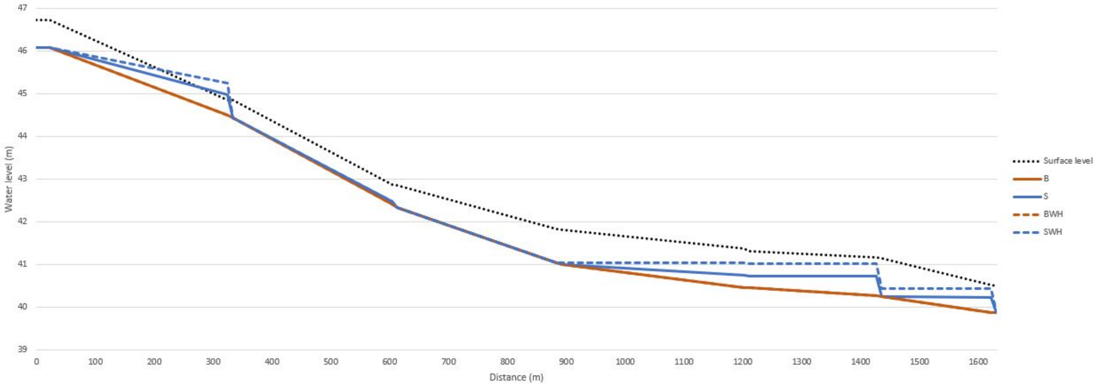


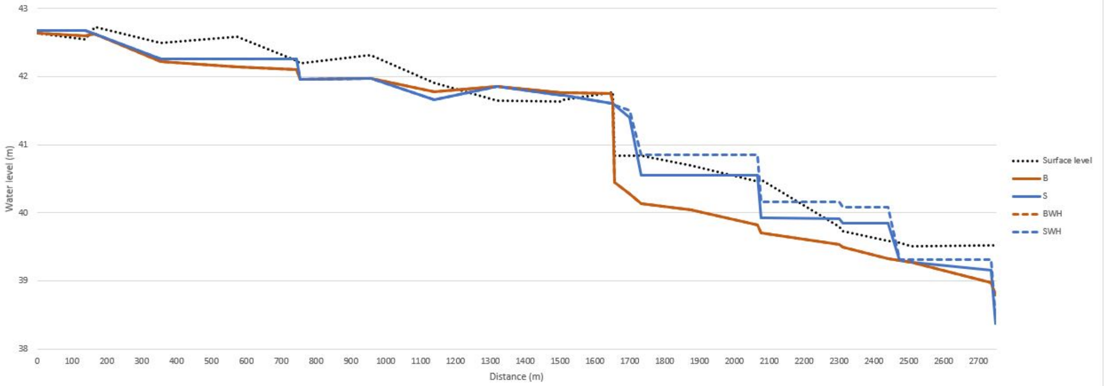
Figure 9: Comparison of the 10-year simulated discharge.



(a) Side view 1, northwest in the water system.



(b) Side view 2, central in the water system.



(c) Side view 3, east in the water system.

Figure 10: Sideviews of three different arms of the water system.

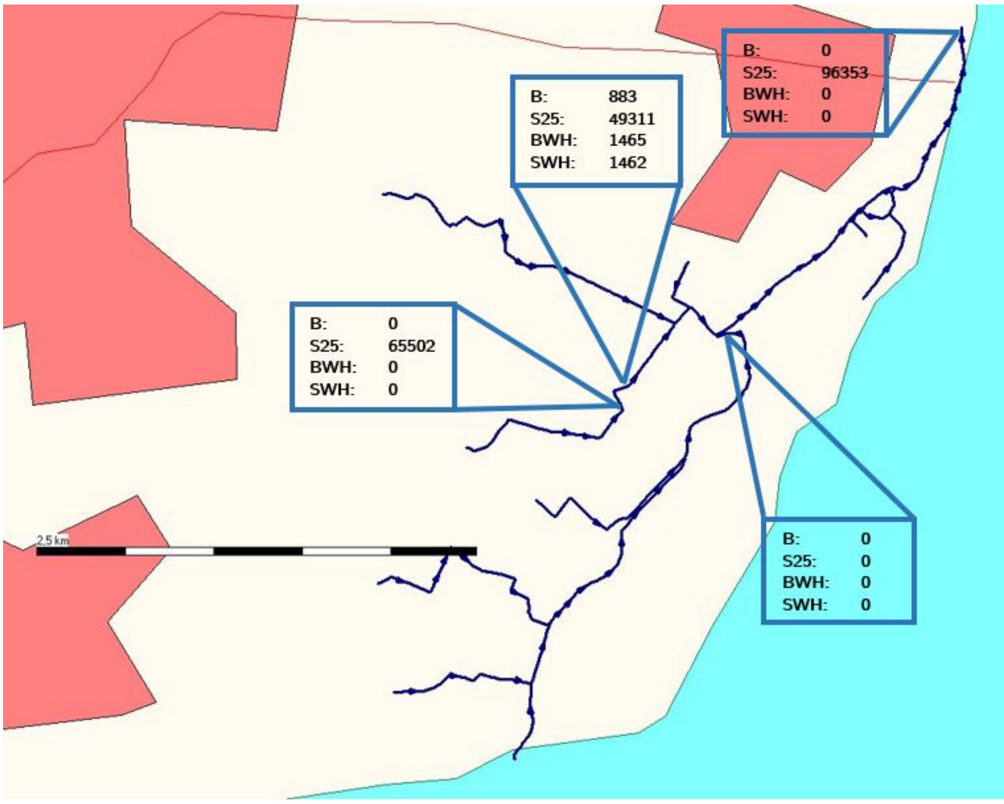
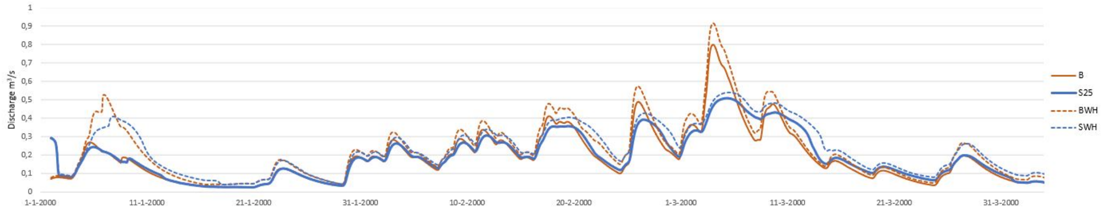


Figure 11: Amount of simulated hours where the water channel is dry (¡0.01 m) at four locations.

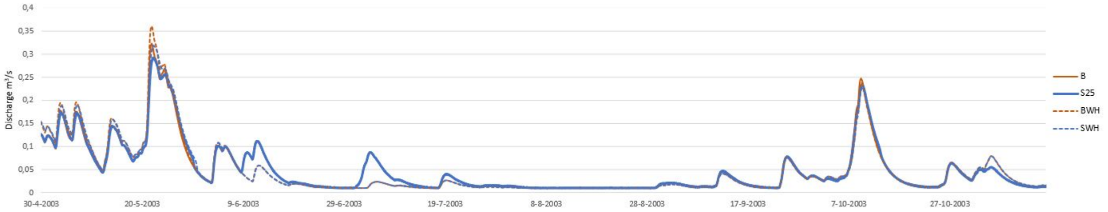
5.2. Characteristics of the water system with pinch culverts installed

The blue line in Figure 9 shows the simulated discharge with pinch culverts installed instead of regular culverts. The main conclusion following from this comparison is that pinch culverts help to reduce the discharge peaks: the maximum discharge has decreased to 0.5 m^3/s and it is visible that all peaks above 0.4 m^3/s are reduced. The average discharge on the other hand does not significantly change and stays 0.1 m^3/s. To investigate the influence of pinch culverts further, three zoom-ins of different situations are made from Figure 9, see Figure 12.

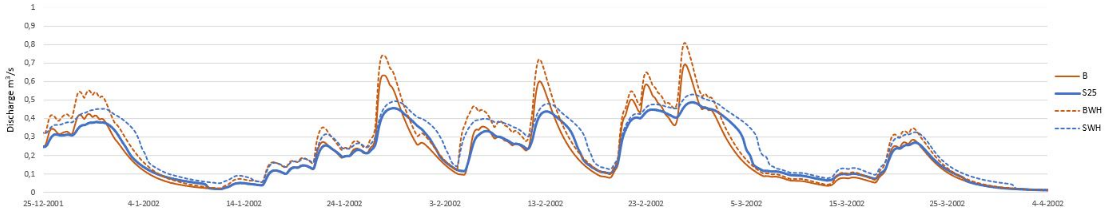
The first zoom-in (Figure 12a) covers the first three months of 2000 and includes the highest discharge peak from the time series. It is clearly visible that the higher the peaks, the more they are reduced with pinch culverts installed. On the other hand do pinch culverts not seem to have an impact on the lower discharges.



(a) Highest peak discharge



(b) Driest period



(c) Three high peaks in rapid succession

Figure 12: 10-year comparison of discharges with three singled out situations.

The installation of pinch culverts also does not seem to flatten the discharge curve: only the top of the peaks are lower. An exception on this happens right after the peak of the 5th of March, where the discharge is spread out into the following peak of the 10th of March. Interesting to note here is that this spreading effect goes on for more than two weeks: the discharge from scenario S25 stays higher than the original discharge until the 28th of March.

The second zoom-in (Figure 12b) includes the very dry summer of 2003. The peaks do show the same as already discussed for Figure 12a. For the long dry period, discharges are more or less the same as in the current situation. In general, pinch culverts do not seem to have an impact on the discharges during this dry period. It should be noted that the discharge is lowest at 0.01 m^3/s, as this is flowing through the modelled system all the time (see Section 4.1.5).

The third zoom-in (Figure 12c) covers three peaks in rapid succession during the first months of 2002. Once again, there are no differences between scenarios B and S25 than the already mentioned muffling effect on the peaks. From Figures 12a and 12c, it comes forward that the pinch culverts start working at discharges of 0.4 m^3/s and higher and that the resulting discharge for scenario S25 never exceeds 0.5 m^3/s.

Compared to scenario B, maximum water heights are above surface level more often, as shown in Figure 10. The longitundinal profiles show that heavy flooding finds place at location 1 and to a lesser extent at location 3. Almost no flooding occurs at location 2. This indicates that the diameter of the culverts in this scenario is too small in certain locations, so that too much water is retained behind the culvert, which leads to flooding.

When looking at the minimum water levels, is is very clear that scenario S25 leads to dry channels very often. At the end of the system, the water height is below the threshold of 0.01 m^3/s in almost 100% of the simulated hours. At location 2, directly behind a pinch culvert, the channel is dry 51% of the time and at the other side of the culvert, this is the case in 68% of the simulated hours. This suggests that there is too much water retained in the water system and that the further downstream you go, the drier channels get, what could mean that a lot of water is retained upstream in the systems. Interestingly, there is no drought at location 3 during the simulation. This is most likely explained by the fact that 0.01 m^3/s was added further upstream in this branch (see Section 4.1.5), as there is not much difference in widths of the channels at locations 1/2 and 3.

5.3. Characteristics of the water system in climate scenario W_H

From the red dashed lines in Figure 12 it becomes apparent that climate change increases the discharges above the actual discharge. Figure 12a shows that the highest discharge increases from 0.8 to 0.9 m^3/s and a similar increase can be seen in multiple peak in Figure 12c. The higher the peak, the higher the increase in discharge becomes, but the overall pattern of the graph does not change. For the dry period in 12b, the discharge of scenario BWH stays more or less the same, compared to scenario B. Because this dry period happens during summer, this is no surprise, as precipitation is mostly expected to increase during winter.

The maximum water levels in Figure 10 do not show an increase from the actual maximum water levels. This is strange, as it could be expected that with higher discharges, also the water depths would increase. The fact that this does not happen could be explained by the size of the culverts. As stated in Section 4.2, a 50% reduction of culvert diameters does not have a significant impact. The existing culverts could therefore be big enough to discharge all extra water from scenario BWH without starting a pinching effect.

In scenario B, water levels were above the threshold of 0.01 meters the whole of the simulation, except at location 2. This stays the same for scenario BWH. The only difference is the amount of hours that the channel right behind a culvert is dry, which increases from 883 to 1465. This difference is however not significant: the percentage of the total simulation time the channel is dry at this location remains 0.9%.

5.4. Characteristics of the water system with pinch culverts installed in climate scenario W_H

Figure 12 show a similar increase from scenario S25 to SWH, which means that the peak discharges are decreased and that this is related to the height of the peak. There is also no change in the pattern of the graph visible, with the exception to two small peaks during the dry summer of 2003 as shown by Figure 12b.

In the current climate, pinch culverts already caused flooding according to the longitudinal profiles (Figure 10). This becomes even worse when pinch culverts are combined with climate change. In the northwest of the system, water levels rise to a highest point of 1.5 meters above surface level, as can be seen in Figure 10a. This problems is less in Figure 10c, but still present. Only in Figure 10b the water level just temporarily exceeds the surface level. The longitudinal profiles clearly show that the chosen size of culvert diameters is too small to discharge a sufficient amount of water to prevent flooding.

Logically following from the higher water levels is that the amount of hours when the channels are dry decreases. At location 1 and 4, the percentage of hours the channel was dry has decreased from 68% and 100% respectively to both 0%. Location 3 is now the only location where dry channels appear, but also this decreased, from 51% to 0.9%.

5.5. Comparison of the results

To give more insight in the frequency and heights of discharges, a discharge duration curve is made for every scenario. These graphs are shown in Figure 13. The effect pinch culverts have on the peak discharges is clearly visible here: the difference between scenario B and S25 is 38%, which is an absolute difference of 0.3 m^3/s.

For the climate change scenarios, it appears that the peak discharge increase from scenario S25 to SWH is smaller than this increase from B to BWH: 8% (0.4 m^3/s) compared to 10% (1 m^3/s). On average, the discharge increase caused by climate change without pinch culverts installed is 11%, while this is 13% with pinch culverts installed. In a future climate, the decrease in peak discharges between scenarios BWH and SWH is 40%, or 3.6 m^3/s.

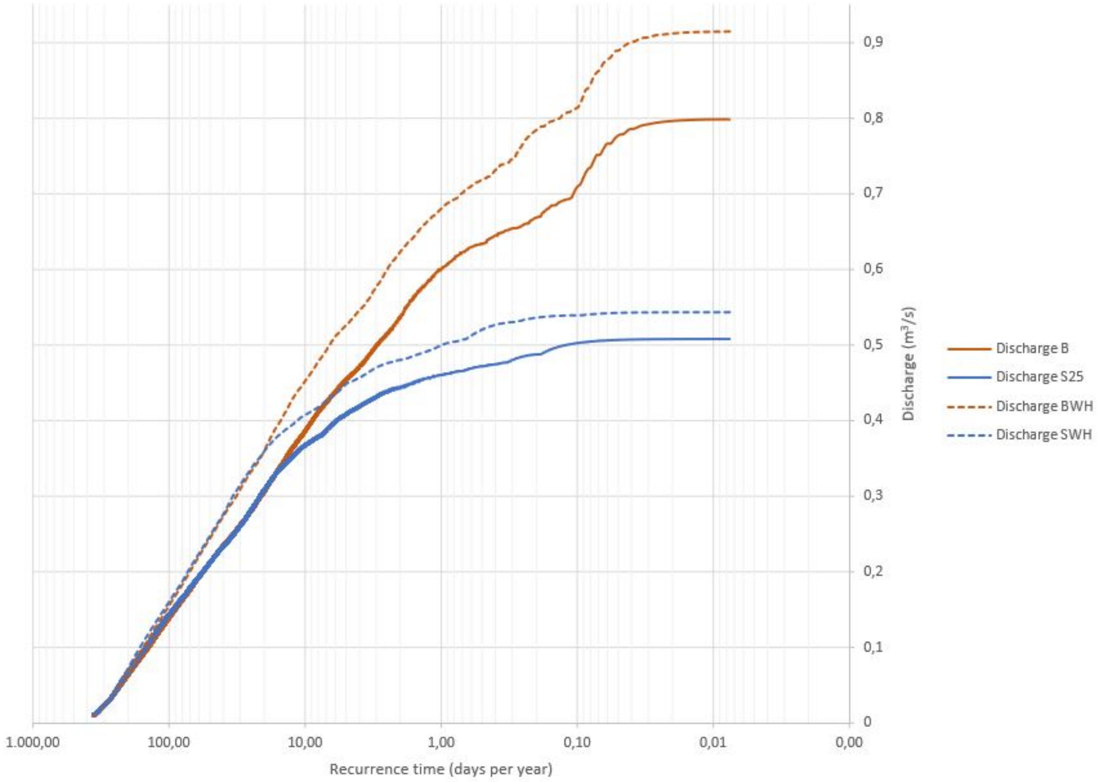


Figure 13: Discharge duration curves for the four scenarios.

When looking at the lower side of Figure 13, shown in Figure 14, it becomes apparent that lower discharges will become more frequent. By looking at the points where the lines divert from each other, we can read the number of days where the installation of culverts has an effect on the discharges. For the current climate this is approximately 240 days. In the climate scenarios, the number of days in which pinch culverts have an influence increases to 260. From this, we can conclude that pinch culverts become more active in a future climate scenario, effectively increasing the amount of days where they make a difference by 8.3%. Once again, the discharges are at lowest 0.01 m^3/s due to model constraints as described in Section 4.1.5.

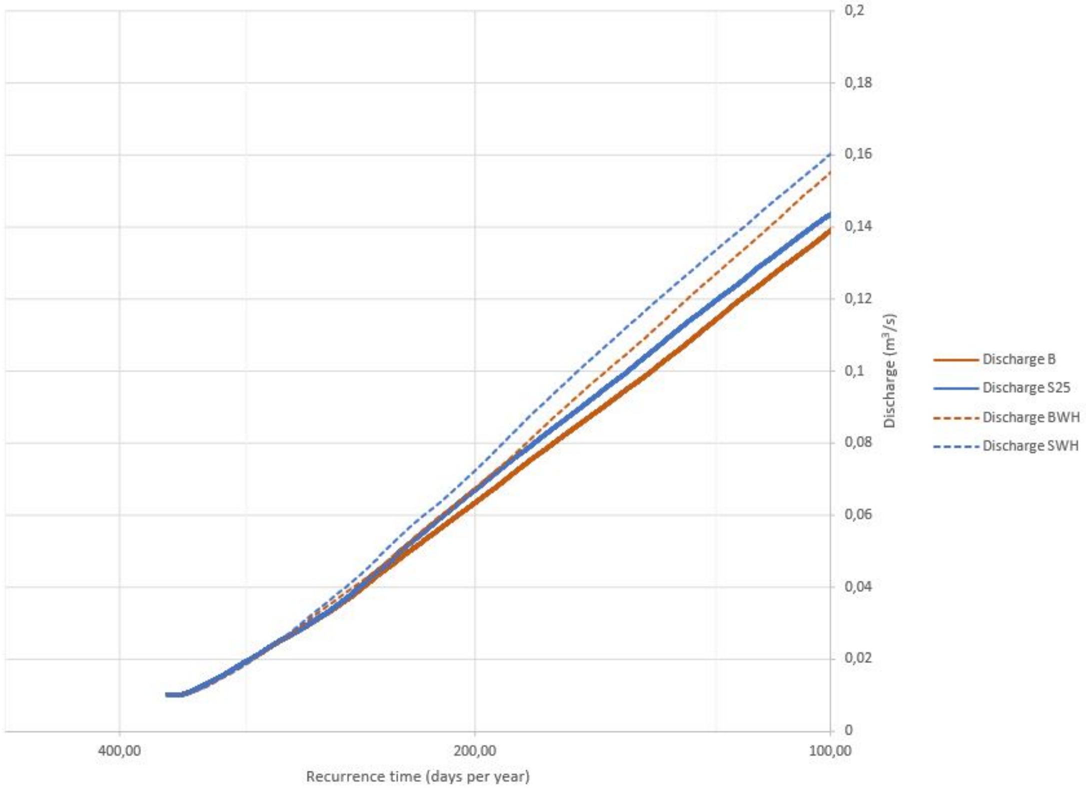


Figure 14: Zoom-in to the lower side of the discharge duration curves for the four scenarios.

6. Discussion

This chapter discusses the results and choices made during the execution of this study. Limitations during the research that have had an effect on the results are discussed in Section 6.1. The results of this study are compared to the results of previous studies in Section 6.2.

6.1. Limitations

6.1.1. Models

Both the original Sobek model and Walrus model have their problems. As already stated in the report written by Attema (2020), the discharge as calculated by the Walrus model does not match the measured discharge: the patterns are the same, but the discharge is consistently lower. According to Attema, this is caused by the lack of reliable data he had available and the fact that seepage and infiltration were not properly included in the model. This may have caused the calibration to not be exact. Because this study works with the parameters from Attema, the discharge results of this study are similarly lower compared to observed data.

The original Sobek model is a very basic model which only contains the major water channels. This makes the absolute results less realistic, as a large number of smaller, private ditches is not included into the model. Hehenkamp (2019) constructed a model that includes all these ditches, but this model is not available anymore. To greatly increase the reliabiliy of the results of this study, Hehenkamps model should have been recreated.

6.1.2. Data

The data which is used for this study was collected at measurement station De Bilt. To make the results more applicable to the study area, data from measurement station Twenthe could be used. The reason this has not been done for this study is that data for climate scenario W_H is not available for this location. Data from the Bilt might not be applicable to the study area, as they are 120 kilometers apart.

6.1.3. Design of pinching structures

It was not possible to model a pinch weir for this study. Possibly, a pinch weir could be modelled as a culvert which is raised above the channel bed. More research could be done in the possibilities of this or other solutions that make modelling an effective pinch weir possible.

Similarly, the pinch culverts in the model used for this study do not have an overflow, while this could be the case for real culverts. Including this into the model could have effects on the discharge, but mostly the water levels at every pinch culvert. This could prevent the flooding which is visible in Figure 10.

6.2. Comparison of the results to Hehenkamp (2019) and Attema (2020)

The results from Hehenkamp (2019) showed a similar conclusion to the results of this study. Installing pinch culverts in the main channels of the water system decreases the peak discharges.Interestingly, pinch culverts had more of a flattening effect on the dicharge peaks in Hehenkamps study than came forward in this research. This could be explained by the fact that Hehenkamp included all smaller branches of the water system in his model as well, while that has not been done for this study. Hehenkamps study also showed slightly lower water levels behind pinch culverts than behind regular culverts. This corresponds to the results from this research and can be explained by the fact that pinch culverts discharge less water, causing lower water levels downstream of the structure.

Attema (2020) concluded that the discharge from the study area would increase with 4% in climate scenario W_H. The difference shown in this study between discharge during reference climate and scenario W_H is 12%. Because the used reference years are not the same, these results can not be directly compared. Yet, the difference of 8 percentage point is quite large. A potential reason for this difference are the different methods for potential evaporation used in the studies: Attema used the method of Thom-Oliver combined with Penman-Monteith (TOPM), while this study uses data from the KNMI which is calculated using the method of Makkink.

7. Conclusions and recommendations

7.1. Conclusion

This study has shown that the average discharge in the water system of the Glanerbeek is 0.1 m^3/s, but that this fluctuates between basically 0 and 0.8 m^3/s. The water system currently never overflows, as the water channels and the culverts present in the area are well-sized for the amount of water the system has to process.

The study has also shown that pinch culvert with a diameter of 50% of the original diameter have almost no effect on discharge and water levels. Pinch culverts where the diameter is 25% of the original do however have a great influence on the discharge of the water system. Implementing pinch culverts causes the peak discharges to drop by 38% and in general they influence the discharge during 240 days of the year. The study does however not show that pinch culverts retain more water during dry periods: although the peaks are decreased, they are only slightly flattened, which does not lead to more discharge in drier times. These pinch culverts do on the other hand cause (severe) flooding in the study area during high water levels and cause channels to fall dry during dry periods.

Lastly, the study has shown that climate change increases the discharge in all but very dry situations, both with and without culverts installed. Once again, the effect of pinch culverts on the discharges are decreased but unflattened peaks. Climate change in combination with pinch culverts cause heavy flooding throughout the area during high water levels, but there are little to no dry channels during dry periods.

It can be concluded that pinch culverts do have a positive influence on the discharge of the study area, but cause problems concerning water levels. It is strongly recommended to install pinching structures in the future, as pinch structures can compensate for the effects of climate change on the discharge of the Glanerbeek. Implementation of pinch culverts does however require a more detailed research into the dimensions of these structures.

7.2. Recommendations for further research

For any continuation or follow-up of this research, it is recommended to consider three things. Firstly, to reconsider the calibration of the Walrus model made by Attema (2020). Secondly, to recreate the detailed model of the water system of the Glanerbeek made by Hehenkamp (2019). Thirdly, to check whether the data needed is available at measuring station Twenthe.

Further research could be done into the locations and corresponding effects of pinch culverts and pinch weirs. This study only looked into pinch culverts at the locations of already existing culverts, but this does not have the be the most efficient configuration.

Another suggestion is to optimize the configuration of pinch culverts used for this research. This study has shown that one universal diameter causes problems regarding water levels. A detailed analysis of the water system could make it possible to design multiple pinch culvert sizes. The height of the culvert above the channel bed and an overflow could also be taken into consideration, as does the application of pinch weirs.

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Appendices

A. Nodes at which water levels are calculated

Table 3: Overview of the four locations where water depths are measured.

Location	**Node name**	**Description**
1	fxcpAV01177_42	Directly uptream of a culvert
2	fxcpAV01177_43	Directly downstream of a culvert
3	fxcpAV16712_28	Joint of the major water channels central in the water system
4	fxcpAV06037_15	Downstream end of the water system

B. Walrus parameters

Table 4: Walrus parameters part 1

Walrus area	**ar**	**wa**	**cw**	**cv**	**cg**	**cq**	**va**	**ba**	**qa**	**cs**	**cd**	**xs**	**hst**	**hsmin**	**as**	**st**	**hs0**	**hq0**	**dg0**	**dv0**	**q0**
0	399929	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	0.403	800.	1.5	0	0.0	0.008	22	44.01	0.72	802.5	149.78	0.0251
1	24057	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	2.765	1500.	1.5	0	0.0	0.008	22	44.01	0.72	158.5	149.78	0.0251
2	23628	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	0.403	800.	1.5	0	0.0	0.008	22	44.01	0.72	92.5	149.78	0.0251
3	154444	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	1.417	1200.	1.5	0	0.0	0.008	22	44.01	0.72	166	149.78	0.0251
4	341126	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	0.814	1000.	1.5	0	0.0	0.008	22	44.01	0.72	140.5	149.78	0.0251
5	66740	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	2.765	1500.	1.5	0	0.0	0.008	22	44.01	0.72	186	149.78	0.0251
6	386186	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	0.814	1000.	1.5	0	0.0	0.008	22	44.01	0.72	520	149.78	0.0251
7	58444	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	1.417	1200.	1.5	0	0.0	0.008	22	44.01	0.72	87.5	149.78	0.0251
8	18941	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	2.765	1500.	1.5	0	0.0	0.008	22	44.01	0.72	124	149.78	0.0251
9	1510	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	2.765	1500.	1.5	0	0.0	0.008	23	44.01	0.72	140	149.78	0.0251
10-40-43	152653	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	1.327	1100.	1.5	0	0.0	0.008	22	44.01	0.72	246.5	149.78	0.0251
11	829913	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	0.814	1000.	1.5	0	0.0	0.008	23	44.01	0.72	170	149.78	0.0251
12	165201	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	0.814	1000.	1.5	0	0.0	0.008	23	44.01	0.72	114	149.78	0.0251
13	32992	-1	569.87	49.655	19365910.	63.84	-1	-1	-1	0.403	800.	1.5	0	0.0	0.008	22	44.01	0.72	291	149.78	0.0251
14	962153	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	1.417	1200.	1.5	0	0.0	0.008	22	44.01	0.72	505	149.78	0.0251
15	30949	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	2.765	1500.	1.5	0	0.0	0.008	22	44.01	0.72	239	149.78	0.0251
16	359108	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	1.417	1200.	1.5	0	0.0	0.008	22	44.01	0.72	113.5	149.78	0.0251
17	360338	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	1.417	1200.	1.5	0	0.0	0.008	22	44.01	0.72	72.5	149.78	0.0251
18	478025	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	1.417	1200.	1.5	0	0.0	0.008	23	44.01	0.72	51	149.78	0.0251
19	14670	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	0.814	1000.	1.5	0	0.0	0.008	21	44.01	0.72	111	149.78	0.0251
20	151979	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	1.417	1200.	1.5	0	0.0	0.008	23	44.01	0.72	73.5	149.78	0.0251
21	29	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	2.765	1500.	1.5	0	0.0	0.008	23	44.01	0.72	170	149.78	0.0251
22	80305	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	0.814	1000.	1.5	0	0.0	0.008	23	44.01	0.72	83	149.78	0.0251

Table 5: Walrus parameters part 2

Walrus area	ar	wa	cw	cv	cg	cq	va	ba	qa	cs	cd	xs	hst	hsmin	as	st	hs0	hq0	dg0	dv0	q0
23	32629	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	1.417	1200.	1.5	0	0.0	0.008	23	44.01	0.72	74	149.78	0.0251
24	4327	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	2.765	1500.	1.5	0	0.0	0.008	23	44.01	0.72	81.5	149.78	0.0251
25	16656	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	2.765	1500.	1.5	0	0.0	0.008	21	44.01	0.72	89	149.78	0.0251
26	13246	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	0.814	1000.	1.5	0	0.0	0.008	21	44.01	0.72	170	149.78	0.0251
27	87303	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	0.814	1000.	1.5	0	0.0	0.008	23	44.01	0.72	125.5	149.78	0.0251
28	67417	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	1.417	1200.	1.5	0	0.0	0.008	22	44.01	0.72	153.5	149.78	0.0251
29	109638	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	0.814	1000.	1.5	0	0.0	0.008	22	44.01	0.72	142.5	149.78	0.0251
30	323664	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	0.403	800.	1.5	0	0.0	0.008	21	44.01	0.72	31	149.78	0.0251
31	22148	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	1.417	1200.	1.5	0	0.0	0.008	22	44.01	0.72	88.5	149.78	0.0251
32	44569	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	2.765	1500.	1.5	0	0.0	0.008	22	44.01	0.72	293.5	149.78	0.0251
33	18137	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	2.765	1500.	1.5	0	0.0	0.008	23	44.01	0.72	50.5	149.78	0.0251
34	431674	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	1.417	1200.	1.5	0	0.0	0.008	22	44.01	0.72	960.5	149.78	0.0251
35	954365	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	0.403	800.	1.5	0	0.0	0.008	22	44.01	0.72	531.5	149.78	0.0251
36	109474	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	0.814	1000.	1.5	0	0.0	0.008	21	44.01	0.72	70.5	149.78	0.0251
37	188431	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	0.814	1000.	1.5	0	0.0	0.008	22	44.01	0.72	210.5	149.78	0.0251
38	193004	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	0.814	1000.	1.5	0	0.0	0.008	22	44.01	0.72	63.5	149.78	0.0251
39	69719	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	2.765	1500.	1.5	0	0.0	0.008	23	44.01	0.72	88.5	149.78	0.0251
41	1762	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	0.814	1000.	1.5	0	0.0	0.008	23	44.01	0.72	147.5	149.78	0.0251
42	8520	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	1.417	1200.	1.5	0	0.0	0.008	21	44.01	0.72	80	149.78	0.0251
44	7232	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	2.765	1500.	1.5	0	0.0	0.008	21	44.01	0.72	125	149.78	0.0251
45	83568	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	2.765	1500.	1.5	0	0.0	0.008	22	44.01	0.72	192.5	149.78	0.0251
46	143107	-1	569.87	49.655	19635910.	63.84	-1	-1	-1	0.814	1000.	1.5	0	0.0	0.008	22	44.01	0.72	109	149.78	0.0251

C. Brief explanation on how to connect a Walrus model to a Sobek model.

- Walrus is implemented by means of a special RR-node This type of node is unavailable in the standard released GUI. Therefore, the user has to add this node manually.
    1. Go to the folder *Sobek\Programs\INI*.
    2. Open the file *ntrpluv.ini*.
    3. At line 207, increase Number of Types from 67 to 69.
    4. At line 3584, add the text from Section C.1.
    5. Open the file *ntrpluv.ini*.
    6. At line 246, increase Number of Types from 67 to 69.
    7. At line 3622, add the text from Section C.2.

- Now it is necessary to make sure Sobek uses the Walrus concept instead of an older version.
    1. Open the folder *Delft 3b.ini* by typing this into the Windows search bar.
    2. Under *Options*, add the switch *UseWalrusorWagmod=Walrus*. If this switch already exists, just replace it.

- In the Netter of a Sobek project, it should now be possible to add the RR-node *69, RR - Wageningen Model*. In the standard Sobek GUI, it is possible to edit the ID and Name of such a RR-node, but other information has to be done in the Sobek files.
    1. Go to the folder *Sobek\Project\WORK\SACRMNTO.3B*
    2. Add the text from Section C.3 once for every Walrus node.
    3. Change the values of the parameter accordingly to the results of a Walrus model. The Sobek manual gives an overview of the units and contents of each parameter. Make sure that the ID corresponds to the right RR-node in the Sobek model.

- The values for precipitation, evaporation and parameters FXG and FXS are read from a rainfall file (*.BUI*).
    1. Make a (new) rainfall file in *Precipitation* in the block *Meteorological Data* in Sobek.
    2. Add four stations. Make sure that the names of the stations correspond to the names inside brackets for the parameters *ms*, *evapms*, *fxg* and *fxs* in the file *SACRMNTO.3B*.

3. Add data for each of the four stations/parameters for every timestep and save the rainfall file.

C.1. Text to add to ntrpluv.ini

```
68 Type=RR - LGSI node
68 ID=3B_LGSI
68 BNAname=RR_LGSI
68 In Use=0
68 Visible=-1
68 LabelInactive=0
68 SymbolType=9
68 BorderColor=0
68 FillColor=32896
68 Show in ModelData=0
68 Number of Models=2
68 Model 1 Name=3B
68 Model 1 Index=22
68 Model 1 AllowData=-1
68 Model 2 Name=WLM
68 Model 2 Index=8
68 Model 2 AllowData=-1
68 Active DataEdit=1
68 Syst=SYS_DEFAULT
68 Reach element=0
68 Reach StartEnd=0
68 AllowLinkage=0
68 Grid element=0
68 GridElementFixed=0
68 AllowCalculationPoint=-1
68 AllowCalculationPointToggle=-1
68 CalculationPointIsOn=0
68 CalculationPointIsVirtual=0
68 CalculationPointMinDistDefaultID=
68 CalculationPointMinDistDwn=0
68 CalculationPointMinDistUp=0
68 Spine element=0
68 IncludeInScaleData=-1
68 IncludeInTableView=-1
```

```
68 MonitorStation=0
68 WithD2Grid=0
68 ConnectToD2Grid=0
68 ConnectToD2GridWithValidCP=0
68 Allow Delwaq=0
68 SurfaceWaterType=
68 DelwaqStructure=0
68 Allow boundaries=0
68 Number of boundaries=0
68 MinTo=0
68 MaxTo=0
68 MinFrom=1
68 MaxFrom=1
68 Metafile=
68 PictureActive=0
68 WLM function=
69 Type=RR - Wageningen Model
69 ID=3B_WAGMOD
69 BNAname=RR_WAGMOD
69 In Use=0
69 Visible=-1
69 LabelInactive=0
69 SymbolType=9
69 BorderColor=0
69 FillColor=1872539
69 Show in ModelData=0
69 Number of Models=2
69 Model 1 Name=3B
69 Model 1 Index=23
69 Model 1 AllowData=-1
69 Model 2 Name=WLM
69 Model 2 Index=8
69 Model 2 AllowData=-1
69 Active DataEdit=1
69 Syst=SYS_DEFAULT
69 Reach element=0
69 Reach StartEnd=0
69 AllowLinkage=0
69 Grid element=0
```

```
69 GridElementFixed=0
69 AllowCalculationPoint=-1
69 AllowCalculationPointToggle=-1
69 CalculationPointIsOn=0
69 CalculationPointIsVirtual=0
69 CalculationPointMinDistDefaultID=
69 CalculationPointMinDistDwn=0
69 CalculationPointMinDistUp=0
69 Spine element=0
69 IncludeInScaleData=-1
69 IncludeInTableView=-1
69 MonitorStation=0
69 WithD2Grid=0
69 ConnectToD2Grid=0
69 ConnectToD2GridWithValidCP=0
69 Allow Delwaq=0
69 SurfaceWaterType=
69 DelwaqStructure=0
69 Allow boundaries=0
69 Number of boundaries=0
69 MinTo=0
69 MaxTo=0
69 MinFrom=1
69 MaxFrom=1
69 Metafile=
69 PictureActive=0
69 WLM function=
```

C.2. Text to add to ntrpluvr.ini

```
68 Type=RR - LGSI node
68 ID=3B_LGSI
68 BNAname=RR_LGSI
68 In Use=0
68 Visible=-1
68 LabelInactive=0
68 SymbolType=9
68 BorderColor=0
68 FillColor=32896
```

```
68 Show in ModelData=0
68 Number of Models=2
68 Model 1 Name=3B
68 Model 1 Index=22
68 Model 1 AllowData=-1
68 Model 2 Name=WLM
68 Model 2 Index=8
68 Model 2 AllowData=-1
68 Active DataEdit=1
68 Syst=SYS_DEFAULT
68 Reach element=0
68 Reach StartEnd=0
68 AllowLinkage=0
68 Grid element=0
68 GridElementFixed=0
68 AllowCalculationPoint=-1
68 AllowCalculationPointToggle=-1
68 CalculationPointIsOn=0
68 CalculationPointIsVirtual=0
68 CalculationPointMinDistDefaultID=
68 CalculationPointMinDistDwn=0
68 CalculationPointMinDistUp=0
68 Spine element=0
68 IncludeInScaleData=-1
68 IncludeInTableView=-1
68 MonitorStation=0
68 WithD2Grid=0
68 ConnectToD2Grid=0
68 ConnectToD2GridWithValidCP=0
68 Allow Delwaq=0
68 SurfaceWaterType=
68 DelwaqStructure=0
68 Allow boundaries=0
68 Number of boundaries=0
68 MinTo=0
68 MaxTo=0
68 MinFrom=1
68 MaxFrom=1
68 Metafile=
```

```
68 PictureActive=0
68 WLM function=
69 Type=RR - Wageningen Model
69 ID=3B_WAGMOD
69 BNAname=RR_WAGMOD
69 In Use=0
69 Visible=-1
69 LabelInactive=0
69 SymbolType=9
69 BorderColor=0
69 FillColor=1872539
69 Show in ModelData=0
69 Number of Models=2
69 Model 1 Name=3B
69 Model 1 Index=23
69 Model 1 AllowData=-1
69 Model 2 Name=WLM
69 Model 2 Index=8
69 Model 2 AllowData=-1
69 Active DataEdit=1
69 Syst=SYS_DEFAULT
69 Reach element=0
69 Reach StartEnd=0
69 AllowLinkage=0
69 Grid element=0
69 GridElementFixed=0
69 AllowCalculationPoint=-1
69 AllowCalculationPointToggle=-1
69 CalculationPointIsOn=0
69 CalculationPointIsVirtual=0
69 CalculationPointMinDistDefaultID=
69 CalculationPointMinDistDwn=0
69 CalculationPointMinDistUp=0
69 Spine element=0
69 IncludeInScaleData=-1
69 IncludeInTableView=-1
69 MonitorStation=0
69 WithD2Grid=0
69 ConnectToD2Grid=0
```

```
69 ConnectToD2GridWithValidCP=0
69 Allow Delwaq=0
69 SurfaceWaterType=
69 DelwaqStructure=0
69 Allow boundaries=0
69 Number of boundaries=0
69 MinTo=0
69 MaxTo=0
69 MinFrom=1
69 MaxFrom=1
69 Metafile=
69 PictureActive=0
69 WLM function=
```

C.3. Walrus template SACRMNTO.3B

```
WALR id ’9’ ar 90000000 wa -1 cw 200. wit ’none’ cv 10. cg 30000000.
cq 30. va -1 vit ’none’ ba -1 bit ’none’ qa -1 qit ’none’ cs 5
cd 1500.  xs 1.5 hst 0 hsmin 0.0 as 0.013 st 21 hs0 44.01 hq0 0.72
dg0 1300 dv0 149.78 q0 0.0251 ms ’rain’ evapms ’evap’ fxg ’fxg’ fxs
’fxs’ walr
```