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Water tank Dobbelmannklooster

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Preface

Looking for a research, I came across Frits Ogg's request for a student to perform calculations on a water tank. He stated that he and his neighbours installed a water tank in their garden, all by themselves. This water tank would then catch and store rainwater that falls down and this water would be used for toilets and washing machines. After the tank was installed, however, they noticed that there were a few problems. Since none of the neighbours and himself included were engineers specialised in a water area, Frits Ogg, one of the residents, thought it was a great idea to have a student look at the project and its involved issues. They contacted NovelT, a company located on the University of Twente campus, and through them I discovered this assignment and immediately found it an interesting project.

The reason for writing this report is that I want to show other people, who are thoughtful about their water use, that this is an option. I want to make it easier for these people to implement such a tank, by showing what parts are necessary and how the tank works in different circumstances. For this reason I have also added recommendations on what to expect and avoid, composed together with Frits Ogg and Wijndel de Waal, who are the experts concerning the tank system.

This is also why I first would like to thank Frits and Wijndel. They have been really patient with all of my questions and helped me often as well as they were able to. If I asked them something about the tank, they would make sure to look into everything they had ever collected of that subject and email it to me as soon as possible. Especially Frits, who was involved from the very beginning and never lost his enthusiasm.

Then I would really like to thank dr. M.S. Krol, my supervisor. He was always available for questions, whether it was by email or during a meeting. He also really helped me with shaping my report and figuring out which subjects were the most important to include. I am most thankful for his ability to have me think about my problems regarding the research and how to handle them adequately.

Even though we have not had much contact, I would also like to thank Egbert van Hattem, from NovelT. He introduced me to this matter and would occasionally ask if I needed something and how everything was going.

Lastly I would like to thank my family, for proofreading the final version of this report but most of all for supporting me, helping me and always staying interested in this project. I also want to thank my friends, for being there for me and helping me through my struggles.

Maartje Geurts

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Summary

At the Dobbelmannklooster in Nijmegen, a tank system is placed into the ground. The tank is collecting and temporarily storing rain water for household usage and infiltration crates are in place for surplus rain water. The whole system is providing water to the four connected washing machines inside the monastery. The goal of this research was to determine whether or not the tank system provides the amount of water, with the required quality, that the residents need and if this would work out in future scenarios as well. For the purpose of answering this question, a MatLab model has been built that simulates the workings of the tank and its infiltration crates. Further research questions were drawn up to get a concrete picture of the workings of the tank.

The first research question went further into the water quality topic. In May 2018 a heavy rain shower caused unfiltered rain water to enter the tank and mix with the filtered water. This then caused laundry clothes to smell dirty and unwashed. A hypothesis was that the infiltration crates got too full due to the sudden amount of rain and water flowed back up into the tank. With the outcome of the model, this hypothesis was disproven. The model pointed out that the infiltration crates were not full during the whole month of May, making the hypothesis untrue. Another solution has yet to be found.

To answer how many days in the year the tank provides water to the residents the model was run again. In its current state, with only four washing machines, the model showed that extra water was necessary on 22 days of the year. With five extra toilets and one extra washing machine added to the system, this number increased to 71 days of extra water necessary.

The effect that heavy rain has on the tank is measured by choosing a rainfall intensity of $65\,\frac{mm}{hour}$, which has a repetition time of once every one hundred years. It was determined that the tank would be full at the start of the simulation, since the tank is full the majority of the year. The results of the simulation showed that the tank stayed full the whole time which meant that all the water entering the tank system would directly go to the infiltration crates. This did not fill up the infiltration crates, which means that the tank system has no trouble processing heavy rain.

Climate change was a cause of concern for the tank. The effects of climate change could be that there is either lots more rain, or longer periods of draught. Both could have a considerable effect on the tank. Scenario W_L, in which there would be more rain, has been tested on the tank. The main fear was that there would not be enough infiltration crates for the increased precipitation. However, the soil underneath the crates has such a high permeability that no water is collected inside the crates. The tank then usually still provides enough water for the residents, they only need to add water on 70 days of the year. Scenario W_H expects longer periods of draught. Running the model showed indeed that extra water was necessary on 72 days of the year.

The ideal amount of tank volume depends on preference and expectations. If the residents would not have wanted to add extra water, the ideal volume of the tank would be $12{,}3\ m^3$. With this volume the tank would be able to store enough water to keep providing to the resident's needs, even in the dry periods of summer. However, a tank of that volume is bigger and takes up more space than the tank that is already in place. For the infiltration crates, it turns out that only one crate is necessary to take care of the excess water. The permeability of the soil is high enough to infiltrate the water quickly.

1 Introduction

In the introduction it is explained how the research came to be, what the motivation was behind it and the research questions. It also elaborates on which methods are used and which data is important. Lastly it describes the report structure.

1.1 Context

In the middle of the Dutch city Nijmegen a large monastery has been transformed into a home for 36 residents. The foundation to maintain the Dobbelmannklooster is a foundation set up to have the residents involved in the process of making the monastery, with its habitants, more sustainable. Back in 2009, the residents decided to replace an old oil tank in the garden with a water tank, which collects rainwater and stores it. After the tank was installed, these residents installed the water pipes running from the tank towards the houses, to use the harvested rainwater for toilets and washing machines. In order to achieve a sufficient quality of this water, a filter is installed right before the water gets distributed to the different machines. This filter, consisting of three different filter mechanisms, removes small particles, smells and colour (Fijnfilters, 2019). When the tank gets full, excess water flows towards infiltration crates, implemented deeper into the ground.

The goal of implementing this water tank is to make households more sustainable. The residents show that they are thoughtful about the future. With climate change happening, it is suspected that heavier and more frequent rains will occur (Milieu, 2018). These heavier rains will bring problems such as water damage and sewer nuisance. The water tank is uncoupled from the sewerage which enables it to be a space for storing water. This provides a solution to dealing with these water overflows and turning it into something useful.

Another expected climate change scenario that might happen in the future is that temperatures rise and periods of drought during the summer will elongate (Milieu, 2018). Drinking water will be harder to get by and due to this water tank, less drinking water will be needed for functions that do not require such clean water.

1.2 Motivation

My main motivation for choosing this project instead of others, is that I really want to contribute to a more sustainable way of living. I find the environment extremely important and I am convinced that lots of changes need to be made, either in order to get climate change to slow down or to be able to live with the effects. Using less drinking water in households and capturing rainwater in uncoupled systems are a few of those changes. With this project I am hoping to show that we, as people, need to be more thoughtful about the future and the water we use. And even though the project does not seem financially profitable at first sight, it shows that active residents care enough to invest in a more sustainable way of living.

1.3 Goal

1.3.1 Research aim

The aim of this research is to show how the tank system functions and if it functions well enough according to the residents' needs. Throughout the year, the residents find the tank working well enough, but in May 2018 there has been a really heavy rainfall. Due to this rainfall, dirty water ended up in the tank and messed up the tank filter, which then resulted in washed clothes smelling dirty. It is hypothesized that during this rainfall, the ground underneath the crates could not infiltrate the large amount of water fast enough and the crates filled up. This might have led to unfiltered water flowing back into the tank (despite the check valve), pushing off the lid of the tank filter which then caused unfiltered water to enter the tank.

Usually there is enough water in the tank for the current residents connected to the tank, but in the future they want to add five more toilets and a washing machine to the chain of the four washing machines already in place. It is questionable if there will still be enough water in the tank for these extra usages.

Since climate change is happening and the effects will be noticeable within the following decades, these occurrences have to be taken into account as well. There are different scenarios predicted, but only the ones where there either is going to be a lot more rain or long periods of draught might alter the functionality of the tank and the rest of the system.

With the results of this research, the residents of the Dobbelmannklooster have enough information to determine whether or not their system of infiltration crates is still functioning well enough, or if they need to think of other options. They also have the possibility to simulate scenarios further ahead, enabling them to make decisions based on a future perspective.

Another outcome of this research is that it gets easier for other residents, or even big companies, to implement such a water tank. The results will give a clear vision on what to expect when using a water tank and will provide guidelines on how many infiltration crates are needed.

1.3.2 Research questions

The main focus of this research is to discover how well the tank system works currently and in future scenarios. In order to provide a broad understanding of this general question, a few other questions need to be answered first. These are the following:

1. Is the hypothesis about the origin of the dirty water, in May 2018, possible?
2. In its current state, how many days in the year does the tank provide enough water for the residents? What is the situation when extra toilets and washing machines are added?
3. What effect does a heavy rain have on the workings of the tank?
4. Will problems occur due to climate change?
    a. What happens when the amount of rain increases?
    b. What happens when the amount of rain decreases?
5. For their current situation, did the residents make the right decisions regarding the tank volume and the amount of infiltration crates?

1.4 Method & data

As stated before, the goal of the research is to determine whether or not the tank system works well enough for the residents to keep using it. This has been done by constructing a mathematical model, which leads to results from which conclusions can be drawn. The building of this mathematical model is done according to the modelling cycle interpretation of Blum and Leiß (Blum & Leiß, 2006). This approach was chosen because its modelling cycle matched best with the intended structure for this research. The choice for a mathematical model is based on Weisberg's "Three kinds of models" (Weisberg, 2013). Both a concrete and a computational model would take too much time and would be too complicated for the desired results. This does not mean that both of these models cannot be used, but constructing a mathematical model provides satisfactory results and takes less construction and calculation time.

The modelling cycle starts with assessing the situation and the problems. This knowledge leads to construction of a situation model. This model is like a conceptual framework, which shows the expected relations between causes and consequences in the tank system. Certain aspects of this conceptual framework are simplified, after which the events in the model are replaced by mathematical formulas. Results are produced, interpreted and validated with the mathematical model, which then lead to final conclusions. Figure 1 clarifies this Blum and Leiß modelling cycle. The tool used to build this model will be MATLAB R2018a. This tool is used because of its ability to easily change parameters and add formulas. Another important factor is that with this tool, the results can be transferred to an Excel sheet, which makes it easier to work with the results.

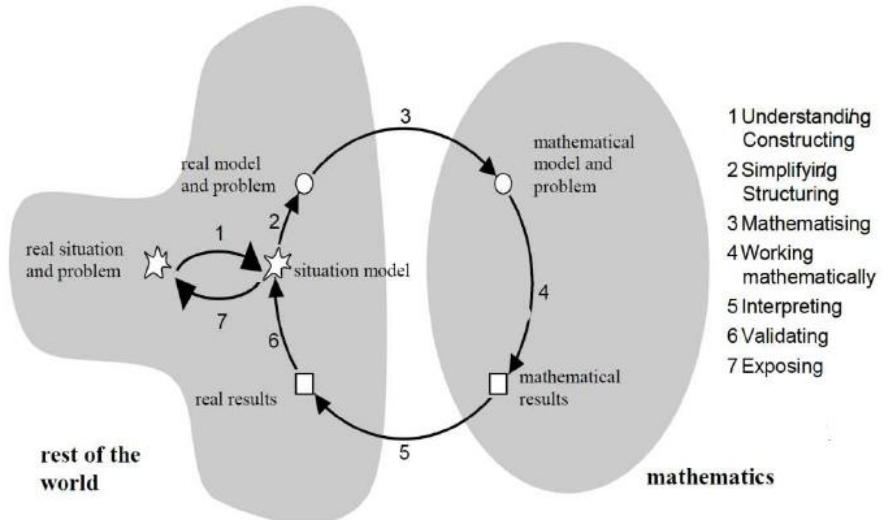

FIGURE 1 - BLUM & LEIß MODELLING CYCLE (BLUM & LEIß, 2006)

As mentioned, the mathematical model is used for answering the research questions. This is done by using different sets of input data corresponding to the questions.

Answering the first research question will be done by doing an experiment. The hypothesis is drawn up and this will be tested using the model. As soon as the results provide a satisfactory result to the research question, further experiments will be abandoned. The datasets used for this experiment are the usage measured by Frits Ogg and the daily rainfall values in 2018 of the weather station in Nijmegen (Weerstation Kessel, 2018).

The second and the third question will be examined with the help of various datasets. These datasets are used as model input and the results lead to conclusions. For the second research question, the same dataset will be used as for the first question. At some point, the usages will be altered to represent a future scenario in which five toilets and a washing machine are added. The third research question uses KNMI data which shows the rainfall intensity per repetition time (Regenintensiteit, 2018).

The KNMI takes into account four different climate change scenarios that might play out in 2050 (Milieu, 2018). Increase and decrease in precipitation are given in percentages and imported for the two used scenarios. The 2018 rainfall dataset is mixed with these 2050 scenarios and, together with the future resident usages, they are used as model input. Again, the results are examined and conclusions can be drawn.

Getting a result for the fifth research question is done by determining the optimal technical functioning of the tank and the infiltration crates. In order to determine this, certain parameters in the model are changed and the results of these changes are investigated. When an optimal functioning is established, it is compared to the current situation. The same datasets are used for this question as for the first research question.

Four initial sets of data are used and altered to serve as input for the model:

- The amount of water the residents of the Dobbelmannklooster use per week. This data has been obtained from Frits Ogg, one of the residents. To use it as valuable model input, the data has been modified to portray the usage per day instead of per week. It is also the foundation for calculating the usage in the future, with the extra toilets and washing machines added.
- The amount of rainfall per day in Nijmegen. This comes from the site: Het weer actueel, and is measured by weather station Nijmegen (Weerstation Kessel, 2018). This data is given per day, but for the validation of the model, this is changed to weekly statistics. In order to get results for the research questions, it is used again with its daily values.
- The rainfall intensity data is given by the KNMI (Regenintensiteit, 2018). This contains a graph of the rainfall intensities per repetition time. From this graph a certain repetition time is chosen and the intensity that belongs with it is adapted to portray the amount of water per minute.
- The last set of data is also provided by the KNMI (KNMI'14-klimaatscenario's, 2019). It contains a table which shows per scenario in 2050 what will happen to the precipitation. In percentages it illustrates if the precipitation will increase or decrease.

Table 1 shows a total overview of the used datasets, including the ones that are adapted and altered as stated above. The table also shows the name of these datasets and in which paragraph they are mentioned.

Table 1 - Overview datasets

Matlab name	**Used for research question**	**Data Inflow water**	**Data Outflow water**	**Paragraph**
2018 Current	1,2,5	2018 rain	2018 usages	3.3.1 3.4.1 3.4.2
2018 Future	2	2018 rain	Expected usage residents	3.3.1
Intensity	3	KNMI Extreme rainfall (Regenintensiteit, 2018)	–	3.3.2
2050 Wl Future	4	2018 rain 2050 W_L	Expected usage residents	3.3.3
2050 Wh Future	4	2018 rain 2050 W_H	Expected usage residents	3.3.3

1.5 Report structure

This report will first start off by describing exactly what goes into the system. After that, some research into the infiltration crates and the soil underneath these crates will be conducted. This information is necessary for the next chapter, which will be the actual building of the model. This explains the start of building the model and which formulas are used for calculations. This chapter also explains what parameters are important and how the model is validated. The following chapters are about using the model and getting results. Different scenarios are implemented in the model and this will lead to more insight in how the tank system works. These scenarios are either about the present time, to see how the system works and functions nowadays, or they are a prediction of the future, in which climate change plays a huge part. Lastly the optimal distribution of tank volume and crate volume will be determined, using the model to do so.

After the research a conclusion is drawn and points for discussion are mentioned. Then there is also a chapter of recommendations for future use or implementation tactics for the tank system.

2 System description

The whole tank system is quite largely set up and water goes a long way before it ends up in either the tank or the infiltration crates. Water first gets captured by the surrounding flat rooftops and is transported by downpipes first and then trough water pipes towards the tank filter. As long as the tank is not full, water will pass through the filter and fill up the tank. As soon as the tank is full, water flows past the filter and ends up in the infiltration crates. Water from the infiltration crates will end up infiltrating deeper into the ground and water from the tank will be used for flushing the toilets and cleaning clothes. If the infiltration crates are full, it is presumed that the water inadvertently flows back up into the water tank, which then causes a problem. Normally this would not be possible because of the implementation of a check valve in the pipes between the water tank and the crates, but it is suspected that this no longer works when the pressure on both sides is equal.

The following flowchart, Figure 2, is added to give a clear overview of what exactly happens to the caught rain water.

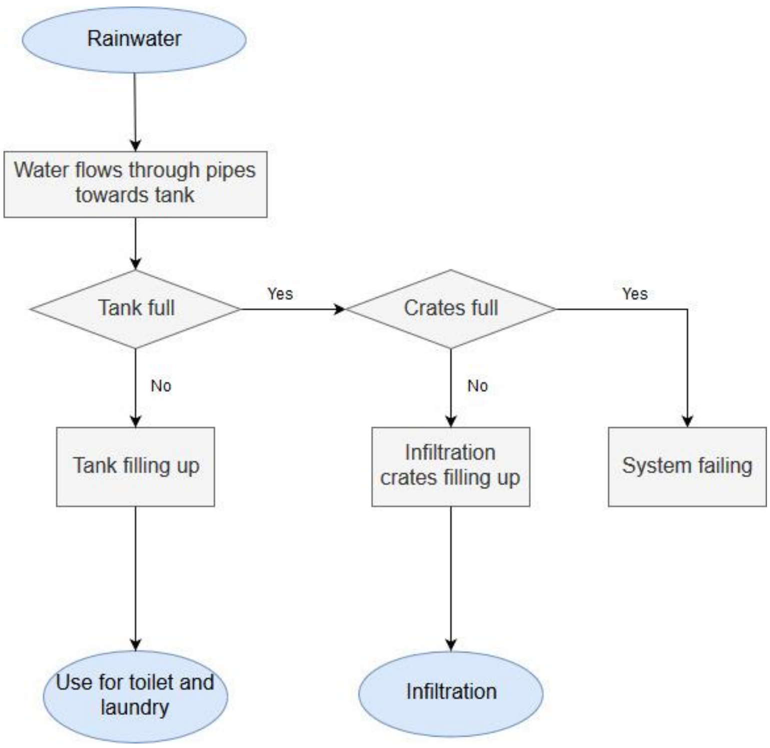

FIGURE 2 – FLOWCHART OF WATER SYSTEM

2.1 Rainwater harvesting

Above the ground, on the rooftops, the water is first caught. For this particular project, a flat rooftop area of 400 m^2 has been demarcated to capture the water before it flows onwards into the downpipes. One type of filter has been placed in the downpipes: the leaf catcher. This filters out leaves and other large particles. When the downpipes reach the ground, they are replaced by water pipes and take the water further into the ground. The angle of this slope is just steep enough to keep the water flowing, but the goal was to keep the slope as minimal as possible because of the large distance the pipes have to cover. If the slope was steeper, the water tank would have to be much deeper into the ground. Therefore a 1% slope has been chosen.

Figure 33 shows where the water pipes are located. The red lines portray the water pipes and the letters A to H stand for the downpipes where the water is coming off the roof.

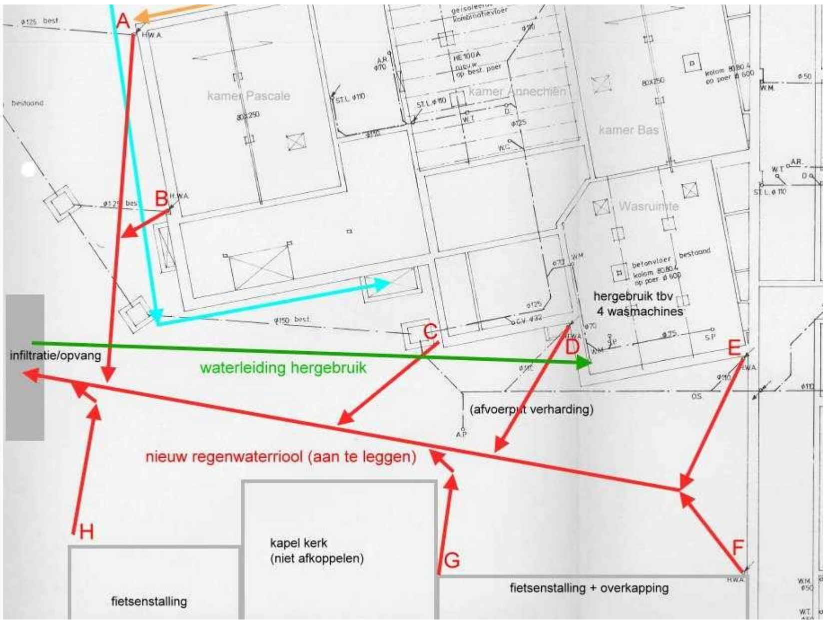

FIGURE 3 - LOCATION WATER PIPES (FRITS OGG)

2.2 Tank filter

The tank filter is located inside the tank. It is placed directly underneath the manhole, which makes it possible to clean the filter without having to go inside the tank. This tank filter filters all the water that enters the tank (Regenwaterfilters, 2019). It filters grain sizes from 1 mm to 1.2 mm or bigger out of the water. However, the filter consists of lots of small strips, meaning that larger pieces which are very thin (like grass) can still get through when placed correctly. This results in portions of sediment still entering the tank.

As soon as the water level in the tank reaches the bottom of the filter, the tank is considered full. Water cannot flow through the filter any more, which means that the water passes the filter and flows onwards in the direction of the infiltration crates. Figure 4 shows where the water enters the tank and clearly shows the tank filter (the black box in the middle) and where the water flows onwards into the infiltration crates.

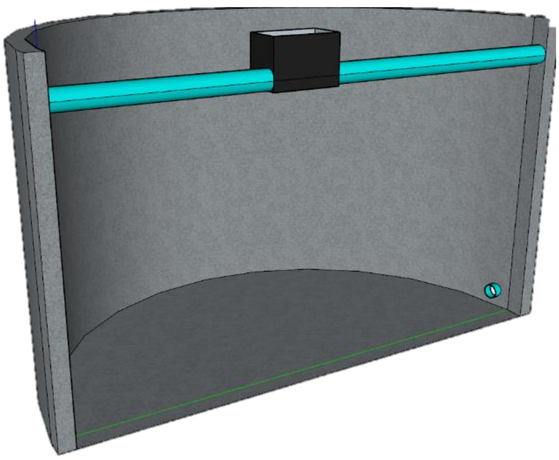

FIGURE 4 - WATER TANK AND FILTER (FRITS OGG)

2.3 Water tank

The water tank in Nijmegen is an 8000 litre big concrete cylinder. The tank is used to temporarily store the water before it gets transported into the households. At the bottom of the tank there is room for sediment to pile up. Therefore the pump which pumps the water towards the houses is not placed directly at the bottom, but 10 centimetres higher, to allow for the sediment to stay at the bottom.

In the rare occasion that the tank is empty, either because of usage or cleaning, there is a system installed that will automatically fill up the water level in the tank to a satisfying volume.

2.4 Infiltration crates

When the tank is full, water flows onwards into the infiltration crates. The infiltration crates are placed deeper in the ground than the tank. The purpose of the crates is to infiltrate water further into the ground.

The performance of the infiltration crates is determined by the surrounding soil. Since the infiltration crates and the geotextile have no influence on the speed of the water flowing through, the soil type and the groundwater level are the only restraints which cause the infiltration crates to fill up (Dyka, 2018).

The crates are placed directly next to each other, and with the tallest side up. The crates have been packed with geotextile, which prevents the surrounding soil and roots from entering and clogging up the crates. Figure 5, shows how they are placed.

FIGURE 5 - INFILTRATION CRATES (FRITS OGG)

3 System modelling

The research starts by looking further into the workings of infiltration crates. When the performance of these crates becomes more clear, it is possible to start building the model. As soon as the model is complete, different types of scenario's can be run and this provides more information about the workings of the whole water tank and infiltration crates structure.

3.1 Infiltration crates

3.1.1 Surrounding soil

The only factor that can influence the workings of infiltration crates is the type of soil that surrounds them. The type of soil determines how fast the water exits the crates and how useful they are. When the crates are placed in a clay environment, water will have a hard time infiltrating deeper into the ground. The density of clay is much higher than that of sand, which causes infiltration to take longer (Bot, 2011).

According to the Bodemkundig Informatie Systeem the soil underneath the Dobbelmannklooster is coarse sand (dr. JP. Okx, 2018). However, this is still such a rough indication, that Frits Ogg and his colleague Wijndel de Waal decided to perform their own testing. The test itself is quite simple, but it does give an indication of the permeability of the soil. They placed a hollow tube with an inside diameter of 25 millimetres in the ground, to a depth of 1,65 meter. As seen from Figure 6 there is a large package of the same colour sand surrounding the area where the crates are supposed to be placed. The reason for a depth of 1,65 meters is explained by the fact that the tube reaches well into that type of sand and the experiment will therefore be measuring the permeability of that type of sand.

They inserted water into the tube and measured with a floating device how fast the water disappeared. This test was repeated 5 times over 2 days and the results can be found in Table 22 in Appendix A. Taking the average of these five experiments results in a permeability of $0{,}0187\ m/s$.

FIGURE 6 - HOLE FOR INFILTRATION CRATES (FRITS OGG)

3.1.2 Silting

Whether or not infiltration crates will silt up is dependent on the amount of sediment that can enter the infiltration crates. It is highly unlikely that silting inside the infiltration crates happens because of sand coming through geotextile, since this is the whole purpose of the geotextile. However, the geotextile can clog up, making it more difficult for water to flow out (Bezuijen, Beek, & Schenkeveld, 2012). Sand particles surrounding the geotextile can partially get stuck inside the holes of the textile, causing an obstruction of the water. This is what is causing the geotextile to clog up.

Then the only reason for the infiltration crates to silt up from the inside would be if there is sand and other particles on the roof which get inside the system and are too large for the tank filter to filter out. These particles then end up in the infiltration crates. The speed of this silting up is determined by the amount of particles present on the roof, which is unknown.

There is only one type of filter that filters the water going towards the infiltration crates and those are the leaf catchers. These filters are not fool proof and only filter really large particles, therefore it is assumed that there already is a layer of silt on the bottom of the infiltration crates. Since the crates have been in use for so long, it is even estimated that the layer of silt is so thick, water can no longer exit through the bottom, only through the sides.

3.2 Model building

The building of the model starts by determining the model structure, then entering the necessary parameters and calculating their values. These parameters are then used to solve the implemented calculations, thus providing the desired simulation.

3.2.1 Conceptual framework

The start of the conceptual framework is inspired by looking at different compartment models and in particular the one mentioned in the reader “Waterbeheer” from dr. ir. MJ. Booij (Booij, 2017).

This model, however, is largely focussed on water in and on top of the ground, surrounded only by soil. This has not much to do with the scenario of the tank system, but it provides the inspiration to look at all the components separately and the interactions between those components. With this idea as a foundation, a complete conceptual model is formed.

Figure 2 shows this conceptual model, with clear relations between the causes and their consequences.

3.2.2 Parameters

To transform the conceptual model into a mathematical model, the parameters need to be established. There are lots of parameters involved in this model. These will be discussed in the following paragraphs.

3.2.2.1 Design features

In the model there are two important parameters which are dependent on the design of the tank system. These two parameters are the maximum volume of the tank and the maximum volume of the infiltration crates.

The concrete tank that is implemented in Nijmegen is one that can store 8000 litres, also known as 8 m^3. The diameter of this tank, including the surrounding concrete, is 2,80 meters. The height of it is 1,85 meters. The outside concrete walls of the tank are 8 centimetres wide, or 0,08 meters. This means that the actual diameter of the inside of the tank is 2,64 meters. Giving the tank a radius of 1,32 meters (Hout & Jong, 2019).

The pipe where the water flows out of the tank and into the households is placed 0,10 meters from the bottom. This is done to make sure that the sediment that does go through the tank filter, stays inside the tank. In this stagnant water, it is easy for the sediment to sink to the bottom.

The tank is considered full when the water reaches the bottom of the tank filter. This gives the part of the tank that is actually used for storing water a height of 1,40 meters.

With this information, the actual amount of water that the tank can store can be calculated. The formula for the volume of a cylinder is:

$$Volume = pi * r^2 * height$$

The volume of the tank that can be used for storing water is then:

$$Volume_{Tank} = pi * 1{,}32^2 * 1{,}4 = 7{,}66\ m^3$$

The parameter for the maximum volume of the tank is called $Tank\_max$.

The tank is thus considered empty when there is still a layer of 0,10 meter left. This is because of the height of the pump and to leave the sediment at the bottom of the tank. If the tank is empty, water will be added until it reaches a height of 0,30 meters from the bottom. This means that 0,20 meters in height is added. Figure 7, which is not to scale, shows schematic representation. The added volume is then:

$$Volume_{extra\ water} = pi * 1{,}32^2 * 0{,}2 = 1{,}09\ m^3$$

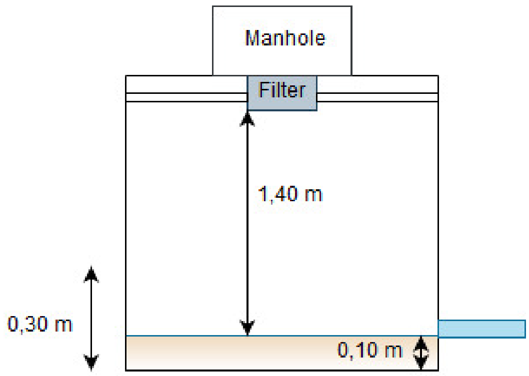

FIGURE 7 - SCHEMATIC REPRESENTATION TANK

Calculating the maximum volume of the infiltration crates takes less steps. There are 16 crates, each with a volume of 0,256 m^3. This means that the total volume of the crates is then:

$$Volume_{crates} = 16 * 0{,}256 = \ 4{,}096\ m^3$$

This parameter is called $Krat\_max$.

3.2.2.2 Infiltration

In a normal situation, water inside infiltration crates will mainly exit through the bottom of the crates. As seen in paragraph 3.1.2, it is expected that the amount of silt inside the crates is so large that no water can exit through the bottom. This means that it would exit trough the sides. There is barely any research done on this type of horizontal infiltration, and what there is is not sufficient enough, that it would be unjustifiable to use calculations for that type of infiltration. This goes together with the fact that the permeability of the soil is $0{,}0187\ m/s$. Water infiltrates so fast trough this type of soil that it the infiltration crates are barely an obstacle. For these two reasons, the decision has been made to build the model in such a way that it simulates water infiltration trough the bottom of the crates.

The following formula is constructed to calculate the amount of vertical infiltration above groundwater level (Massop, Gaast, & Kiestra, 2005):

$$Q = \frac{k}{2} * \frac{h + d}{h} * A$$

Where:

- Q is the amount of water infiltrating into the ground (m^3/s)
- A is the surface where the water is going through (m^2)
- k is the permeability of the soil (m/s)
- h is the distance from the bottom of the infiltration to the ground water level (m)
- d is the amount of water above the infiltration surface (m)

The first parameter is the permeability of the soil, called $Permeability$. As mentioned before in paragraph 3.1.1 the permeability of the soil underneath the Dobbelmannklooster is $0{,}0187\ m/s$.

The groundwater level in this particular area in Nijmegen is 10-25 meters below surface (Witteveen+Bos, 2018). Since it is impossible to say at what depth the ground water really is, the estimation used for further calculations will be a depth of $17{,}5\ meters$. Parameter h is the vertical height difference between the bottom of the infiltration crates and the ground water level. The bottom of the crates is at a height of 2,70 m below ground level. This gives h a height of:

$$h = 17{,}5 - 2{,}7 = 14{,}8\ m$$

The vertical hydraulic conductivity of the infiltration crates is thus dependent on the amount of surface that makes up the bottom of the crates. Each crate has a height of 0,79 m, a length of 0,75 m and a width of 0,43 meters. This gives the area the water flows through a surface of:

$$Area = 0{,}75 * 0{,}43 * 16 = 5{,}16\ m^2$$

This parameter is called A_krat.

The equation also speaks of parameter d, the height of the water inside the crates, but this is a variable and will therefore be discussed in paragraph 3.2.3.

3.2.2.3 Time steps

The most complex parameter in the model is the amount of timesteps that need to be taken. The amount of time steps is dependent on the time frame the model should run through and the units of the other parameters. If the model is supposed to display the events of an hour, and the units of other parameters are in minutes, then the amount of time steps necessary is 60. The model then simulates the events for each minute within one hour. This parameter is called t.

3.2.3 Process descriptors

To complete the mathematical model, mathematical formulas need to be inserted.

The model runs one time unit at a time. In that set frame, it goes through a couple of formulas that are necessary to simulate what is happening in the system. The whole script is found in Appendix B.

The section Formulas, Appendix B starts with a simple choice: whether or not the tank is full. If the tank is full, or will be full due to the new water coming in, the amount of water that still fits in the tank is added to the tank. The rest of the water is added in the infiltration crates. At the same time, water that will be used within that time unit is taken out of the tank. When the tank is not full, water that is supposed to go out gets deducted from the amount of water that is going in.

The next part of the section Formulas is about the infiltration happening around the crates. First the surface over which the water can infiltrate is determined, followed by a formula calculating the height of the water still in the tank. Both these calculations are necessary for solving the equation mentioned in paragraph 3.2.2.2. If the amount of water that would be infiltrated is more than the amount of water that is in the crates at that moment, the amount of water in that crate is set to zero, since it cannot be negative. If there is more water in the crate then that would be infiltrated, these two values get deducted from each other to create a new crate volume.

The third code section is installed to calculate the amount of water that needs to be added into the tank. When extra water needs to be inserted, the model shows how often it happens and how much is added. Inside the tank, there is a system that adds the water automatically. As discussed in paragraph 3.2.2.1, the amount of extra water added is $1{,}09\ m^3$.

The last section of code is to show when the amount of water in the crates is larger than the maximum crate volume. Every time this happens, the number goes up by one, counting the amount of times it occurs.

In the end the code $k = k + 1$ makes sure that the following loop will loop over the next time unit.

3.2.4 Calibration and validation

Calibrating the model is very difficult, since there is no model such as this to compare it with.

The validation of the model is done by comparing the results of the model with data of its current state against the data received from Frits. The model simulates when extra water was added and this is compared to the times that Frits actually saw that extra water was necessary. Frits' measurements are shown in figure 17, Appendix C, where the green line portrays the drinking water added to the tank. The model simulation is shown in figure 18, Appendix C. Comparing the two gives figure 8.

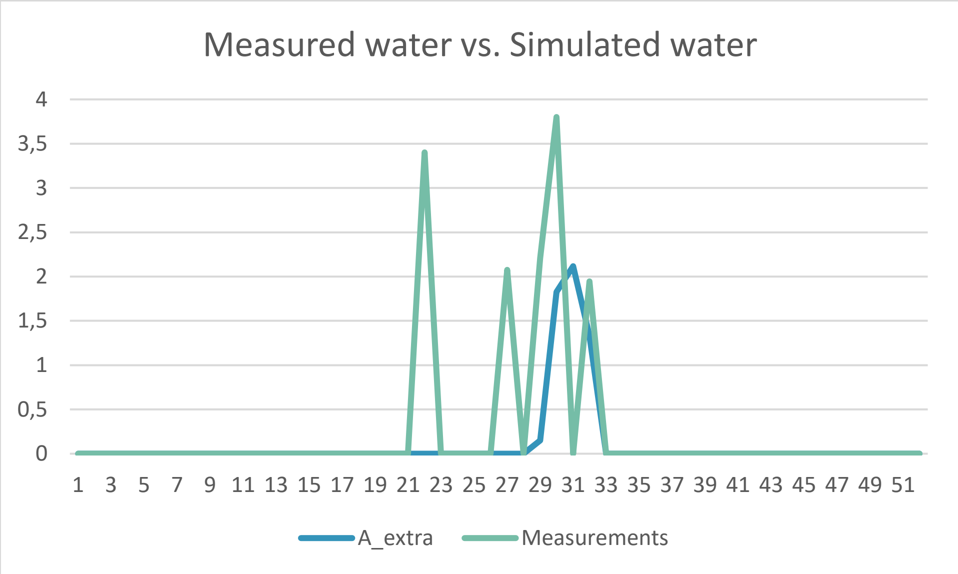

FIGURE 8 - EXTRA WATER, MEASURED AND SIMULATED

The two lines are very similar, the first peak of Frits' measurements does not match with the simulated data, but this is explained by the fact that the residents cleaned the tank at that point and extra water was added to fill the tank back up again. The fact that according to the measurements more water was added, than simulated in the model, can be explained due to the model only adding to the tank what is necessary. In reality, the tank gets filled up to where it should be about enough water.

3.3 Model use

3.3.1 Present rainfall values

The first research question will be examined by using data of the usage of residents and the amount of rainfall from the year 2018. Using this as input data for the model will give a graph of how often the infiltration crates were full and caused problems. If this is the case around May 2018, the hypothesis mentioned in paragraph 1.3.1 may be correct. If the graph does not show this, something else must have caused the dirty water in the tank.

To research the amount of days the tank provided enough drinking water over a year, the same data and graph will be used as mentioned above. This provides an outcome of how often extra water is added. The days where no extra water had to be added, are the days that the tank provides enough water with the rain it has harvested. In the future however, extra washing machines and toilets will be connected to the tank. In order to know how many days the tank will provide water then, the total usage with these additions needs to be calculated. With this new input data, the model provides a different graph that shows on how many days there would be enough water in the tank to meet the resident's needs.

The Dutch website "Het weer actueel" provides detailed data on the amount of rain that has fallen each day in Nijmegen (Weerstation Kessel, 2018). This data is used as input for the model. The Dobbelmannklooster has a surface of 400 m^2 available for collecting the fallen rainwater. The amount of rain entering the tank per week is then calculated as follows:

$$Rain = Data\left(\frac{m}{day}\right) * 400\ m^2$$

These values can be found in figure 19 and figure 20, Appendix D. The first figure portrays the amount of rain that fell each day in 2018. The second figure portrays the usages of the residents for each day last year. Entering above data into the model gives graphic shown in figure 9.

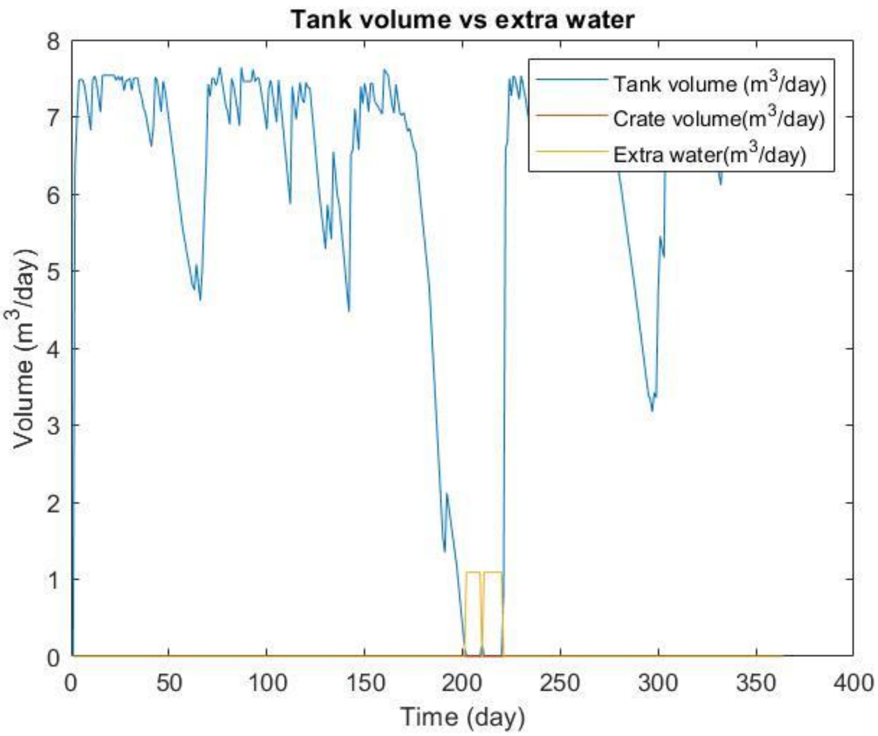

FIGURE 9 - TANK VOLUME IN CURRENT SITUATION

The figure shows that during the summer time, extra water is necessary because of the draught. The tank is providing enough water for all the residents the rest of the year.

The water demand that is used for this graph is provided by Frits Ogg, who collects it weekly. However, for a future situation, the water demand is difficult to know for certain. Therefore an estimation has been made.

Nowadays, 4 washing machines are hooked on the tank. This costs x litres of water per day. Now 1 washing machine is added, giving the following equation:

$$Demand\ washing\ machine = x + \frac{1}{4}x$$

For the toilets, the estimation is a little rougher. Frits and Wijndel mentioned that of the 5 toilets added, some of them use 6 litres per flush and some use 9. Since it is unclear which is which, an average of 7,5 $litres$ per toilet is used for the calculations. Furthermore, a person goes around 5 times a day to the toilet (Groot glorix toilet onderzoek, 2009). Guessing that 3 of those times will be at home and having 11 people using these toilets, results in 33 toilet visits per day, each time using 7,5 litres.

$$Demand\ toilet = 33 * 7{,}5 = 247{,}5 \frac{l}{day} = 0{,}248 \frac{m^3}{day}$$

$$New\ demand = x + \frac{1}{4}x + 0{,}248$$

This new data can be found in figure 21, Appendix D. Running the model with this data provides the graph shown in figure 10.

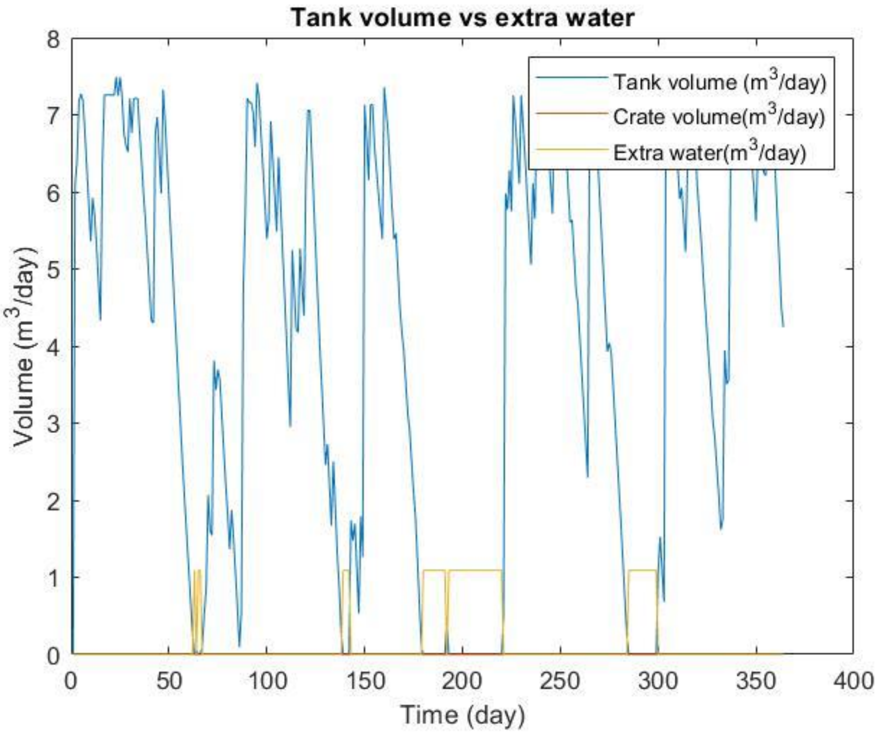

FIGURE 10 - TANK VOLUME IN FUTURE SITUATION

It is clear that the increased consumption of the rainwater has an effect on the water levels in the tank. More often extra drinking water needs to be added into the tank. The tank is often not that full anymore and there is often not enough precipitation to fill up the tank completely.

3.3.2 Rainfall intensity

To get a better look of how the whole tank system behaves during a heavy rainfall, a rainfall intensity will be chosen from figure 11 and this will be simulated in the model over the time span of 1 hour. As seen in figure 9 and figure 10, usually the tank is quite full. Therefore the simulation will start with an almost full tank. It is assumed that during this one hour, residents do not use the toilet or washing machine.

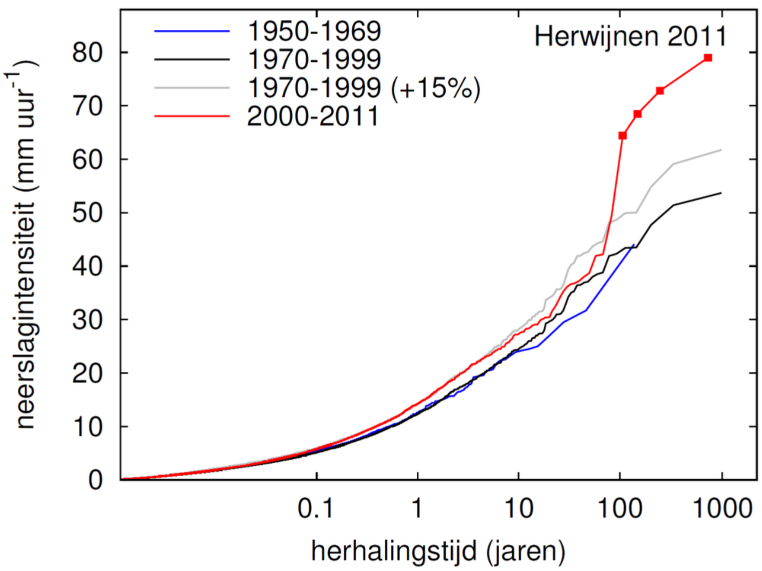

Figure 11 - KNMI Extreme Rainfall (Regenintensiteit, 2018)

The repetition time of 100 years is chosen, giving a rainfall intensity of 65 $\frac{mm}{hour}$. This provides the simulation shown in figure 12. The data input for this simulation is available in Appendix E.

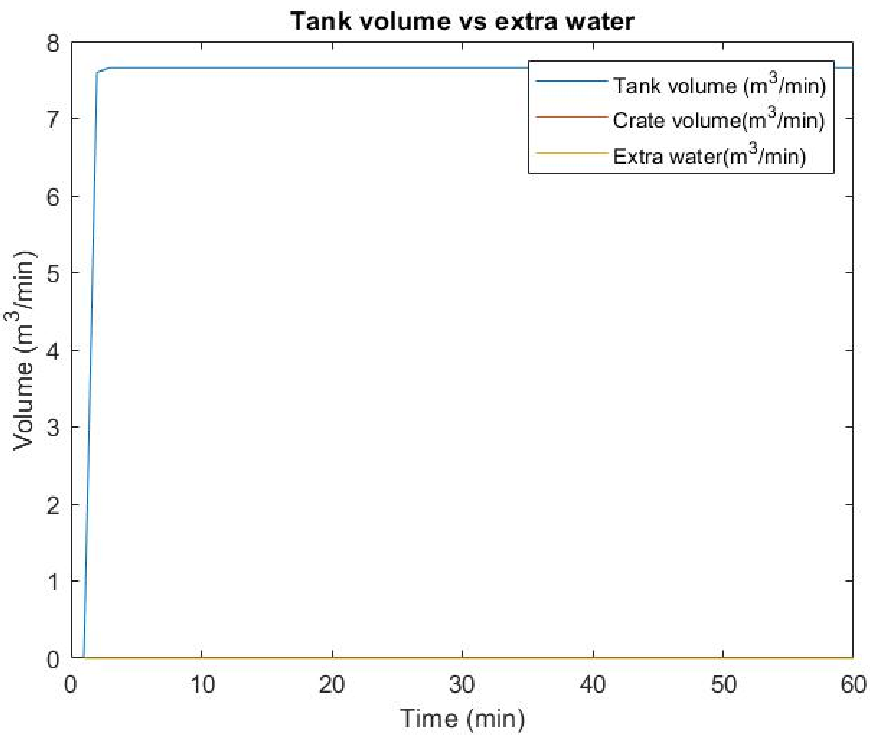

Figure 12 - Simulation intensive Precipitation

This figure shows that the tank is full the whole time during the rain. All the water that is collected by the rooftops goes straight to the infiltration crates. However, the figure does not show the crates filling up, which means that the infiltration crates have no trouble processing a downpour.

3.3.3 Climate change rainfall values

According to the KNMI climate change scenarios, there are four predictions of what can happen in the future (KNMI'14-klimaatscenario's, 2019). Only two of these scenarios are valuable for simulation. This is the scenario in which the amount of rain increases the most, scenario W_L. The other scenario is where the largest decrease in rain is expected, scenario W_H. Throughout the year this scenario is predicted to increase in rain, but during the summer a decrease of 13% of the rain is expected.

The results the two scenarios are measured by combining the data from precipitation in 2018 with the expected climate change scenarios. This gives the expected amount of rainfall in 2050 for both scenarios and is plotted against the expected water usage in the future. Table 3 in Appendix F shows the predicted increase in rainfall. With these numbers the data of figure 23 and figure 24 in Appendix F is constructed.

With the expected data of scenario W_L implemented in the model, figure 13 is created.

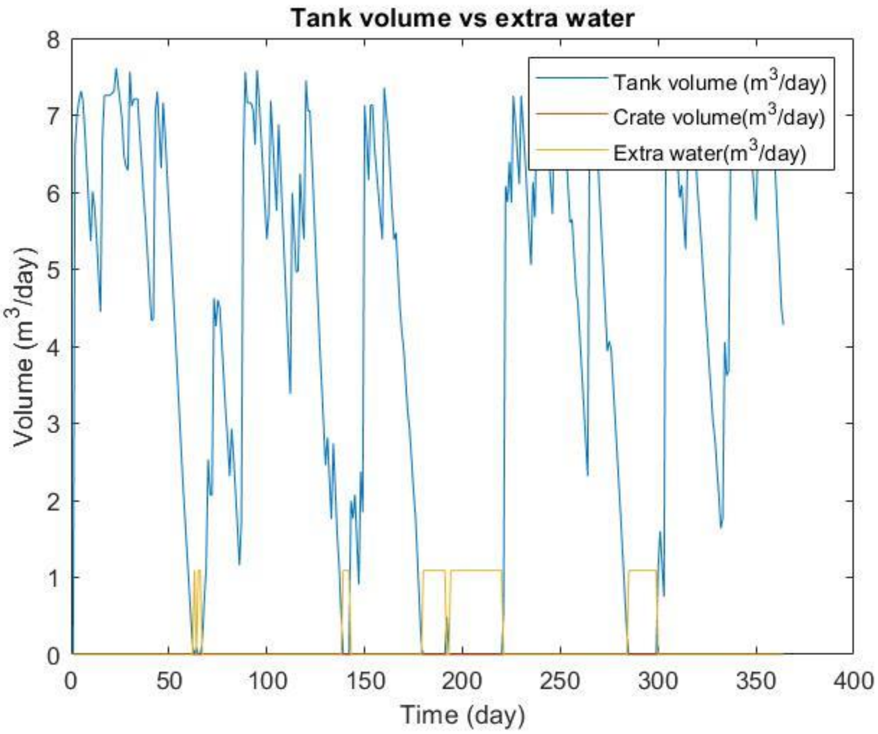

FIGURE 13 - 2050 WL SIMULATION

The expected data for scenario W_H gives the simulation shown in figure 14.

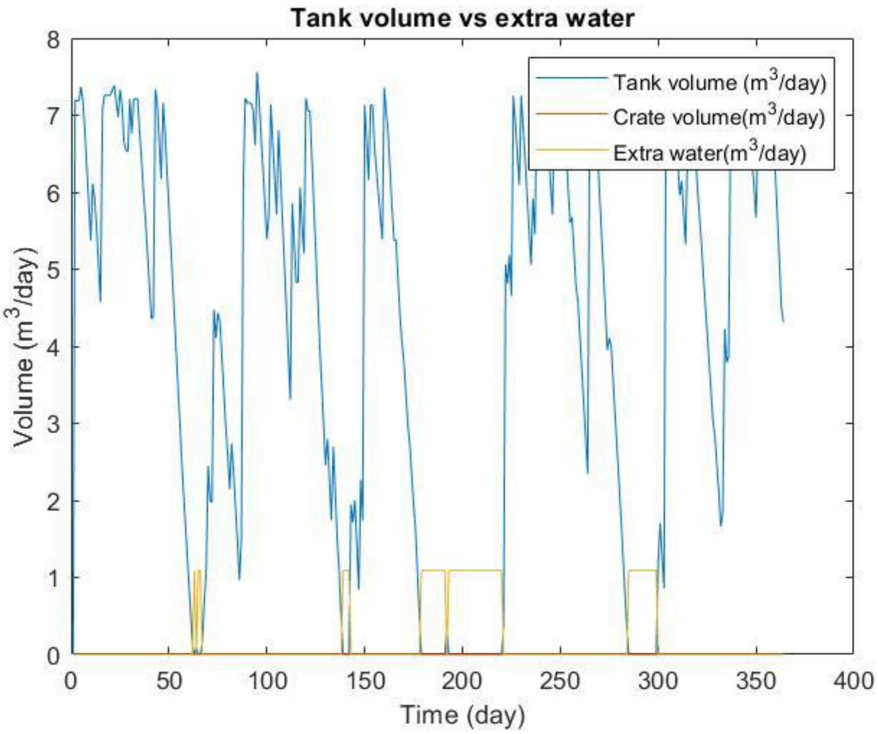

FIGURE 14 - 2050 WH SIMULATION

Both figures look similar, but there are some minor differences. There is often more water in the tank in figure 13, due to the extra rain. The periods of draught in both scenarios are not pressingly longer than they are in the current scenario.

3.4 Optimal structure

The tank and infiltration crates in Nijmegen are already in the ground. But with the model and the obtained data, it is possible to re-evaluate the volume of the tank and the amount of infiltration crates. Data of the current precipitation are used and plotted against the data of the usage of the current devices (the four washing machines).

3.4.1 Tank volume

The best solution would be if the residents never had to add any extra water to the tank. To determine this volume, the parameter of the tank volume in the model is changed until no extra water is necessary. The tank volume that relates to this is $12{,}3\ m^3$. With this volume, no extra water is necessary throughout the whole year, as seen in figure 15.

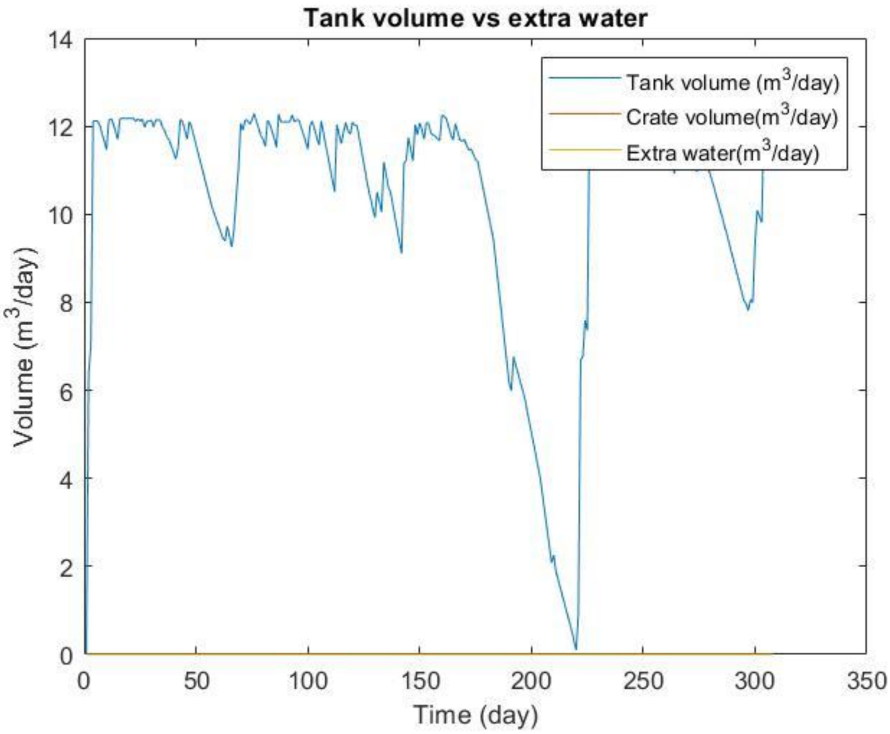

FIGURE 15 - OPTIMAL TANK VOLUME

3.4.2 Amount of crates

The ideal amount of crates would be the least ones, where still no errors occur due to them getting full. In the model, the amount of crates is decreased until simulation shows that they overflow. It turns out that no problems occur with 1 crate, but they do occur when there are no crates. Thus the optimal amount is 1, since then there are still no problems with the system, as seen in figure 16.

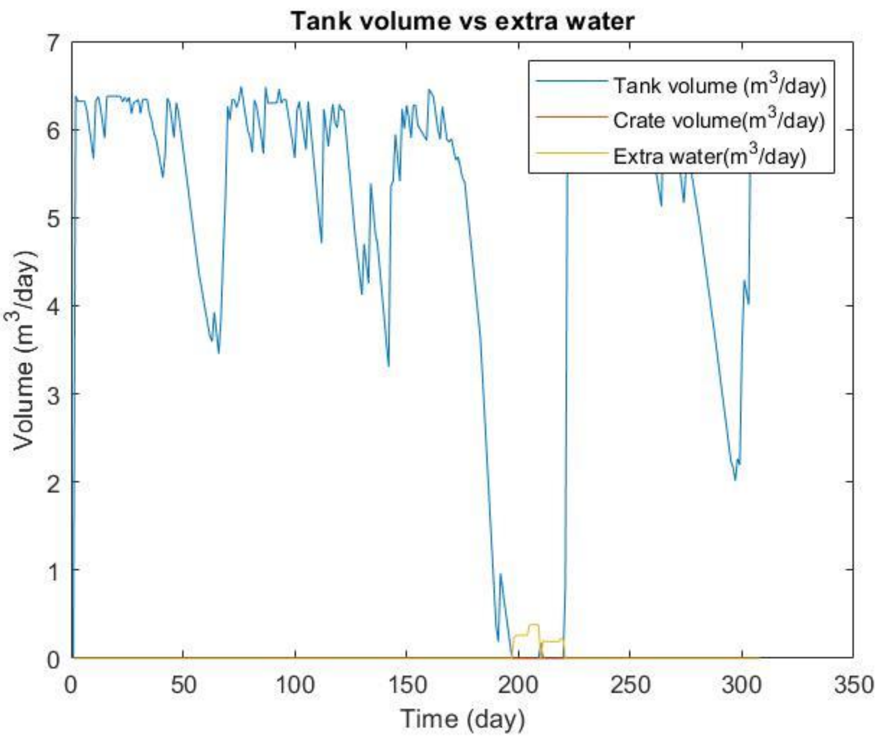

FIGURE 16 - OPTIMAL CRATE AMOUNT

4 Discussion

With the research conducted, there are assumptions and simplifications made. These have been appointed per research subject and are explained in the following paragraphs.

4.1 Infiltration crates

The largest uncertainty concerning the infiltration crates is the permeability of the soil. Frits Ogg and Wijndel de Waal did this research themselves, with a technique they came up with themselves, instead of having the soil professionally tested. This, however, does not mean that their results are not correct, it merely makes it uncertain whether or not they are. Besides that, on the basis of their findings when building in the infiltration crates, they assumed that the soil around these crates is the same in every place. This is a rough estimation, since they only looked at the colour of the sand surrounding the crates and found that it all had the same colour, which they then understood as being the same type of soil. Since the did not dug deeper than that the crates needed to go, it is uncertain if the soil type changes further into the ground.

Furthermore, the effect of geotextile surrounding the crates is not taken into consideration. The permeability of geotextile must be at least 10^{-4} m/s or faster (Materiaaleigenschappen geotextiel, 2018). Since the permeability of the soil is $0{,}0187\ m/s$, this means that the geotextile could be a serious impediment unless its permeability is a lot faster. Apart from that, there is also an article that states that geotextile pushed against the surrounding sand is causing the geotextile to not let water through as easily (Bezuijen, Beek, & Schenkeveld, 2012).

4.2 Model building

The model is constructed to simulate that water exits and infiltrates through the bottom of the crates, not the sides. However, as already mentioned, it is suspected that the amount of silting up in crates without filter is so terrible that water can only exit through the sides. With the research about this topic not being sufficient enough and with such a high permeability, it has been decided to design the model as if water flows out through the bottom of the crates. This creates an enormous simplification of the reality and more research has to been done into the specifics of this topic in order to use this model for future purposes.

Another issue with the model is that the formulas that are used are also simplifications of reality. Even though it is expected that the outcome of the model might not be that different if no simplifications were used, it is still an uncertainty.

The value of parameter h, concerning the height difference between groundwater level and the bottom of the crates, is an estimation. Since the range is so large (10 to 25 metres) an average is used to give an indication.

The model is not calibrated since there are no models similar to compare it to. This leaves a big uncertainty in the reliability of the model. Validation has been done, but only over the values of extra water added, not with measurements from the crates or from the tank. These measurements were not available, but this as well provides a lot of uncertainty.

4.3 Model use

After the model was completed, it was used for conducting research on certain topics. This research generates a few points of concern.

4.3.1 Present rainfall values

The weather station which collects the precipitation data of each day of the year is located a few kilometres away from the Dobbelmannklooster. This means that the amount of rain could differ from the input data. The site also warns that the data is not validated and malfunctions of the system have not been filtered out. This also adds to the uncertainty of the input data.

Then it is also assumed that all the water that falls onto the roof, gets into the tank as well. Evaporation has not been taken into consideration and neither has the fact that not all the water might flow towards the downpipes. The roof surface might be uneven which causes some of the water to remain there.

The data for the future use is an estimation and not a proven amount. The new data is derived from actual amounts of usage from the residents, combined with assumptions on how much water extra toilets and a washing machine will use. These assumptions will most likely not live up to reality and therefore the model output will not be the exact reality either.

4.3.2 Rainfall intensity

With researching the effects of heavy precipitation, a certain intensity is chosen which is then repeated for the time span of one hour. This would hardly ever happen in reality, a rain shower with the exact same intensity for over one hour. An assumption made for this scenario is that no one uses any of the devices for an hour. This is a possibility, but this might not be the case for every downpour.

With this amount of rain for one hour, it could be possible that the soil underneath the crates gets so full with water that the groundwater level rises. As this rises, it makes it harder for the rainwater to infiltrate quickly into the ground. Since the groundwater level in Nijmegen is at such a depth, this is unlikely to happen with just any rain shower, but a very intense precipitation could give such an effect. This is however not taken into account for the model. For future research it is worth looking into.

Lastly, as seen from figure 12, the water inside the infiltration crates flows out so quickly that it does not even fill up the infiltration crates partially for longer than one minute at a time. It would at least be suspected that the crates fill up a little bit with such a heavy rain, which then contributes to the suspicion that other faults are present in the modelling of the infiltration crates.

4.3.3 Climate change scenarios

The input data for climate change is generated from percentages given by the KNMI. These percentages are very uncertain and also come with limit values, which were not taken into account. These percentages are more guidelines on what to expect, instead of hard facts.

The results of scenario W_H are expected to show long periods of draught. However, this is not the case. Seen from Table 3 in Appendix F, the summer period would be the one in which a draught could occur. This is visible in the results, but it is not much different than the draught period in the current situation. The reason for this is that in the summer of 2018, it already did not rain for a long period of time and the data for climate change is based upon the 2018 data. Decreasing the amount of rain further than zero is not possible and therefore the effects of scenario W_H are not as distinctive. This leaves it still questionable whether or not scenario W_H will have a big impact on the use of the tank in the future.

Lastly it is very uncertain if not other factors will influence the workings of a tank system in 2050. The composition of the surrounding soil might have changed or the usage might increase or decrease. The situation could be entirely different and it is impossible to determine that at this time.

5 Conclusion

The main goal of the research was to find out if the tank provides enough water for the residents. To provide a broader perspective, several research questions were composed. With the results of the research, the research questions can be answered and conclusions can be drawn.

5.1 Hypothesis

According to the theory stated at the beginning, in May 2018 dirty water from the crates flowed back up into the tank, causing dirty smelling clothes to come out of the washing machine. This would have happened because the crates were too full and the water could only go back up, ignoring the check valve because the pressure on both sides was equal. However, May would start at about day 120 and end around day 150. During that time period, the simulation results do not show any signs of the crates being full. There was not even enough water to fill up the crates a little bit, before it infiltrated into the ground. Therefore it is concluded that unfiltered water must have come in the tank in a different way. The tank filter is made from plastic. The pressure of the intense rainfall could have caused the plastic to deform slightly, letting larger pieces of sediment through. The lid of the tank filter also shifted. The pressure could have caused it to move, which then caused unfiltered water flowing out on the top and entering the tank.

5.2 Tank water for resident use

In its current state, the tank usually provides enough water for the residents. Only 18 days of the year, the residents have to add extra water. Throughout a year, the tank currently provides 95% of the necessary water.

With the five additional toilets and one washing machine, the number of days where extra water is added is increases. In the future, the residents have to add extra water on 62 days of the year. The water demand is then for 83% provided by the tank.

5.3 Heavy rain

Figure 12 does not show that the infiltration crates are affected by the heavy rain. They do not get full because the water infiltrates into the ground quick enough. Even a rain that only occurs once every 100 years has no effect on the crates, only fills the tank to the brim.

5.4 Climate change

The climate change scenarios provide some interesting insights in what might be the situation in 2050. Climate change scenario W_L is chosen for its increasing amount of rain. The results show that this does have an effect on the tank and residents only need to add extra water on 61 days in one year. This means that the tank is responsible for providing 83% of the water demand. The crates are not affected by the increased water volume.

Scenario W_H is chosen for its most decrease in rain. Concluded from the results is that the tank is less full for longer periods and the residents need to add extra water on 63 days in the year. The tank then provides for 82% of the water demand.

For both scenarios it is concluded that the tank will still be providing a sufficient amount of water for the residents. Apart from that, the infiltration crates still function as intended and are able to infiltrate the water quick enough.

5.5 Optimal structure

From a technical point of view, the optimal volume of the tank would be $12{,}3\ m^3$. With this volume, no extra water is necessary and the tank provides for 100% of the water demand. Still, concrete is very expensive compared to drinking water so it could be worth more to the residents to have a smaller tank and pay for the 18 days of extra water. Economically seen, the residents made the right decision to go for the smaller tank.

The optimal amount of infiltration crates is 1. The water infiltrates so quickly into the soil that there are hardly any crates necessary. The residents could have saved money by only buying 1 infiltration crate instead of 16.

5.6 Final conclusion

In conclusion, this set up of the tank system with this particular soil permeability works good enough for he residents. The permeability of the soil surrounding the infiltration crates is so high that no water stays inside the crates, not even longer than one minute. In its current situation, the tank provides more than enough water for the residents throughout the year. With the additional facilities, water shortages will occur more often, but they still have enough water 294 days of the year. Even with a downpour which occurs once every one hundred years, the infiltration crates will cause no problem to the tank. There could be other problems that might occur, but they have not been researched. The climate change scenarios did not cause any problems for the tank system either. The amount of days where extra water is necessary hardly changed, the difference only being one day. At last, the optimal structure for the tank is hard to determine. It is a consideration between paying for a larger tank or paying for the necessary extra drinking water. With a tank size of $12{,}3\ m^3$, no extra drinking water would be necessary. For the crates it turns out that only one crate is necessary to infiltrate the excess water from the tank deeper into the ground. This means that the sixteen infiltration crates that are currently in place will definitely be able to handle all the water.

Using the model for simulations was an important part of the research. This model provided the results from which the conclusions were drawn. After discussing and evaluation the results of this model, it can be said that the model works quite alright. The calculations of the tank volume and extra water match with what has been observed in reality. There are some large uncertainties in the calculations for the infiltration crates, which led to some strange conclusions. However, the model still performs as well as can be expected with the lack of available research on this topic.

The model is quite general because of its many simplifications. The results are good enough for this research, since the research was largely focussed on getting a general idea of the workings of the tank. For future research, the model might have to be altered to get more precise results. Depending on the type of research, certain simplifications needs more clarification where others can stay the same.

6 Recommendations

The recommendations are divided into recommendations for future research and researchers and in recommendations for private individuals or companies thinking of installing a tank system. The recommendations have been composed with the help of Frits Ogg and Wijndel de Waal.

6.1 Future research

For further research, it is recommended to recalculate the permeability of the soil in a professional way. It is also a good idea to understand what happens to the soil when enormous amounts of water get infiltrated at the same time, since there is a possibility that this causes problems that are not taken into account at this moment.

Further research should also be done in the occurrence of the dirty tank water in May 2018. The model did not provide a solution to this, but there might be other factors which were not taken into consideration. In order to help the residents, this should be looked into further so a suitable solution can be found.

A local device that measures the amount of rain is desirable for future research. In the most optimal scenario this device would be as close to the tank as possible. This would give a much more precise data input and will result in a more reliable outcome.

Understanding the exact workings of geotextile is also a field in which the research should go further. The combination of geotextile pressed against sand could make it more difficult for the water to infiltrate.

Furthermore, more research needs to be done about the horizontal infiltration of the infiltration crates. There was hardly any information found on this topic, even though this is a serious possibility in the tank system.

Lastly, with a soil type as the one in Nijmegen, that allows for so much water to infiltrate in a short period of time, soil pollution is a serious threat. The water flowing through takes lots of sediment deeper into the ground, whereas it would have been filtered out naturally way before reaching such depths. Further research into the microorganisms in the crates can confirm if action should be taken and what other methods should be used to prevent pollution.

6.2 Individual use

For implementing such a system it is highly recommended to measure the permeability of the soil before implementing infiltration crates. Even though guidelines can give quite a general idea, there is a possibility of needing less or more crates when the permeability is known.

Another recommendation is to implement more filters of different sizes into the system. This will limit the amount of sediment from entering the tank and the crates, which causes less blocking in the system. With more filters, it is important to place them in spaces that are easy to reach, so cleaning them often is not a problem.

It is advised to always keep the infiltration crates accessible, whether it is through big opening or just a small peephole. This allows for assessing the amount of water in the crates and is easy for performing tests on the amount of silting. It is a good idea to implement an emergency overflow system on to the crates, so when the crates are full, the water can still go somewhere.

For the maintenance on the tank, it is preferred when it has a smooth wall and floor, which makes cleaning easier. It would be optimal if the bottom has a small area that is lower than the rest of the bottom. This would make it possible to sweep al the sediment to one place and would make removing easier.

In order to use the precipitation for washing machines, the quality has to be maximum. For just the littlest decrease in quality, laundry coming out of the machines will immediately smell bad. Focussing on only flushing toilets is therefore easier.

Lastly, operating and maintaining such a tank system takes up quite some time and effort. If this is not possible, it is advised to only install infiltration crates and forget about the reuse of water.

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8 Appendix

8.1 Appendix A

Table 2 - Experiment permeability indication (Frits Ogg)

Proef #	Distance in cm			Time in seconds				
	Begin	End	Difference	Begin	End	Difference	Σcm / Σsec	Σm/ Σsec
1	80	128	48	23	47	24	2,00	0,02
2	60	128	68	14	52	38	1,79	0,0179
3	54	128	74	0	43	43	1,72	0,0172
4	53	128	75	14	56	42	1,79	0,0179
5	53	128	75	7	44	37	2,03	0,0203
								Average 0,0187

8.2 Appendix B

Contents


```
clear,clc
```

Entering data

```
filename ='2018 current.xlsx';
tijdreeks = xlsread(filename);
```

Parameters

```
P = tijdreeks (:,1);                              % precipitation [m^3/w]
t = [1:363];                                      %[step = 1]
Week = [1:364];                                   % time step [week]
Uit = tijdreeks (:,3);                            % usage [m^3/dag]

% Parameters - Design
Tank_max = 7.66;                                  % maximum tank [m^3] 6.5
Krat_max = 4.09;                                  % maximum crate [m^3] 4.09

% Parameters - Infiltration
L_krat = 0.748;                                   % length crate [m]
B_krat = 0.434;                                   % width crate [m]
Opp_krat = 0.3246;                                % surface bottom 1 crate [m^2]
A_krat = Opp_krat * 16;                           % surface bottom crates total [m^2]
Permeability = 1615.68;                           % permeability [m/dag] 8,64 -
0.020833
    %1.122 metres/minute
    %1615.68 metres/day
h = 14.8;                                         % height difference crates to
groundwater level (10-15)
```

Initial values

```
Tank = 0;

Krat = 0;

Extra_water = 0;

Error = 0;

k = 1;
```

```
Amount = 0;

Possible = 0;
```

Formulas

```
for i=1:length(t)

    Possible = Tank_max - Tank - Uit(k);

    % If the tank is not full, water goes into the tank, otherwise to
    % crates
    if  k<=length(P) && (Tank<=Tank_max-(P(k)-Uit(k)))
        Tank = Tank + P(k) - Uit(k);
    elseif k<=length(P) && (Tank>Tank_max-(P(k)-Uit(k)))
        Krat = Krat + (P(k)-Possible);
        Tank = Tank + Possible;
    end

    % Infiltration through the crates
        d = Krat./(A_krat);
        Infiltratie = (Permeability./2)*((h+d)/h)*A_krat;
    if Infiltratie > Krat
            Krat = 0;
    else Krat = Krat - Infiltratie;
    end

    % Indicate when tank is empty and extra water is necessary
    if Tank<=0
        Extra_water = Extra_water+1
        Amount = 1.09;
        Tank = 0;
    else Amount = 0;
    end

    % Indicate when the crates are full
    if Krat_max <= Krat
       Error = Error +1
    end

  k = k+1;

  I_tank(k,:) = Tank;
  U_krat(k,:) = Krat;
  A_extra(k,:) = Amount;

end
```

Tables

```
T = table([1:364]',I_tank,U_krat,A_extra)
```

Plots

```
% figure(1), clf(1)
 x = Week;
 y1 = I_tank;
% plot(x,y1)
% title('Tank level tegenover tijd')
% xlabel('Tijd (w)')
% ylabel('Tank volume (m^3)')
%
% figure(2), clf(2)
 y2 = U_krat;
% plot(x,y2,'r')
% title('Krat level tegenover tijd')
% xlabel('Tijd (w)')
% ylabel('Krat volume (m^3)')

figure(3), clf(3)
y3 = A_extra;
plot(x,y1)
hold on
plot(x,y2)
hold off
hold on
plot(x,y3)
hold off
title('Tank volume vs extra water')
xlabel('Time (day)')
ylabel('Volume (m^3/day)')
legend('Tank volume (m^3/day)','Crate volume(m^3/day)','Extra water(m^3/day)')
```

Export

```
filename = 'Map 3.xlsx';
writetable(T,filename,'Sheet',1,'Range','A1')
```

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8.3 Appendix C

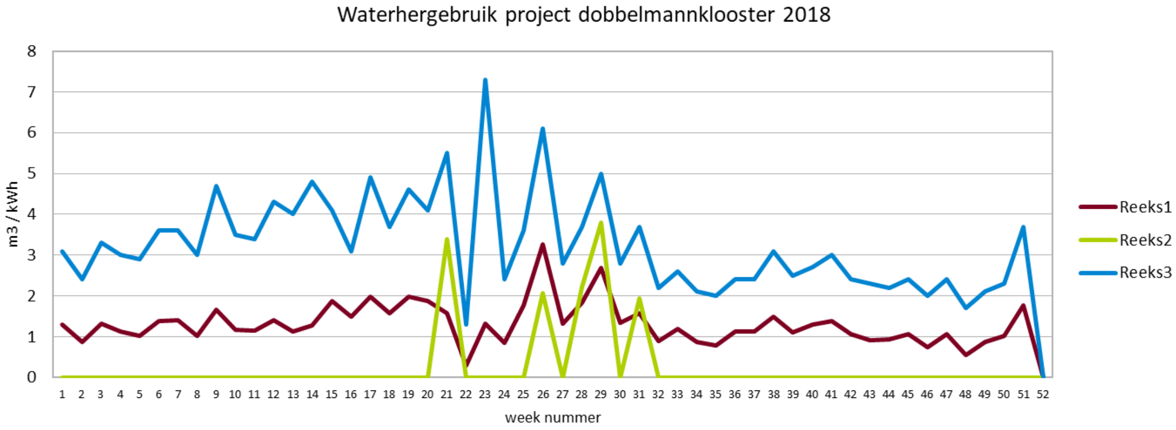

FIGURE 17 - MEASURED DATA (FRITS OGG)

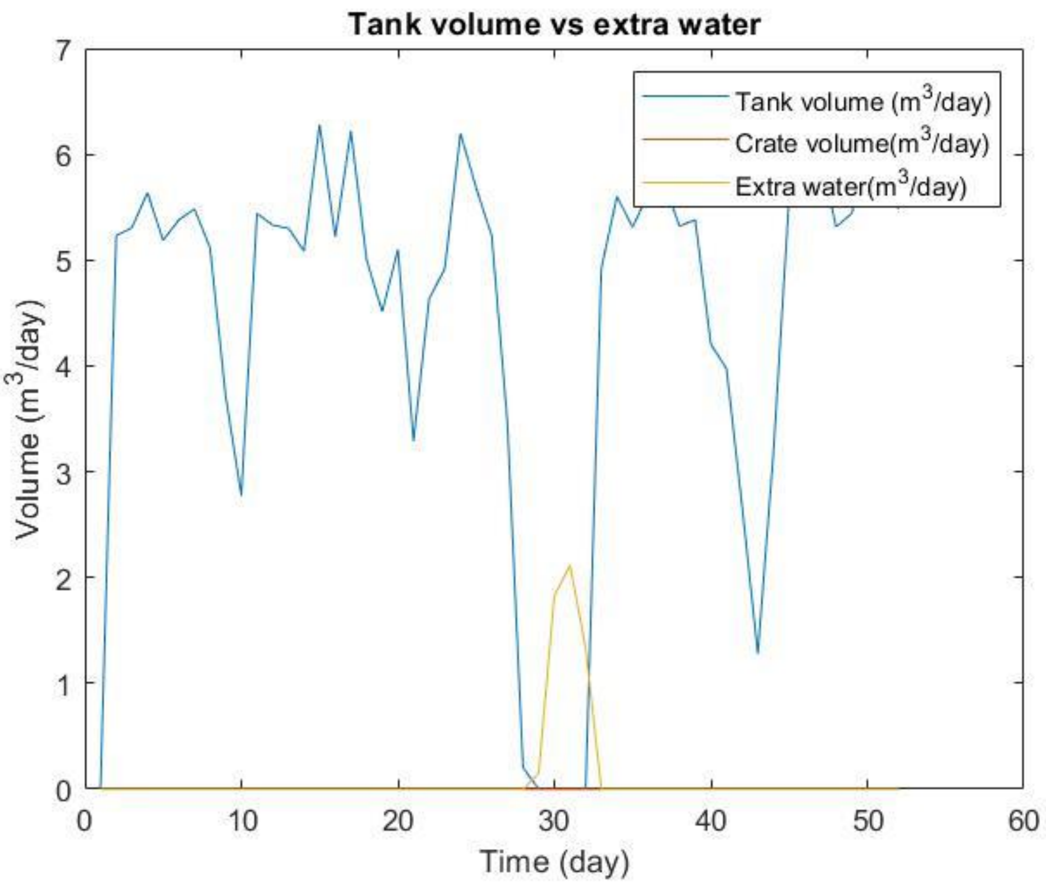

FIGURE 18 - VALIDATION SIMULATION

8.4 Appendix D

Since the amount of data is so large, it has been reduced to a graph from which the data can be read.

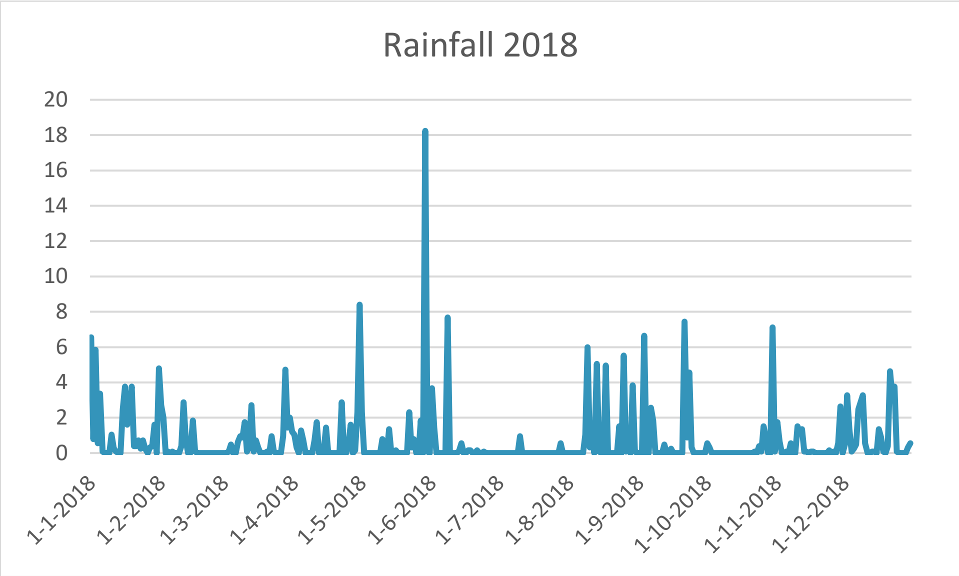

FIGURE 19 - RAINFALL IN 2018

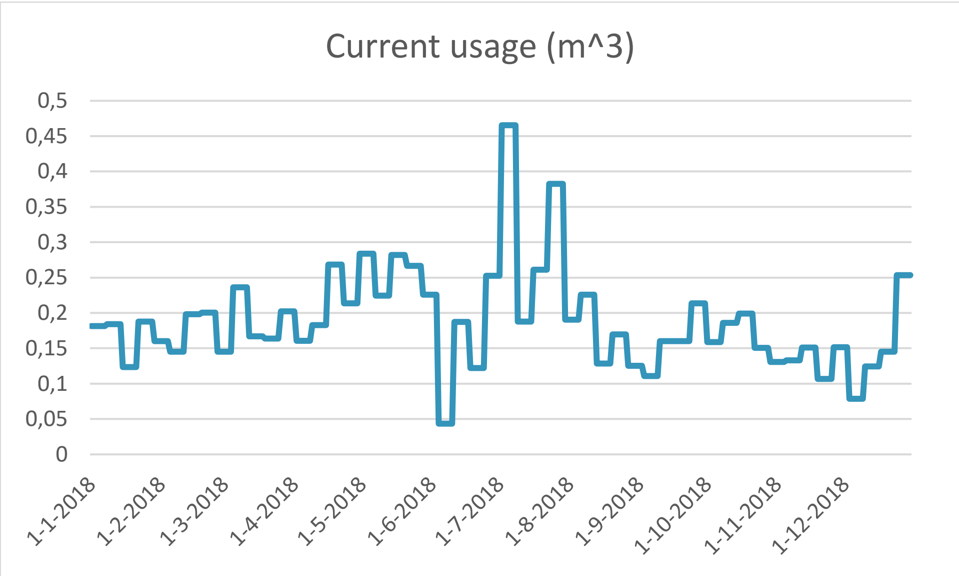

FIGURE 20 - CURRENT USAGE

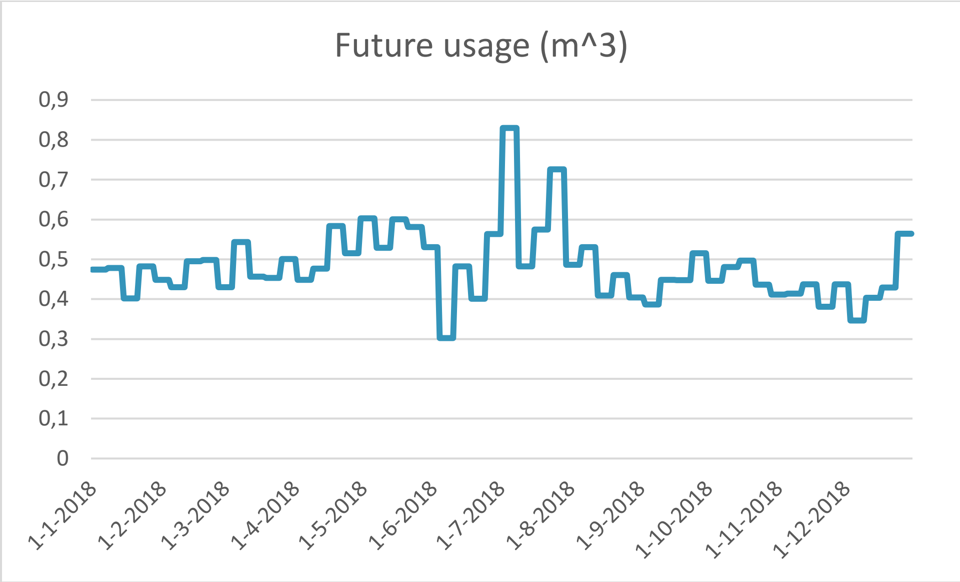

FIGURE 21 -FUTURE USAGE

8.5 Appendix E

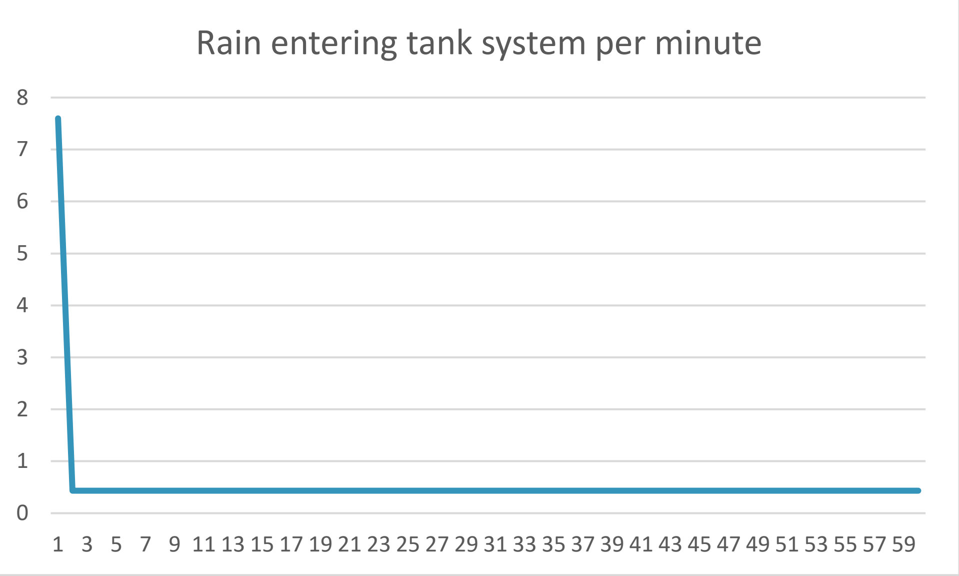

Figure 22 - Rain entering tank system

The values of figure 22 start of so high because the tank starts of full. The first minute is therefore used to fill up the tank.

8.6 Appendix F

TABLE 3 - INCREASE IN RAIN 2050 (KNMI'14-KLIMAATSCENARIO'S, 2019)

Season	Increase in rain scenario W_L	Increase in rain scenario W_H
Winter	+8%	+17%
Spring	+11%	+9%
Summer	+1,4%	-13%
Autumn	+3%	+7,5%

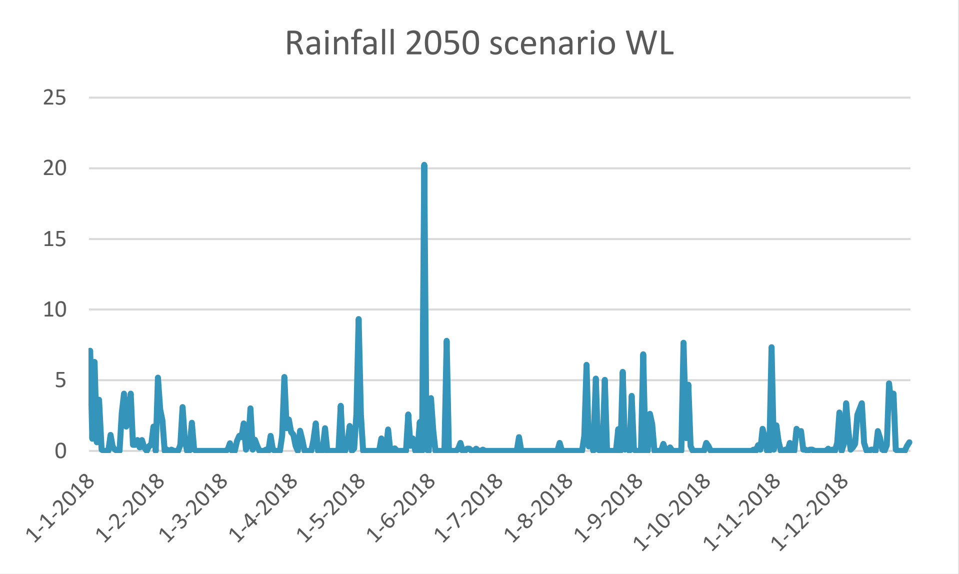

FIGURE 23 - RAINFALL 2050 WL

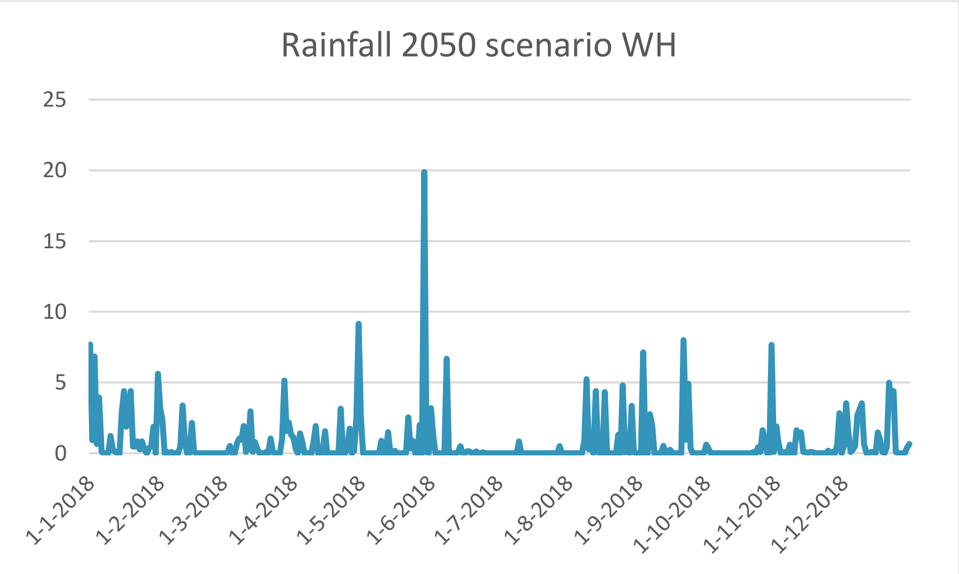

FIGURE 24 - RAINFALL 2050 WH