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Developing a smart rainwater buffering system for the municipality of Enschede

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Abstract

This bachelor thesis describes the process of developing a monitoring and control infrastructure for a smart rainwater buffering ecosystem for the municipality of Enschede. There was specifically looked at 1) how rainwater buffers can be made 'smart', and 2) how the system's data can be presented to the municipality. The purpose of the system is to reduce the strain on the sewerage system of the Oldenzaalsestraat, in order to combat urban flooding. As such, the system was supposed to be implemented on the private property of citizens living in the neighbourhoods De Bothoven and Velve-Lindenhof. A group of four people worked on the project. This report is written from the perspective of group member Gelieke Steeghs.

Literature research, neighbourhood research and interviews with stakeholders led towards the following concept: a system of smart rainwater buffers which adapt their performance according to the predicted rainfall and show their data on an interface. A prototype of the system was realised using a rainwater barrel, called 'Tonnie'. The barrel contains sensors to measure the water level as well as the outflow to the sewerage system, the garden and through a faucet. Furthermore, the barrel contains controllable valves to the sewerage system and garden. When rainfall is predicted for the next 2 hours, the valves are opened to release water and create sufficient capacity for the expected rainwater. This precipitation-dependent behaviour gives the buffer its intelligent nature. The data produced by the rain barrels is presented in a graphical way on two web interfaces: one for the municipality and one for the citizens. The overall buffer performance can be monitored by the municipality on their interface, while the buffers can be monitored and controlled locally by the citizens on theirs.

The prototype of the system was evaluated during functional and user tests. The interface for the municipality was tested with representatives of the municipality and was found to fulfill its job. The performance of the barrel, however, was not yet accurate and stable enough for long-term implementation. A rain barrel was found suitable as a buffer for such an ecosystem. However, the prototype should be developed further in order to create an autonomous system. Furthermore, the system should be implemented with more than one barrel and with multiple types of buffers to find out the performance on a larger scale and create a flexible buffering solution suitable for different locations and users.

Acknowledgements

There are several people who I would like to thank for their help and contribution to this graduation project. First of all, I want to thank my supervisor Richard Bults and my critical observer Hans Scholten. They provided me with helpful feedback and facilitated communication with stakeholders.

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Lastly, I would like to thank my friends and family. Their support means a lot to me.

Contents

Chapter 1

Introduction

In this chapter, the context of this graduation project will be explained by describing the problem statement, the goal and the research questions. Furthermore, the report organisation is described.

1.1 Problem statement

One of the main challenges that cities all over the world have to face today is urban flooding. Due to climate change, the average precipitation increases, as well as the frequency of extreme rain showers. Next to this, the temperature is rising, leading to situations of drought (van den Hurk et al., 2014). Dutch municipalities have to adapt to these changing circumstances, making sure that their city is rain-proof. Among them is the municipality of Enschede, a city with almost 160,000 inhabitants in the east of the Netherlands (Centraal Bureau voor de Statistiek, 2016).

The city of Enschede is built on a push moraine, a gentle slope. Therefore, there is a height difference of around 44 meters between the highest and the lowest point of the city (Gemeente Enschede, 2012a). Additionally, most neighbourhoods in the city have a combined sewerage system, meaning that sanitary water and stormwater end up in the same pipe. This causes extra pressure on the sewerage system. Furthermore, the rate with which water infiltrates into the ground is quite low, due to large amounts of impermeable surfaces and the clay and loam soil in Enschede (Gemeente Enschede, n.d.). As a result, heavy rainfall leads to the flooding of streets as well as buildings, causing damage and dangerous situations.

Aside from extreme rain showers, Enschede is dealing with a high groundwater level, which causes flooding in the basements of citizens (Gemeente Enschede, Lensink, TV Enschede FM, & TC Tubantia, 2010). The groundwater level in the city is naturally high. In the late 19th century, there used to be a lot of textile plants that took care of this. These plants obtained water by using pumps, lowering the groundwater level and enabling the city to expand. However, after the second World War, the textile industry collapsed and the groundwater level started to rise again.

These factors together caused the problem that exists today, as shown in Figure 1.1.

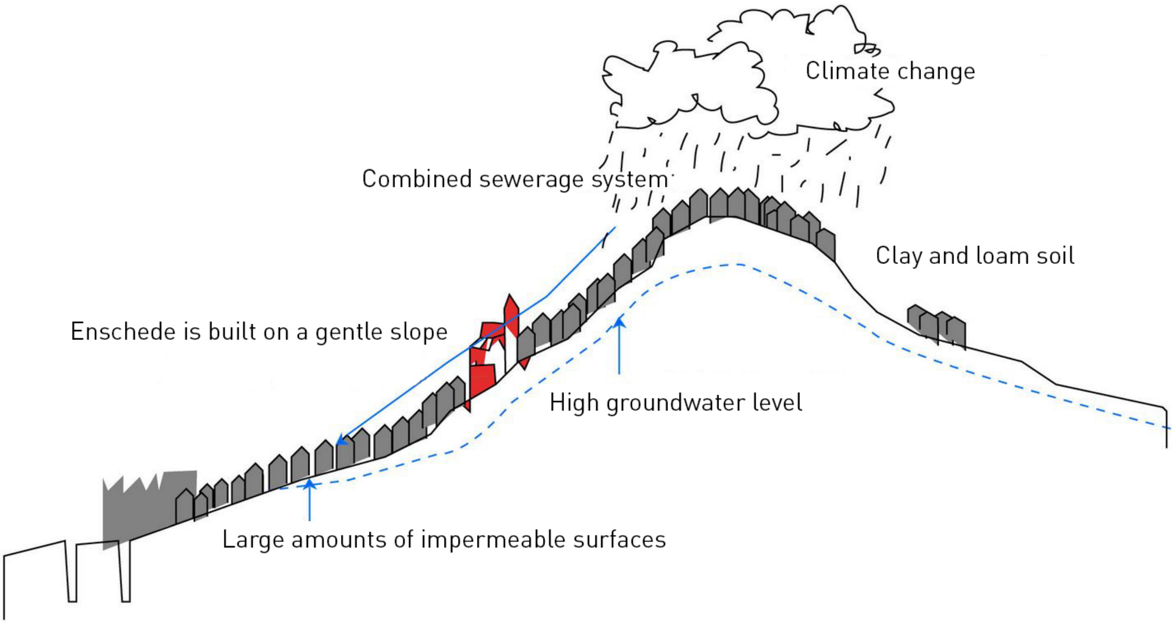

Figure 1.1: Causes of the water problems in Enschede. Based on a figure from the municipality, translated to English (Gemeente Enschede et al., 2010).

In order to deal with this problem, Enschede joined KlimaatActieve Steden (KAS), or Climate Active Cities, cities that take measures towards climate mitigation and adaptation (STOWA, Unie van Waterschappen, & Ministerie van I & M, 2015). The municipality pointed out several bottleneck areas they want to work on in the upcoming years in their 'Waterprogramma' (Gemeente Enschede, 2012b). In this report, water management goals are linked to concrete plans and activities that Enschede wants to carry out in the future. One of the bottleneck areas is in the city centre, around the Oldenzaalsestraat and De Heurne, where there are a lot of shops. The strain on the combined sewerage system here would be reduced significantly if the neighbourhoods east of this area would take up (a part of) the stormwater runoff. These neighbourhoods are De Bothoven and Velve-Lindenhof (see Figure 1.2) and they are the focus area of this graduation project.

1.2 Goal

The goal of the project is to develop a solution that reduces the strain on the sewerage system of the Oldenzaalsestraat. This solution should consist of an ecosystem of smart rainwater buffers in De Bothoven and Velve-Lindenhof, which communicate with each other and produce capacity data. The buffers should adapt their performance to the weather forecast, i.e. empty themselves when rainfall is anticipated, in order to make sure that the buffering capacity is sufficient. The whole system is supposed to be monitored and controlled by the municipality. The challenge is to make the system low-cost and low-maintenance, matching the municipality's and citizens' needs. Furthermore, the water board Vechtstromen will be involved. The design will have to take into account both technical and governance aspects.

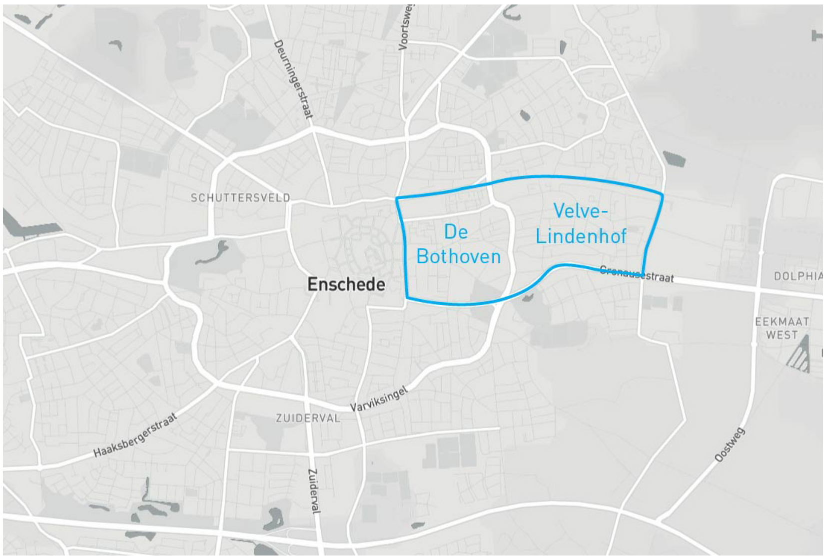

Figure 1.2: The focus area of the graduation project, featuring the neighbourhoods De Bothoven and Velve-Lindenhof.

1.3 Research questions

Based on the problem statement and challenges, the follow research question and two subquestions were formulated:

1. How to develop a monitoring and control infrastructure for a smart rainwater buffering ecosystem that will be placed in the neighbourhoods De Bothoven and Velve-Lindenhof?
   (a) How can rainwater buffers be made 'smart', so they adapt their performance and capacity according to the anticipated rainfall?
   (b) How can the system's monitoring data be processed and presented to the municipality of Enschede?

1.4 Report organisation

The remainder of this report is organised as follows. In Chapter 2, the problem is described in more detail and a literature review is given, including a state of the art. This chapter serves as exploration and inspiration for the brainstorming process later on. Chapter 3 describes the methods and techniques that will be used throughout the project. Then, in Chapter 4, the ideation phase is described including the neighbourhood research and communication with stakeholders. Chapter 5 and Chapter 6 deal with the specification and realisation of the concept, stating the requirements and the software and hardware that was used. After this, the prototype is evaluated during functional and user tests, as described in Chapter 7. Finally, in Chapter 8, conclusions and future recommendations are given.

Chapter 2

Context analysis

This chapter starts with a section on background information. Then, a literature review is conducted, as well as a review of the state of the art. Finally, the relevance of the research question is demonstrated and the chapter is concluded.

2.1 Background research

In this section, the extent of the water problems in Enschede is illustrated with several examples. Furthermore, the way that the water management works in the city is explained.

2.1.1 Past and current water problems and management in Enschede

In the past few years, Enschede increasingly has had to deal with urban flooding events. For example, heavy rainfall caused water on the streets on June 20, 2013 (Wateruniversiteit Twente, 2016; RTV Oost, 2013). Another incident took place in May 2016; the Facebook page 'Gespot: Wateruniversiteit Twente' reported that several streets in the city were flooded (Wateruniversiteit Twente, 2016).

In the 20th century, the municipality of Enschede already took measures to combat their water problems. They placed water retention basins ('bergbezinkbassins') all around the city and implemented a combined sewerage system in several neighbourhoods. Furthermore, they researched the possibility of re-introducing the water pumps that the textile industry once used, in order to get rid of the groundwater surplus.

As part of Climate Active Cities, the municipality is currently developing new solutions in collaboration with water board Vechtstromen. An initiative that is still under construction is the Stadsbeek (Gemeente Enschede & Marion, 2015), a stream in two neighbourhoods in the western part of the city. This stream will take in a part of the surface runoff. Already finished projects are the Kristalbad, a large retention area in between Hengelo and Enschede (Gemeente Enschede, 2015), and the bioswales in Ruwenbos (atelier GROENBLAUW, n.d.). Unfortunately, such measures are often time-intensive and expensive. For instance, the Kristalbad needed an investment of more than 6 million euros (Gemeente Hengelo, 2009). Also, these measures alone are not sufficient to tackle all problems. Different,

Table 2.1: Risk matrix for the Oldenzaalsestraat (Stichting RIONED & STOWA, 2015b).

location	repetition time (years)	maximum water height (cm)	hour (min)	extent	risk
De Heurne and Oldenzaalse-straat	T = 5	10-15	30	street/ neighbourhood	high
	T = 10	20-25	60	neighbourhood	high
	T = 100	20-25	60	neighbourhood	moderate

innovative and bottom-up solutions are needed. In their sewerage report ('Gemeentelijk Rioleringsplan') the municipality of Enschede describes their aims and plans concerning water management for the years 2016-2020 (Gemeente Enschede, 2015). They state two goals: 1) tackle the water problems in the areas with the highest risks and 2) make sure that the sewerage tax does not increase by more than 6.1%.[1]

In order to help reaching the first goal, Stichting RIONED and STOWA created a report in which they introduce the concept of risk-based management (Stichting RIONED & STOWA, 2015b). By using a risk matrix, the municipality can decide in which cases they take action and in which cases the risk is negligible. This risk matrix assesses water problems by looking at the severity of the organisational values (healthy & safety, quality of the living environment, finances and image & branding) and the frequency of the event (time T in years, how often does the event occur). The risk matrix for the Oldenzaalsestraat is shown in Table 2.1. To find out the severity and frequency of the event, the municipality makes hydraulic calculations using the software 'RainTools'. With this software, one can test whether a certain rainshower with a certain frequency results in water on the streets.

Concerning the second goal, there is a need for low-maintenance and low-cost solutions that are developed in close collaboration with the citizens themselves, using a bottom-up approach. That is where this graduation project comes in. But first, a look will be taken at urban water management practices all over the world and the different ways to treat rainwater.

2.2 Literature review

The aim of this literature review is to get an overview of how municipalities and citizens can work together to combine smart or intelligent technology with flooding mitigation measures. This will be achieved by first looking at the newest practices in urban rainwater management. Case studies from all over the world are considered, as one city can learn from the other. Secondly, the factors that determine the success and failure of such systems will be explored. The steps that should be taken before a proper solution can be chosen are described. Third of all, a look will be taken at the possibilities of incorporating smart technology

[1] The sewerage tax is paid by the citizens of Enschede. It has been increasing consistently over the past few years.

into urban water management. Finally, it is investigated which barriers and challenges come up when transitioning towards 'water smart cities'.

2.2.1 Novel approaches to urban rainwater management

There are four recurring aspects in the novel approach to urban rainwater management that can be identified from the literature: 1) integrating different measures, 2) shifting the focus from centralised to decentralised systems, 3) treating water as a resource instead of waste and 4) using best management practices (BMPs) and low impact development (LID) strategies. All over the world, countries have been using one or more of these aspects in their urban rainwater management practices, as a response to the increasing occurrence of extreme rainfall and severe drought. To start off, the key element that is stressed by many studies is to take an integrated approach (Carmon & Shamir, 2010; van Leeuwen, 2017; Schuetze & Chelleri, 2013). According to Camon and Shamir, integrated water resource management aims to improve the planned environment, reduce damage done by stormwater, improves and increases water resources and preserves the biodiversity. All these objectives are reached in a cost-effective way, and take the citizens into account.

Secondly, there is a focus on decentralised instead of centralised systems. The decentralised collection and retention of rainwater can help to avoid stress on the water cycle and improve climate resilience (Schuetze & Chelleri, 2013; Zeng, Tan, & Wu, 2007). According to Schuetze and Chelleri, floods and water shortages will be avoided: a surplus can be drained and seasonal storage of rainwater can be helpful during periods of drought. They argue that citizens will be self-sufficient in their water provision. Zeng *et al.* support this, describing that urban rainwater should be 'shared' between human beings, animals and plants, but also between the wet and the dry season. Both articles support the notion that the system should be in balance.

The third aspect is whether rainwater should be considered as a resource instead of waste. Carmon and Shamir and Shuetze and Chelleri consider it as a resource, but Zeng *et al.* argue that rainwater should be used as both waste and a resource, in order to maintain a healthy hydrological cycle. However, the first two articles are both from 2010 or later, while the last source is from 2007 and therefore not representing the latest insights. Also, the articles from Carmon and Shamir as well as Shuetze and Chelleri were published in journals about water management and the environment, while the article by Zeng *et al.* was published in the Journal of China University of Mining & Technology. As such, the claim that water should be considered as a resource seems more trustworthy.

Lastly, BMPs and LID strategies were mentioned in some case studies. BMPs can be divided into three categories: i) land use planning, ii) land cover design and iii) constructed facilities (Carmon & Shamir, 2010). An example of the second category is to reduce impervious areas and increase pervious areas, as Carmon and Shamir describe. Figure 2.1 shows some additional BMPs. The same authors state that LID 'requires that the hydrological response be kept as it was before development, while allowing the planner to select the means for achieving this'. LID was adopted by the United States Environmental Protection

Figure 2.1: Structural BMPs for stormwater runoff management:
(a) Cisterns, either 1) below or 2) above ground (Water Storage Tanks Inc., 2015; Underground water cistern, 2013),
(b) Rain barrel (Mackenzie, 2008),
(c) Storage beneath a structure (Brett Marin Ltd, n.d.) and
(d) Vertical storage structures (The Tank Depot, 1998).

Agency (USEPA) as a leading approach. Typically, it is applied to pavements, roofs, pipes and the lawn area (Saraswat, Kumar, & Mishra, 2016). Clearly, urban rainwater management has changed in the last few decades and new standards have arisen. The four described elements should be taken into account when developing a new approach to rainwater management in the city of Enschede.

2.2.2 Assessing rainwater buffering solutions

When choosing a suitable rainwater buffering solution, there are six steps that help to assess the options and take into account all relevant factors: 1) gathering baseline data, 2) water governance, 3) creating a scenario and requirements, 4) modelling and simulation, 5) implementation and 6) evaluation. Every step will be discussed in detail in this section and all steps are visualised in Figure 2.2.

The first step is to gather local data based on the current situation. One can investigate the climatological, hydrological and geographical conditions such as precipitation, weather and the groundwater table (Saraswat et al., 2016; Niemczynowicz, 1999; Ellis, Scholes, & Revitt, 2006; van Leeuwen, 2017). According to Niemczynowicz, the data provided by national meteorological services are usually not sufficient. Therefore, it is necessary to conduct field measurements, as proposed by both Niemczynowicz and Carmon and Shamir (2010). Furthermore, the level of urbanisation should be noted by taking into account the

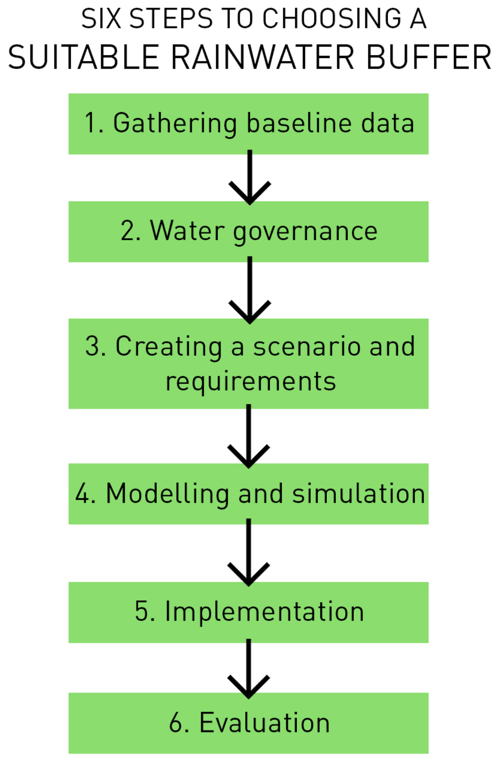

Figure 2.2: The six steps that help by choosing the right rainwater buffer for a certain situation.

amount of impervious surfaces (Saraswat et al., 2016; Schuetze & Chelleri, 2013; Palla, Gnecco, & La Barbera, 2017). Saraswat *et al.* write that the impervious surfaces directly cause a reduction in the infiltration of water, as well as an increase in stormwater runoff by more than 50%. All these elements together determine the context in which the rainwater buffer will be implemented.

The second step is water governance. Water governance can be defined as 'the range of political, social, economic and administrative systems that are in place to develop and manage water resources, and the delivery of water services, at different levels of society and for different purposes' (Rogers, Hall, & Global Water Partnership, 2003). This concept is explicitly mentioned by Saraswat *et al.* and Van Leeuwen. Carmon and Shamir support this, adding that all relevant professionals (e.g. architects, hydrologists and urban planners) should be included and work together.

Thirdly, it is important to list objectives and requirements. Van Leeuwen and Shuetze and Chelleri propose to create a scenario, while Palla *et al.* suggest to develop relevant criteria. In any case, there are several ways to list objectives and requirements, as long as it results in a shared vision. By combining the results of the first three steps, a choice for a correct rainwater buffer can be made.

The fourth step is about testing the solution before implementing it. The literature agrees on the fact that modelling and (numerical) simulation are the best tools for this (Saraswat et al., 2016; Palla et al., 2017; Niemczynowicz, 1999; Carmon & Shamir, 2010). According to Niemczynowicz, advanced calculation methods and modelling techniques are important for predicting how the system works in the hydrological-hydraulic domain. The simulation results can then be compared with the field measurements, as Carmon and Shamir as well as Saraswat *et al.* describe.

The fifth and sixth step constitute the implementation and evaluation of the devised rainwater buffer. Monitoring and evaluating are important for a strategic planning process (van Leeuwen, 2017; Palla et al., 2017). Together, the six steps will be a valuable aid in the development of a smart rainwater buffer for the municipality of Enschede.

2.2.3 Making rainwater buffers intelligent

Smart technology can be combined with rainwater buffering systems by the use of real-time (big) data, the Internet of things (IoT) and by means of intelligent sensing or metering. These three concepts are usually combined. First of all, in the transition towards a smart city, real-time data will become an important tool for real-time decision making. According to Niemczynowicz (1999), real-time control combined with local solutions can help to avoid flooding. Boyle *et al.* (2013) support this, adding that utilities consider data as a way to decrease costs, have a more reliable water supply and limit their waste. Furthermore, big data will increase the efficiency of a city, because it enables countries to make better predictions about the rain. Accordingly, the authorities will know earlier about potential flood events (Rathore, Ahmad, Paul, & Rho, 2016). As Rathore *et al.* write, this information can then be spread throughout the country, warning citizens of extreme weather events. Water reservoirs are also managed by using data on rain levels, according to the author. However, currently only a few parties have a platform for monitoring and gathering data.

Secondly, the Internet of things is mentioned by several authors as a valuable attribute for urban water management (Rathore et al., 2016; Boyle et al., 2013; Ma, Yang, & Wang, 2017). By connecting objects to the internet, devices can communicate and data can be generated, as Rathore *et al.* describe. Ma *et al.* emphasise the role of IoT in the 'gradual improvement of flood control and drainage function' as it can help prevent waterlogging, provides operational services, increases security and makes monitoring and management easier. Figure 2.3 shows a schematic of a process where IoT is used for monitoring.

Third of all, intelligent sensing or metering is a new way to gather information. Geo-information science (GIS) technology is helpful when selecting and evaluating solutions for urban flooding (Saraswat et al., 2016). (Remote) sensors can be used for both real-time and historic data, and they can be combined in a wireless sensor network (WSN) in order to see patterns, as written by Rathore *et al.* A bit more specific is the field of intelligent metering (IM), which concerns sensors used for reading water consumption (Boyle et al., 2013). According to Boyle *et al.*, water service providers use this information to increase their cost-efficiency. It can, however, also be used by the municipality for their climate mitigation strategies and decision making (Ma et al., 2017). It seems that intelligent sensing has several purposes.

Overall, smart technologies are useful for monitoring purposes and for improving existing

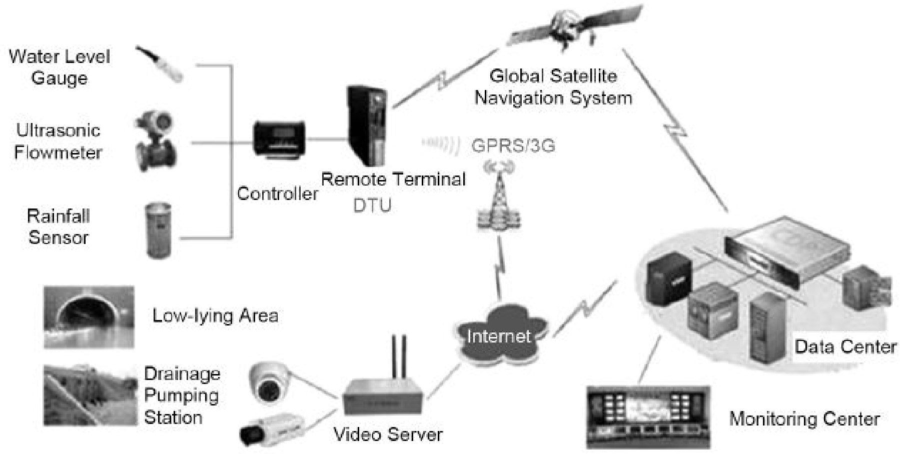

Figure 2.3: Internet of things applied to a monitoring system (Ma et al., 2017).

urban water management. In the city of Chongqing in China, the flood control and waterlogging prevention worked better after an IoT-based system was implemented (Ma et al., 2017). In some cases, the data is already available, but not yet utilised in a proper way. However, real-time data generated by sensors and IoT devices together with historic data, form a great tool for decision making.

2.2.4 Barriers in the transition towards water smart cities

The transition towards water smart cities is not without problems. The barriers most frequently mentioned by the literature are the regulatory framework, the work and education paradigm and the people's behaviour. Laws and regulations can make the implementation of a rainwater buffer quite difficult, as this usually requires changes in the built environment (Saraswat et al., 2016; van Hattum, Blauw, Bergen Jensen, & de Bruin, 2016; Carmon & Shamir, 2010). A weak institutional framework can make it hard for a country to sustainably use (storm)water, according to Saraswat *et al.* Carmon and Shamir support this, noting that policies need to be revised in order to start using runoff as a resource.

Secondly, disruptive water measures often require changes to society as a whole. The existing paradigms in education, work, policies and social habits need to be altered (Niemczynowicz, 1999). Carmon and Shamir write that changing these paradigms is the most difficult part. They point specifically towards education as a tool for publicity and spreading the message. Niemczynowicz agrees with this, as he regards the use of education and information as a way to inform the public.

The last barrier is to change the behaviour of the people. Changing one's lifestyle is never easy, but it is quite necessary (Niemczynowicz, 1999; Boyle et al., 2013). According to Boyle *et al.*, if people do not start saving water then most interventions will be less cost-effective. Carmon and Shamir add that economic incentives might be necessary in order to get stakeholders involved. It seems that there are some challenges to overcome when implementing an intervention to help flood prevention. It is important to take note of these barriers and tackle them, in order to make the transition in Enschede somewhat easier.

2.3 State of the Art

A state of the art research was conducted to find systems similar to the proposed rainwater buffering solution. The findings are described in this section. First of all, ways of treating urban rainwater are described in general. Then, more specific solutions are listed. Both smart solutions and traditional solutions lacking intelligence are considered.

2.3.1 Treating urban rainwater

There are four categories of treating urban rainwater: 1) rainwater harvesting, 2) rainwater infiltration, 3) rainwater storage and 4) rainwater drainage (Zeng et al., 2007; Stichting RIONED, 2006). The categories are visualised in Figure 2.4. Within each of these categories there are several strategies or measures. However, many strategies fall into multiple categories, such as green roofs, which infiltrate, store and drain water. An extensive table with a list of measures per category can be found in Appendix A.

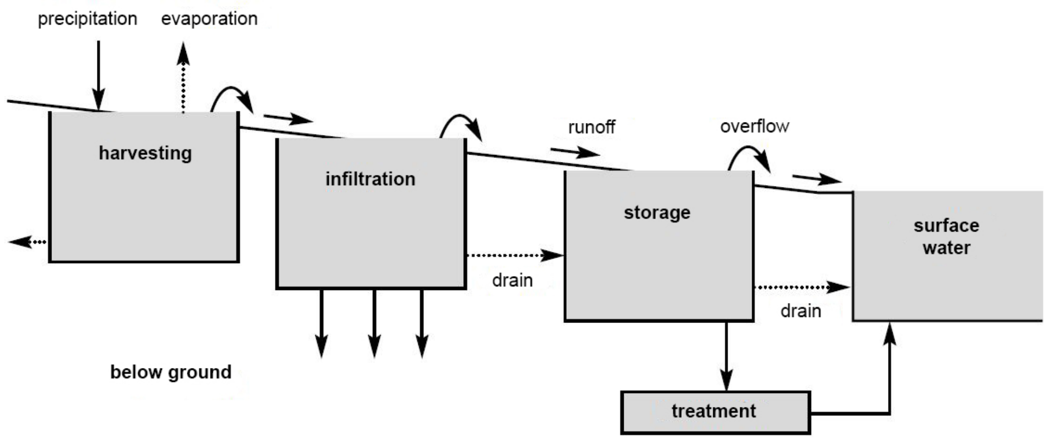

Figure 2.4: Four ways to treat rainwater (Stichting RIONED, 2006).

2.3.2 Rainwater solutions with intelligence

In this subsection, several products related to rainwater buffering that already contain smart elements will be described.

De Slimme Regenton (Studio Bas Sala, 2017)

De Slimme Regenton, or The Smart Rainwater Barrel is a product that is currently being developed by Studio Bas Sala, a design agency in Rotterdam, the Netherlands. The barrel can collect stormwater and store it for a period of time. It uses the weather forecast to predict rainfall and acts accordingly, either keeping or discharging (some of) the water. The capacity of multiple rain barrels can be monitored by water boards. The barrel is constructed for the public area and requires little to no maintenance.

iota OneBox® (iota Services, 2014)

The OneBox is a smart sewerage metering system produced by the Australian company iota Services. The product can be used to monitor and control pressure sewer units in real-time and makes use of the weather forecast. OneBox can be operated remotely, from a computer or smartphone. For this, they iota Services developed an app called 'Tank Talk' which is available on iTunes. A screenshot showing the interface of the app is shown in Figure 2.5. The system is currently being implemented in Aquarevo, an estate south of Melbourne.

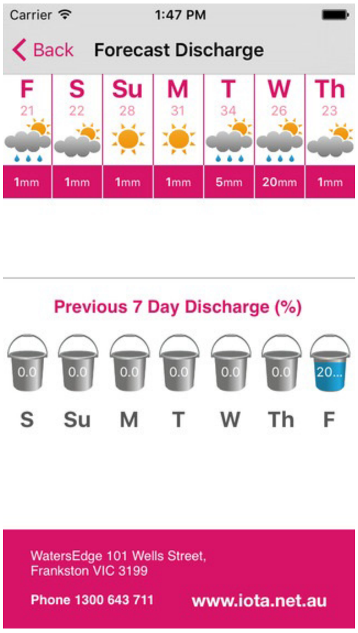

Figure 2.5: Tank Talk app (iota Services, 2016).

Mobile Water Management (Mobile Water Management, 2012)

Mobile Water Management (MWM) is a smartphone app with which one can measure water level and flow. The company is a spinoff from TU Delft, a technical university in the Netherlands. Users simply take a picture with their phone and receive data on (ground)water level, water quality and gate openings in return. This allows users to monitor their water levels easily, without actually measuring it themselves. The system uses image-processing algorithms and a cloud platform in order to do the job.

Smart retention roof by Optigroen (Optigroen, 2016)

The German firm Optigroen designed a greenblue water retention roof that can be controlled by an app. A 'Smart Flow Control' regulator opens and closes a valve according to the weather forecast. The roof will then keep the rainwater, or discharge it through the downspout.

Water level sensors

There are multiple companies that created some sort of (smart) sensor that can measure the water level in a tank. Disdro is a company that created an acoustic disdrometer that serves as a rain gauge, which does not require any maintenance (Disdro, 2014). The sensor produces data on rain intensity and drop-size distributions, which is uploaded to a cloud platform. The company Loxone focuses on smart homes, and as a part of that they produce an ultrasonic sensor that can be used to measure liquid levels in tanks (Loxone, 2014). The sensor sends its data to a smart home platform called Miniserver. Finally, Conservation Technology is an older company (since 1984) manufacturing and distributing technology for energy, water and environmental conservation. They offer two different sensors (Conservation Technology, 2008). They produce a Wireless Ultrasonic Level Indicator, which determines the water level in a rainwater tank by using a directed ultrasonic beam, after which the data is wirelessly transmitted to the control system that can be located up to 1000 feet (300 meters) away. Next to that, they sell a Digital Level Indicator that uses a radio frequency cable sensor hanging in an open tank to measure water levels. Both sensors come with a control panel that displays the water level in a tank as a percentage of the total capacity.

2.3.3 Rainwater solutions without intelligence

This subsection covers rainwater management solutions without intelligence. Possibly, the mentioned products could be made 'smart' in the future.

Hydrorock® and Hydroblob® (Hydrorock International B.V., 2013)

The Dutch company Hydrorock International B.V. develops Hydrorock infiltration blocks which can be used for drainage and infiltration of rainwater in streets and gardens as well as around houses and buildings. The blocks are made of rock wool, which means that they are environmentally friendly. The same company offers a smaller version of these blocks, called Hydroblob. They are meant for the consumer market.

Rainwater and fogwater collecting net (Netherlands Water Partnership, 2007)

A very cheap way to collect water from fog and rain is by using large polypropylene mesh nets. The mesh can capture water droplets sized 1 to 40 µm, which are drained into a series of tanks. The nets are primarily used to provide remote communities with potable water and the typical water production rate is around 160 litres per day.

Rainwinner® (Rainwinner, 2013)

The Rainwinner is a rectangle rainwater tank module. Multiple Rainwinners can be stacked to create a garden fence or wall.

Rain garden (Bakker, 2014)

A rain garden makes use of Sustainable Urban Drainage Design (SUDS). It consists of several elements that work together to create a coherent whole. The following elements could be part of a rain garden (an example is shown in Figure 2.6):

- Overflow structure
- Raised beds
- Bioswale
- Ponds and wells
- Wall garden
- Specific plants that take up a lot of water (i.e. royal fern and yellow iris)
- Special soil mixture

Green(-blue) roofs (Stichting RIONED & STOWA, 2015a)

Green(-blue) roofs can take up rainwater and therefore reduce the water runoff to the sewerage system. There are extensive as well as intensive systems, the difference lies in how shallow and heavy the system is. Extensive green roofs usually only contain grass, mosses or sedum and require little maintenance, while intensive ones need more work and can even carry shrubs and trees. Green roofs consist of several layers, the most important ones being the vegetation layer, substrate layer, filter cloth, drainage layer and the root barrier. The addition of a drainage layer makes a green roof a green-blue roof. Figure 2.7 shows a green roof in the Netherlands.

Stichting RIONED and STOWA created several simulations with green-blue roofs. They concluded that green-blue roofs are interesting because they combine various benefits (such as a cooling effect and increased biodiversity), but that they do not stand out in one of these benefits in particular. When dealing with extreme precipitation, a buffer in the garden or a retention pond are considered more effective by the authors.

Water management in East Almere (Schuetze & Chelleri, 2013)

The development of a self-sufficient polder water management system was investigated in Almere, a city in the Netherlands. This is a key example of integrated water management where multiple water buffering elements are combined into one ecosystem. The system contains amongst others water fields, irrigation canals and seasonal storage areas. In between

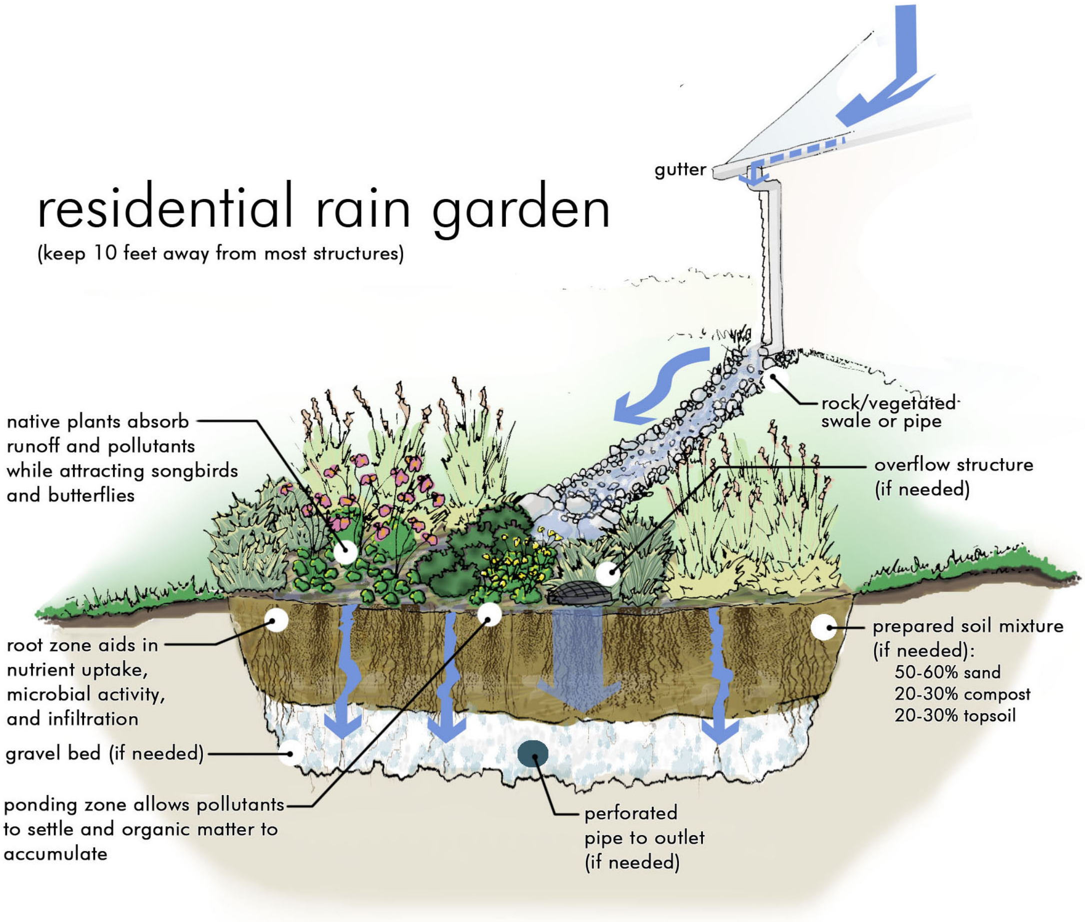

Figure 2.6: Anatomy of a residential rain garden (City of Vienna, 2013).

the seasonal storage areas, a circulation system was introduced to accommodate both peak precipitation and drought events.

Benthem square (STOWA et al., 2015)

The Benthem square ('Benthemplein') is a water square in Rotterdam that stores water in basins during peak rainfall. It can store up to 1.7 million liters of water. The place is multifunctional: when there is no rain, the square can be used to play basketball or other games.

Amsterdam Rainproof (Amsterdam Rainproof, 2015)

Amsterdam Rainproof is a project that tries to raise awareness among citizens about the changing climate and how Amsterdam needs to adapt to that. The city needs to guard itself against the increasing rainfall. To that extent, Amsterdam Rainproof provides several info-graphics that show what can be done in the scope of a building, roof, garden, street, square, park and neighbourhood. Furthermore, on their website they have a toolbox that contains information on all kinds of measures, such as infiltration crates and wadi's (bioswales).

Figure 2.7: A sloping green roof in Assendelft (Optigroen, n.d.).

2.4 Conclusion and relevance of the research question

In this section, the three background research, literature review and state of the art are concluded separately, after which the relevance of the research question is demonstrated.

2.4.1 Conclusion background research

From the background research can be concluded that the solution developed in this graduation project should be low-cost and low-maintenance, both for the municipality and the citizens of Enschede. It should be implemented in an area where the risk of flooding is high. There are a lot of areas where help is needed, but it is out of the scope of this project to treat more than one area. Therefore, together with the water designer of the municipality it was decided to focus on the Oldenzaalsestraat and the area to the east of it. This way, the two goals stated in the 'Gemeentelijk Rioleringsplan 2016-2020' are reached. Furthermore, the municipality and the citizens should be closely involved during the ideation, specification and realisation phases of the project.

2.4.2 Conclusion literature review

The literature review revealed that there are plenty of resources and approaches to learn from. Several authors agreed on the fact that it is best to take an integrated approach to urban rainwater management. There is currently a transition towards decentralised systems that treat runoff as a resource. An example of this are domestic rainwater harvesting systems, where citizens collect rainwater at their homes and use it for flushing the toilet or for their washing machine. These and other solutions appear in the list of BMPs and LID strategies. Such examples can serve as inspiration for the development of a smart rainwater buffering system in the city of Enschede.

Even though there are common elements useful for every city dealing with the problem of urban flooding, it is important to look at the local conditions. In general, certain steps can be defined that help with assessing the practical value of different rainwater buffering systems. A city should start with conducting fieldwork and gathering historic data that represents the current and historic situation. Additionally, intelligent sensors that provide the municipality with real-time data could be installed. In a later stage, scenarios and simulation tools can be applied in order to test and select the best options. After implementing the system and connecting it to the Internet of Things, cities can monitor the rainwater buffers and evaluate whether everything works as desired. In conclusion, smart technology serves as a great tool for decision making.

A few barriers can be defined in the transition towards a smart city that handles water in a sustainable way, such as policies that hinder change to the built environment, or ignorance of the people. However, the literature did not really define ways to counteract these barriers. The only solutions mentioned were education and subsidisation, in order to inform citizens and give them an incentive to participate. It is recommended to do further research on the ways to tackle the challenges that arise when a city wants to implement sustainable water management.

There were limited sources available on the implementation of smart rainwater buffers. Several authors suggested to incorporate real-time control, use sensors to generate data and simulate potential solutions. However, there is a lack of documentation on real life examples as this is a relatively new research area. This makes it even more interesting for this project.

2.4.3 Conclusion state of the art

The state of the art research showed that there are a lot of ways to treat urban rainwater, but they can all be traced back to four basic categories. There are some interesting rainwater solutions that contain smart elements, such as the Smart retention roof and the OneBox. However, these solutions make use of only one type of rainwater buffer, instead of combining different ones. Water level sensors are a simple way to make traditional rainwater buffers smart. Among the rainwater solutions without intelligence, the rain garden and the system in Almere are both interesting examples that show how integrating different measures can create a strong ecosystem of buffers. Furthermore, green(-blue) roofs are already quite common in the Netherlands and since the technology for making these roofs smart already exists, they are a feasible option to consider.

2.4.4 Relevance of the research question

There are numerous case studies and examples of urban rainwater management all over the world, as well as plenty of possibilities for using rainwater. However, it seems that a combination of different measures from various categories is the best way to go. Combining smart technology with an ecosystem of rainwater buffers is something that has not yet been done, which is why this graduation project will look into the development of just that. Climate mitigation measures are possibly more efficient with the addition of intelligence, which in the long run will help municipalities in the fight against urban flooding.

Chapter 3

Methods and Techniques

This chapter describes the methods and techniques that will be used during this graduation project. These methods help to structure the development process as well as this report.

3.1 Creative Technology Design Process

The bachelor programme Creative Technology (CreaTe) teaches students how they can apply existing technologies in novel ways and create new combinations with tools that are already there (Mader & Eggink, 2014). The design process of Creative Technology starts with a design question and continues in four phases: the ideation phase, the specification phase, the realisation phase and the evaluation phase. The method is a combination of Divergence-Convergence and Spiral models, where the iterative development of prototypes is key. In every iteration, the prototype is improved and refined based on human-centered design and established engineering design principles. The design process is visualised in Figure 3.1.

This report is structured according to the Creative Technology design method. Every phase has its own chapter, describing the methods that were used and the corresponding results. In the next few paragraphs, each of the four phases will be described shortly.

3.1.1 Ideation

The ideation phase uses a design question as starting point, looking into related work and tinkering methods as a source of inspiration. Brainstorming tools such as mindmapping can be used to develop a lot of ideas. These ideas can then be refined and narrowed down by stating the requirements (which are specified by the stakeholders). The most promising concept can be developed further by creating mock-ups and a storyboard.

3.1.2 Specification

In the specification phase, the requirements are specified more explicitly (functional/non-functional) and several lo-fi prototypes are developed. Prototyping can be done in several ways: either iterations of the whole product, or an exploration of one aspect of the product. Furthermore, a schematic of the overall system and subsystems is created.

3.1.3 Realisation

The realisation (or implementation) phase begins with analysing the components necessary to make a hi-fi prototype, taking into account the conclusions from the specification phase. In CreaTe, the components usually consist of hardware (electronics), software (code) and a casing. All these components are combined to create a final prototype.

3.1.4 Evaluation

During the evaluation phase, the final prototype is tested with potential users. This user evaluation serves as a way to find out whether the prototype fulfills the specified needs and answers the research question. Furthermore, personal reflection takes place to evaluate the graduation project process.

3.2 Stakeholder analysis

In order to find out which parties should be taken into account during the development of the prototype, a stakeholder analysis can be conducted. Stakeholders are individuals or representatives of a group or organisation who are affected by or may affect a certain decision, outcome or project (Hemmati, 2002; Freeman, 1984). Stakeholders can be categorised according to their role in the project (Sharp, Finkelstein, & Galal, 1999). Sharp identifies four roles:

1. User
2. Developer
3. Decision-maker
4. Legislator

Furthermore, one can create a stakeholder matrix to display the stakeholders alongside a power-axis and an interest-axis (Moore, 2011). This way, it can be clearly seen which stakeholders should be managed closely and which stakeholders should simply be kept up-to-date.

3.3 Surveys

A survey can be used to get an idea of the common opinions of a large and broad group of people. In order to reach as many people as possible, both online and paper surveys can be used. A survey should start with a few demographic questions, which serve as a way to check whether the participant is in fact part of the target group. To facilitate a quick analysis, multiple-choice questions should be the foundation of the survey, supplemented with a few open questions. For more in-depth analysis, interviews are required.

3.4 Interviews

Interviews can be carried out in order to achieve a better understanding of one's viewpoint and gain in-depth knowledge on a specific topic. There are three basic kinds of qualitative interviews used in the social sciences: structured, semi-structured and unstructured ones (Edwards & Holland, 2007).

Structured interviews consist of a set amount of questions, that will be asked to every participant in the same order. This simplifies the analysis, but is also inflexible as there is no possibility to go beyond the questions that were specified. A survey can be seen as some sort of structured interview. This kind of interview is very suitable when it concerns a high number of participants.

Semi-structured interviews are built around a couple of questions that were prepared beforehand, but allow for further exploration of other topics. They are more flexible than structured interviews, but still offer some guidance for the interview.

In **unstructured interviews**, the only thing that is fixed is the subject that the developer wants to discuss. For the rest, the floor is open to the interviewee who is invited to talk about his or her perspective on the topic. This kind of interview is free-form, which can lead to surprising outcomes.

3.5 PACT and FICS scenarios

Scenarios describe the context of use and the activities carried out with a system (David, 2013). PACT and FICS are two tools that can help the developer to align the design of the system with the user's needs and wishes (Widya, Bults, Huis in 't Veld, & Vollenbroek-Hutten, 2009). In order to capture both the user's perspective and the designer's perspective, it is important to implement both frameworks in a scenario (Benyon & Macaulay, 2002).

3.5.1 PACT

PACT is a framework that can be used to describe the user's perspective (Benyon & Macaulay, 2002). PACT is an acronym that can be described as follows (Trulock, 2008):

- **People**: physical and cognitive user characteristics and skills
- **Activities**: goals, tasks and actions
- **Context**: the environment of the activity (physical as well as social)
- **Technologies**: the tools that are used, interfaces, input/output

3.5.2 FICS

In the acronym FICS, the F stands for functions and events, the I for interactions and usability issues, the C for content and structure and the S for style and aesthetics (Widya et al., 2009). FICS is used to describe the designer's perspective.

3.6 MoSCoW

The MoSCoW method can be used to structure and prioritise a list of requirements (Haughey, n.d.). MoSCoW is an acronym where the M stands for must have, the S for should have, the C for could have and the W for won't have. The technique was developed by Dai Clegg in 1994 and has been used by many projects since then.

3.7 Functional testing

Through functional testing, the designed prototype of a system can be tested on its functionalities. This is done by taking a look at the functional requirements, specifically the 'must have' category. If these requirements are fulfilled, the functional test is considered successful and the system can be evaluated with users. It is important that a functional test is executed before the user tests take place, because it should be verified that the prototype functions properly.

3.8 User testing

During a user test, a representative of the target user group interacts with the designed prototype. The goals of user testing in this graduation project are to test the usability of the prototype and to find out whether the prototype fulfills the user's needs (Usability.gov, 2017). This way, problems with the prototype can be identified, if present. Before a user test is conducted, a user testing protocol is created in order to make testing smooth and consistent. The user test protocol defines the purpose of the test, the test setup, the participants, the interaction device, the interaction method and the data collection method. These elements are described in detail below. Furthermore, the heuristics that can be used to test the usability of a system are identified.

3.8.1 User test protocol

The **purpose** of the test defines the underlying goals and concerns of the user test. The **test setup** describes the schedule, location and equipment. The **participants** section describes the participant recruitment criteria. In the **interaction method** section, it is described how the participants will interact with the **interaction device**. The interaction device is usually the prototype of the designed system. Two different interaction methods can be defined for usability testing: free interaction and task based interaction. Free interaction means that the participant can interact with the prototype without any predefined tasks. On the other hand, task based interaction provides the participant with tasks which the participant needs to execute. When choosing the task based interaction, it might be necessary to interrupt the testing and give the participant a hint when he or she does not understand how to perform a certain task.

During the user test, the observer will collect data on how the test participants interact with the prototype. The **data collection method** defines how this is done and specifies which qualitative and quantitative metrics are going to be used. In this graduation project, the methods that will be considered are the thinking-aloud and observation methods. These methods allow to gather the thoughts and experiences of the participants. Qualitative metrics concern the outcome of the thinking-aloud and observation methods, as well as for instance a questionnaire. Quantitative metrics are e.g. successful completion rates, error rates and time spent on a task.

For the thinking-aloud method, the concurrent method will be considered. The concurrent method is meant to make the participants tell about their experiences out loud during the test session (contrary to the retroperspective method, where the participants only reflect on their findings after the test session). It is possible that participants forget the thoughts they had during the test session shortly afterwards. Therefore, the concurrent method is preferred over the retroperspective method.

By observing the participants, additional information can be gathered by taking notes of important discoveries. These discoveries include the emotions that participants show when interacting and if they are interacting enthusiastically with the system. Combining these two methods, the experiences and thoughts of both the developer and the participants can be gathered.

After the user test has been carried out, the results are analysed and a conclusion is drawn.

3.8.2 Usability heuristics

Usability of a system can be tested with ten usability heuristics, developed for user interface design (Nielsen, 1995). These heuristics include:

1. **Visibility of system status**
   The users should be regularly informed about what is going on with the system.

2. **Match between system and the real world**
   The system should make use of familiar icons and concepts, closely resembling what is going on in the real world.

3. **User control and freedom**
   The user should be able to undo or redo an action, enabling a sense of control.

4. **Consistency and standards**
   The design and the terms being used should be consistent, not allowing any confusion.
5. **Error prevention**
   The possibility of encountering errors in the system should be eliminated.
6. **Recognition rather than recall**
   The design should be such that the user does not need to remember too many details in order to use the system.
7. **Flexibility and efficiency of use**
   The system should be tailored to both experienced and inexperienced users.
8. **Aesthetic and minimalist design**
   Only relevant information and data should be shown in the system in order to achieve a minimalist design.
9. **Error recognition, diagnosis and recovery.**
   Clear error messages should be available if necessary.
10. **Help and documentation**
    If the user needs help, he or she should know where to find this.

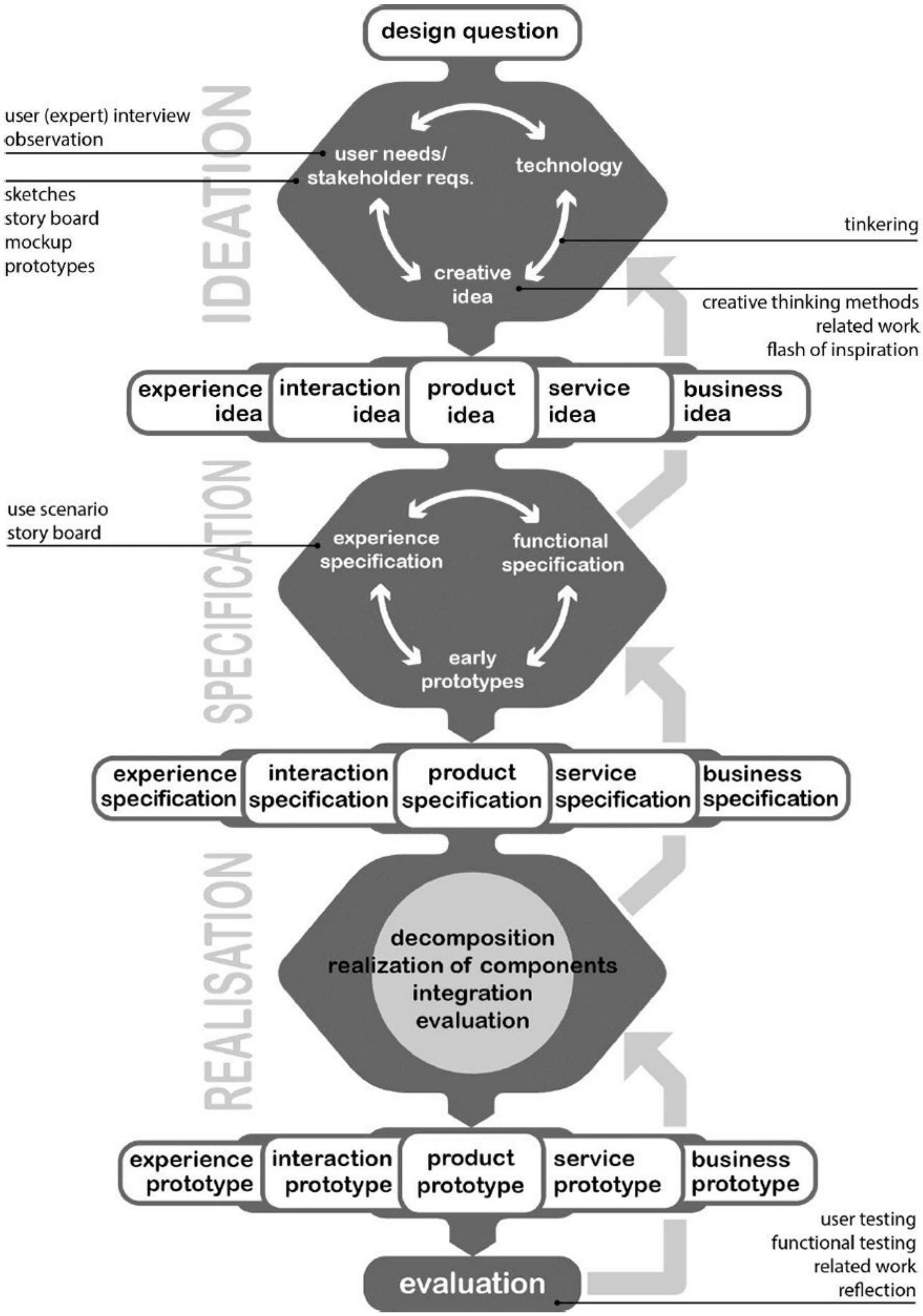

Figure 3.1: Design process for Creative Technology (Mader & Eggink, 2014).

Chapter 4

Ideation

In this chapter, the idea generation is described. As the stakeholders will be referred to extensively throughout the chapter, the stakeholder analysis will be described first. Secondly, the scope of the project is narrowed down and the brainstorming process is described. Thirdly, an analysis of the research area is given. Fourthly, interviews and surveys were held among several stakeholders to get an idea of their needs and wishes. The fifth section describes the chosen concept in detail, which serves as a foundation for the specification phase. The chapter is concluded with user scenarios, built up by using the PACT and FICS frameworks.

4.1 Stakeholder analysis

In this graduation project, the (groups of) stakeholders that could be identified are 1) the municipality of Enschede, 2) the citizens living in De Bothoven and Velve-Lindenhof, 3) the University of Twente, 4) co-developer Felicia Rindt, 5) the Computer Science Master students, 6) Water board Vechtstromen and 7) housing corporations. These stakeholders and their contact persons are listed in Table 4.1. Some of these stakeholders are more important than others. A stakeholder matrix was created to visualise the stakeholders and their role, power and interest in the project, see Figure 4.1. All stakeholders have one role, except for the municipality of Enschede, who is both a decision-maker and a user in this project.

4.2 Brainstorming process

4.2.1 Focus

The research questions of this graduation project were the starting point, repeated below for convenience.

1. How to develop a monitoring and control infrastructure for a smart rainwater buffering ecosystem that will be placed in the neighbourhoods De Bothoven and Velve-Lindenhof?

Table 4.1: Stakeholder groups and their respective contact persons

Stakeholder (group)	Contact
1. Municipality of Enschede	Hendrik-Jan Teekens
2. Citizens De Bothoven and Velve-Lindenhof	Neighbourhood council De Bothoven, neighbourhood council Velve-Lindenhof
3. University of Twente	Richard Bults, Hans Scholten
4. Felicia Rindt	-
5. Computer Science Master students	Jeroen Klein Brinke, Dennis van der Zwet
6. Water board Vechtstromen	Brenda Koopman, Evelien Spoler
7. Housing corporation Domijn	Arno Weppel

(a) How can rainwater buffers be made 'smart', so they adapt their performance and capacity according to the anticipated rainfall?

(b) How can the system's monitoring data be processed and presented to the municipality of Enschede?

Together with supervisor Richard Bults and co-developer Felicia Rindt, it was decided to make a distinction. This graduation project would be carried out on behalf of the municipality of Enschede, while Felicia would work on the buffer with the citizens as target group. Because of the collaboration with her, it was chosen to only look at buffers that will be placed on private ground. Also, it was decided that a part of the realisation would be done by the two Computer Science Master students, Jeroen Klein Brinke and Dennis van der Zwet. This meant that the project allowed for a more elaborate prototype with several subsystems.

Furthermore, it was discussed with Hendrik-Jan Teekens that the envisioned smart water buffering solution would be able to buffer 1 million litres of water, as an addition to the current plans of the municipality to build a basin underneath the Oldenzaalsestraat that will have a capacity of 7 million litres (Gemeente Enschede & Water board Vechtstromen, 2017). In total, 8 million litres will then be buffered.

In the next two paragraphs, the brainstorming process for the two subquestions (with a focus on the municipality) will be described. The state of the art-research conducted in Chapter 2 served as inspiration for this process.

4.2.2 How can rainwater buffers be made 'smart', so they adapt their performance and capacity according to the anticipated rainfall?

In order for the buffer to adapt its performance according to some data, it needs to have sensors as well as actuators. Sensors can be used to measure the performance and capacity, while actuators control and alter these factors. As described in Chapter 2, there are many different rainwater buffers and some of them are more suitable for sensing and controlling than others. As the project is about buffering, or temporarily storing rainwater, the rainwater solutions in the 'rainwater storage' category (as defined in Appendix A) are most applicable.

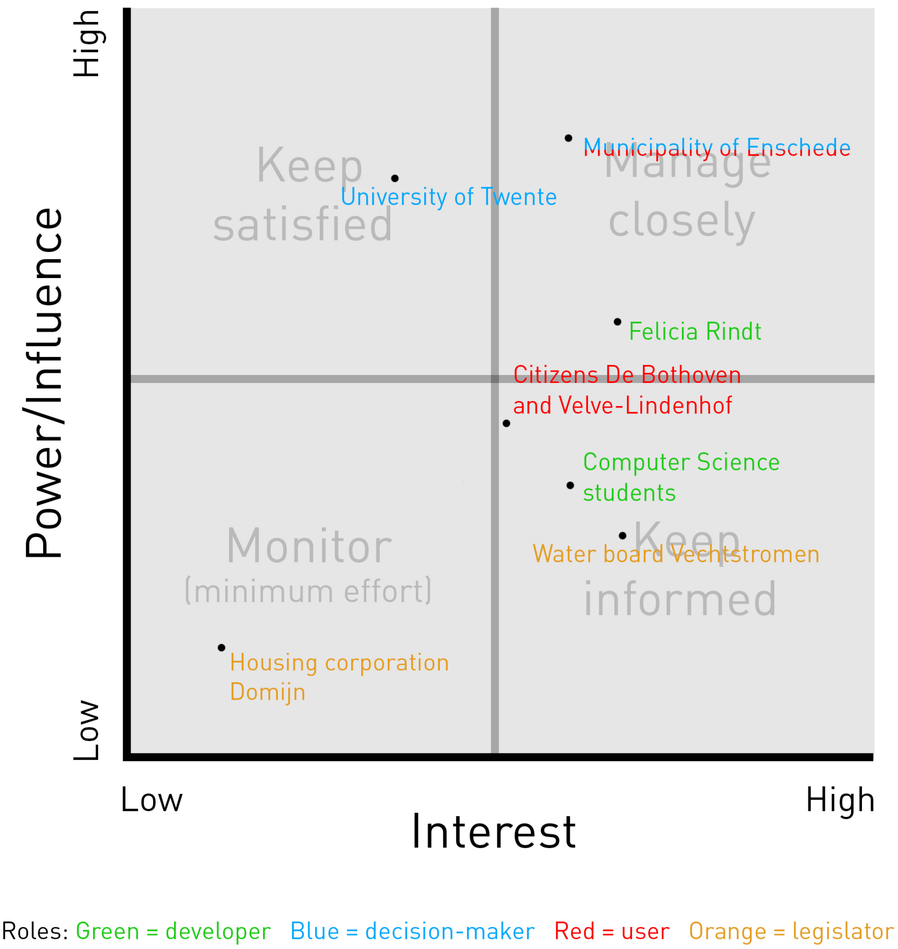

Figure 4.1: A power-interest stakeholder matrix, using the categorisation of roles by Sharp and the matrix template by Moore (Sharp et al., 1999; Moore, 2011).

There are four buffers in this category that were found the most suitable for sensing and controlling purposes on private ground:

1. Rainwater barrel
2. Rainwater fence
3. Rainwater roof
4. Rainwater plant box

Which buffer is most suitable for which occasion depends on the building. A rainwater roof is for instance not suitable for sloped roofs, while sloped roofs are quite common in the area as described in the previous section. However, this option is very applicable for buildings with large, flat roofs.

4.2.3 How can the system's monitoring data be processed and presented to the municipality of Enschede?

A mindmap was created to explore the kinds of data that could be shown on the interface for the municipality. This mindmap is shown in Figure 4.2.

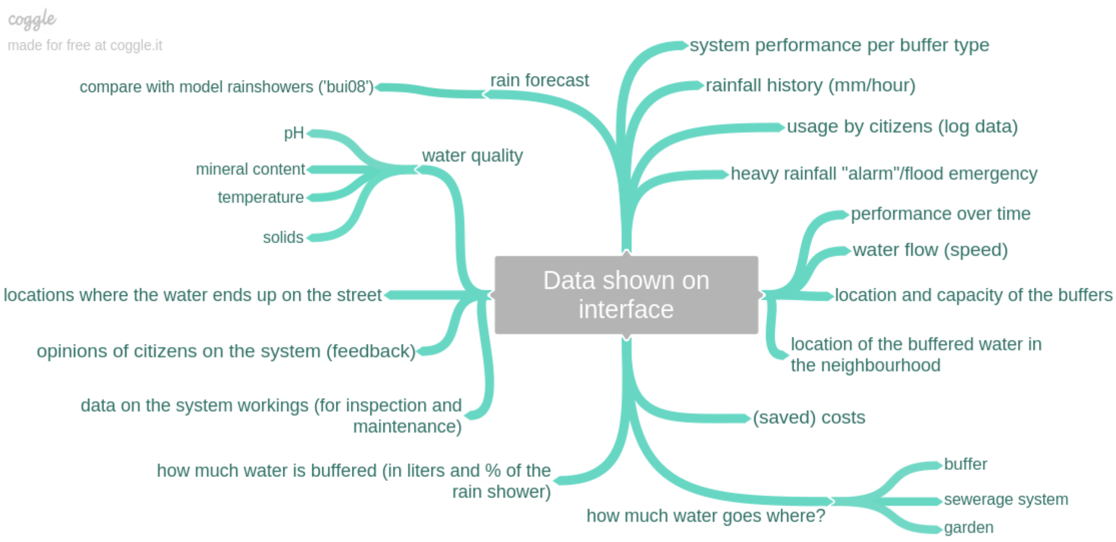

Figure 4.2: Mindmap for the data that could be shown on the interface for the municipality.

There are different ways to visualise this data. The data can be shown in 1) charts and graphs, 2) on a map of Enschede and 3) in numbers and percentages. Furthermore, the municipality will have some kind of web interface that shows all data visualisations in an overview.

4.3 Neighbourhood research

Several sources were consulted in order to get an overview of the research area and its possibilities. Firstly, a round through the neighbourhoods De Bothoven and Velve-Lindenhof was made together with Felicia Rindt. The goal was to get a feeling for the area and get a quick glance at the kind of buildings to see which possibilities there are. The pictures that were made during this round can be found in Appendix B. Secondly, a look at Google Maps was taken. Thirdly, a map of engineering consultancy Witteveen+Bos was used that shows where the (im)permeable surfaces are located and which roofs are flat or sloped. This map is shown in Figure 4.3. Fourth of all, an online map showing the construction years was used, see Figure 4.4. The results of these sources were combined and the key findings are listed below.

- There is little vegetation throughout the whole area.
- There is no water (ponds, rivers, lakes) in the area.

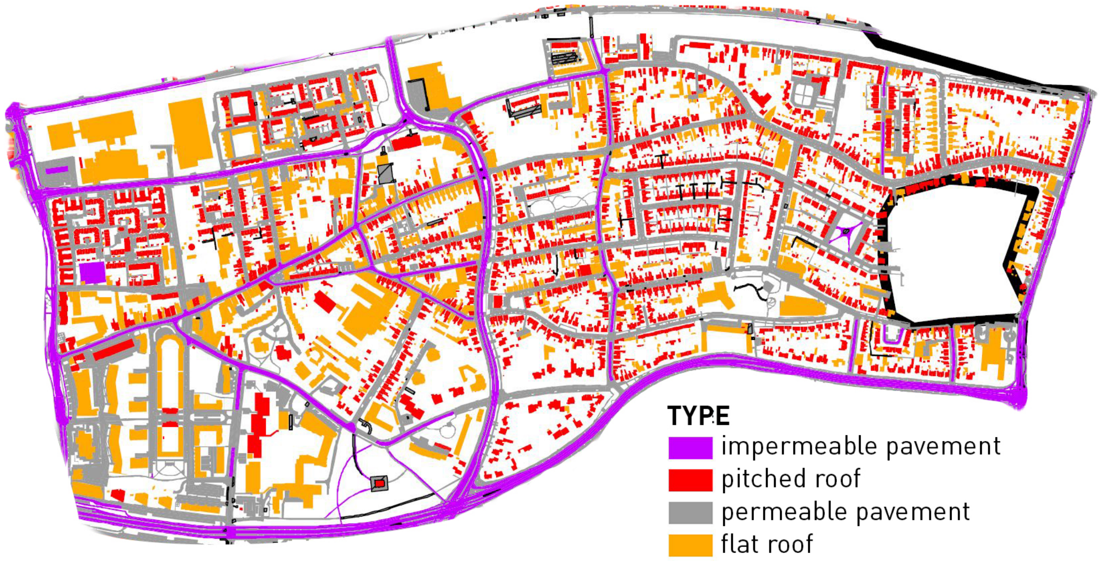

Figure 4.3: A section of the map showing paving permeability and roof type in De Bothoven and Velve-Lindenhof, by Witteveen+Bos (Dekker, 2017).

- There are mostly terraced houses, but also a few apartment blocks.
- Most of the houses have a pitched roof (roof with a slope), while the larger buildings (such as the Performance Factory) and apartments have a flat roof.
- The main roads are impermeable, while the smaller streets contain permeable pavement.
- Many of the houses do not have a front yard and their downspout is close to the sidewalk. In these cases, it is not possible to install a rainwater barrel.
- There are already a couple of houses that have a green roof in Kremersmaten.
- There is a big patch of unused greenfield land east of the supermarket Emté at the Lage Bothofstraat which could serve as a water retention area.
- There are several playgrounds and parks where a water square or wadi could be implemented.
- Next to the Performance Factory, there is a paved area that could serve as a water square.
- The buildings in De Bothoven are relatively new: 88.8 % of the houses were built after 1960.
- The buildings in Velve-Lindenhof are rather old: 63 % of the houses were built before 1960.

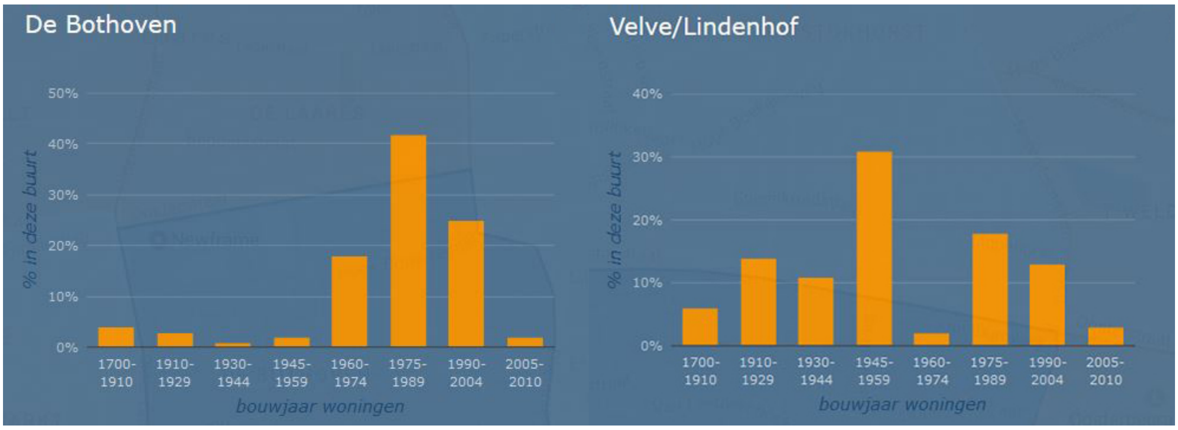

Figure 4.4: The construction years of buildings in De Bothoven and Velve-Lindenhof (Brouwer in Beeld, 2011).

4.4 Interviews and survey with stakeholders

In order to learn the opinion of the different stakeholders, all stakeholders visualised in the stakeholder matrix in Figure 4.1 were contacted. Regular meetings were held with the developers and decision-makers, which were Felicia Rindt, the Computer Science students, the municipality of Enschede and the University of Twente. They were closely involved in the design process. To reach the users, a survey was conducted among the citizens living in De Bothoven and Velve-Lindenhof and interviews were carried out with the municipality. Finally, housing corporation Domijn was interviewed and water board Vechtstromen was contacted via email. The findings of the interviews and the survey are described in the following subsections.

4.4.1 Interview with the municipality

In order to decide on the data that would be shown to the municipality, a semi-structured interview was carried out with Hendrik-Jan Teekens. A first design of a potential interface was created to explore different data visualisations. Inspiration was drawn from Google Images, Chapter 2 and the report 'Ervaringen met de aanpak van regenwateroverlast in bebouwd gebied' (Stichting RIONED, 2014). The design was shown to the municipality and can be found in Appendix C, Figure C.1. The most important findings of the interview are summarised below.

Currently, the municipality owns a water tank of which the valves are opened or closed according to the weather forecast. However, this is manually done by a person. They would therefore like to have an automatic, smart water buffering system. In the case that such a system would be created, the municipality is not so interested in the (design of) the individual buffers, they rather wish to have an overview of the whole system. They want to know how much water the buffers can take up together and how that relates to the predicted rainfall. The municipality prefers a simple and robust system. They do not wish to interfere in the workings of the buffers themselves, they want the system to manage it. As such, they do not see themselves actively controlling the smart rainwater buffering system, merely monitoring it.

To 'compensate' the citizens for installing a smart rainwater buffer at home, they are open to subsidisation. However, they want the citizen to prove that they are really part of the system. Hendrik-Jan liked the first design of the interface, it shows the workings of the system in a plain and neat way. He would prefer the interface to be in Dutch, as this is the language used for internal communication as well.

Currently, the municipality simulate their rainwater measures with software called Rain-Tools. This software might be useful for this project as well. Furthermore, Hendrik-Jan suggested to use the 'model rain showers', which are extreme rain showers that actually took place in the past, to test the workings of the system.

The full interview can be found in Appendix D, section D.1.

4.4.2 Survey with citizens

The neighbourhood councils of both De Bothoven and Velve-Lindenhof were contacted in order to reach the citizens living in these two areas. A survey was created to get an idea of the general opinion among these citizens, as this is a diverse group of people. The survey was shared on social media such as Facebook and Twitter, published on the websites of the two neighbourhoods, as well as promoted on a flyer which was distributed in several public buildings throughout the area (Lumen, 'De Speeltuin' and the Performance Factory).

Unfortunately, only 13 citizens living in De Bothoven filled in the survey and there were no respondents living in Velve-Lindenhof. However, a few things could be noted regarding the willingness of citizens to acquire a rainwater buffer, the kind of buffer citizens would like to have, and the opinion of citizens on sharing the buffer's data.

The results were the following. First of all, more than 70% of the respondents know people who have experienced urban flooding, or they experienced it themselves. This shows that they know the relevance of the problem. To the question whether they are interested in obtaining a rainwater buffer, 7.69% answers 'Yes' and 69.23% answers 'Maybe'. As an explanation for this answer, citizens write that they are not sure whether the benefits are higher than the costs, or whether they have enough space in their garden. Next, the same question is asked, but now it was stated that such a buffer contributes to a solution. In this case, 30.77% answers 'Yes'. If they receive subsidy or other compensation for this, the buffer is more attractive. It is even better when the citizens can re-use the rainwater for their own purposes, such as in the garden or for flushing the toilet. In that case, 69.23% answers 'Yes'.

Participants were asked which buffering solution they preferred (rainwater barrel, rainwater fence, rainwater roof and rainwater plant box). They were allowed to choose multiple options. 36% choose a rainwater roof, 28% a rainwater fence, 20% a rainwater plant box and 16% a rainwater barrel. It seems that the roof and the fence are the most popular options.

At the end of the survey some questions concerning privacy were asked. If the rain buffer were smart and gathered data, the majority (69.23%) is willing to share the data with the municipality. They would not mind if this data would be used to improve the system's performance. Finally, most citizens (53.85%) prefer a plug-and-play product that comes with little to no maintenance.

The full survey can be found in Appendix E.

4.4.3 Interview with housing corporation Domijn

Domijn is a housing corporation in the province of Twente. A semi-structured interview was held with them in order to find out what their role in the project might be. The findings are described below.

Domijn is already working on some measures to combat flooding of buildings, but mostly in relation to ground water. They are involved in a pilot project of sloped green roofs in Transburg. which is located in De Bothoven. However, they do not use any (smart) technologies in this.

Tenants are allowed to put a rain barrel in their house, that is not a problem. Domijn is potentially interested in the project, but they do not see many possibilities for implementing a smart rainwater buffering system in existing buildings, especially since many of the houses they own in the neighbourhood are quite old (built before 1960). If the rainwater can be re-used by the inhabitants, it might be interesting, because then it can be used to give the house a higher energy label. Still, in their opinion, a smart rainwater buffer is more something to consider for newly built houses and apartments.

As far as Domijn knows, young people in the neighbourhood are fairly enthusiastic about water measures, but older and foreign people are more resistant.

Lastly, Domijn mentions the idea to make a map of the possibilities in the neighbourhood, where water could be buffered in what way (on roofs, in tanks, et cetera). That helps the parties involved to see where a smart rainwater buffering system could be implemented.

The full interview can be found in Appendix F.

4.5 Concept

Based on the brainstorming sessions, the neighbourhood research and the interviews and surveys held among the stakeholders, the concept was narrowed down. This is described in the next paragaph.

In Section 4.2.2 it was said that there are four types of rainwater buffers most suitable for sensing and controlling purposes on private ground. As most of the houses in De Bothoven and Velve-Lindenhof have a pitched roof, the rainwater roof was not considered anymore, even though it was the most preferred option by the citizens. The rainwater plant box proved to be expensive, as well as difficult to calibrate with the sensors. The only options left were the rainwater fence and the rainwater barrel. The citizens were more interested in the fence than the barrel, however, rainwater fences appeared to be hard to find as well as quite expensive (a few hundred euros). Therefore, the barrel was left as the most practical and feasible option.

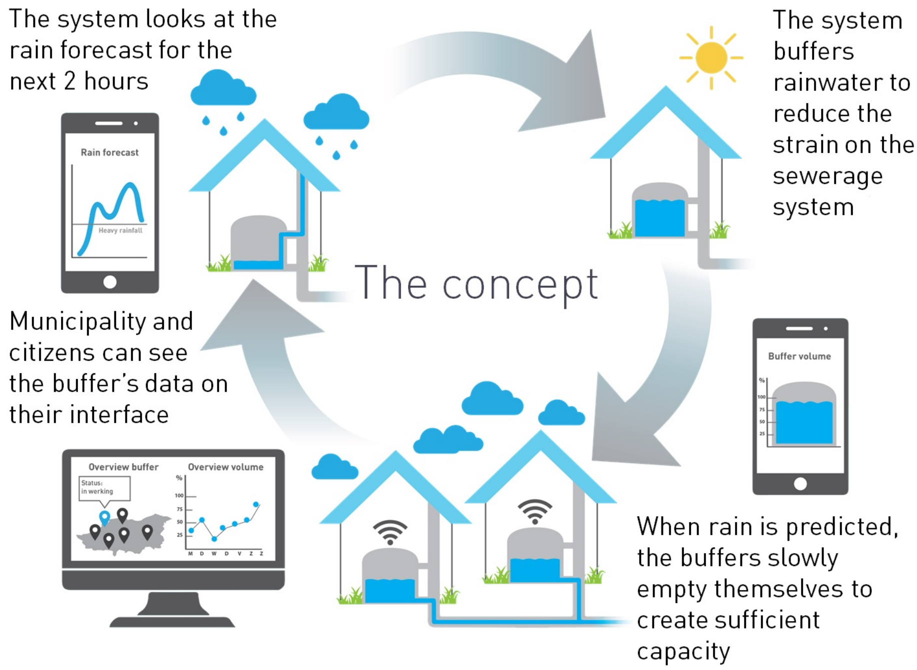

Figure 4.5: The smart rainwater buffer concept visualised.

4.5.1 A system of smart rainwater barrels

The concept, which is visualised in Figure 4.5, is a system of smart rainwater barrels, which are placed above ground at citizen's homes. The system will be called Tonnie, inspired by the Dutch word for rain barrel (regenton). Each barrel contains sensors to measure its water level and actuators to control its valves to the sewerage system and the garden of the citizen. It looks at the rain forecast to decide whether the valves should be opened or closed - if there is a lot of rain predicted, the valves will open in order to release water, so there is enough capacity to capture the expected rainwater.

There are two interfaces that show information about and obtained by the system. The interface for the municipality shows data of the overall system (the combined performance of all buffers), while the interface for the citizen only shows data of his/her own buffer. Both interfaces show the rain forecast.

4.6 PACT analysis

In this section, a PACT analysis for the smart rainwater buffering system is described.

4.6.1 People

There are two types of user groups to be considered:

- The citizens

- The municipality

Both groups have their own characteristics and skills, which will be described in their own section. Even though the developer of this graduation project focuses on the municipality, the information for the citizens will be provided as well in order to give a full picture of the system's workings.

The citizens

The citizens living in the neighbourhoods where the system will be placed (De Bothoven and Velve-Lindenhof) are a diverse group of people. In other words, the users are quite heterogeneous. However, it can be expected that mostly adults (<18 years old) are concerned with the use of the buffer. Their cognitive and physical characteristics can differ a lot, due to age and education differences. If they have mental or physical disabilities, this can inhibit them from using the buffer. The product does not require much physical strength, but it does include an interface that is purely visual. Therefore, people that are blind will not be able to use the buffer system.

Citizens with cultures different from the Dutch culture might not understand the need to engage with the water management in their city. They might not fully master the language. Also, the motivation of the people can differ a lot. If people are individualistic, they might not want to invest in a smart rainwater buffer that helps to prevent flooding in other areas of the city. On the other hand, already established communities form an opportunity for such a product to take off and be used by a large group of people. Personal interests and hobbies play a big role as well in determining whether one wants to use the buffer. If someone is interested in climate change and preventing the effects thereof, then he/she is more likely to adopt the buffer. Furthermore, if a citizen is already familiar with smart home technology or for instance the smart thermostat Toon[2], they might have a lower barrier to acquire the buffer. Finally, the smart buffer might be more attractive to experts and frequent users than to novices and infrequent users.

The municipality

The municipality that will be using the system is the municipality of Enschede. As all these people work in the same place, they are homogeneous rather than heterogeneous. The people working there are adults, in the range of approximately 20-67 years. This means that there can be quite some difference in physical abilities. However, not much physical strength is necessary in order to fully use the product. The buffer is more demanding in the cognitive field, as it requires some attention and perception in order to navigate the interface of the buffer system effectively. But since the role of the municipality is mostly to monitor and not control the system, a limited amount of mental capability is sufficient. There might be people

[2]Toon is a product from the Dutch energy company Eneco, that comes with an interface that gives users a clear overview of their energy usage. See https://www.eneco.nl/toon-thermostaat/.

with special needs, i.e. mental and physical disabilities. However, these disabilities are not very severe, because in that case they would not be working at the municipality.

Since the smart rainwater buffering system is something directly related to the work of the people that will use the interface, it can be expected that they are interested in using it. Their interests and experiences are already in line with the product. Cultural differences are not too much of a problem, as the people working at the municipality are usually Dutch, or at least proficient in the Dutch language and familiar with the Dutch culture.

Some employees might be more proficient users of technology than others, which means that they will find it easier to learn using the interface. However, since the terminology of the interface is familiar to them as they are working with it on a daily basis in their work (frequent users), it should be easy to navigate the system even for novices.

4.6.2 Activities

The smart rainwater buffering system has several different functions. The main goal of the smart rainwater buffer itself is buffering rainwater and the interface gives the users insight in the buffers' systems performance. Tasks that can be executed by the users individually depend on the type of users described above, the citizens and the municipality.

The citizens

The smart rainwater buffering system will be able to function completely autonomously. However, if needed the users will be able to operate the system manually by using the interface. The three main tasks that the citizen can execute is getting insights in their own smart rainwater buffer's performance, manually operating the smart rainwater buffer by deciding the amount of water that the buffer should discharge into the sewerage system and re-using the harvested rainwater for private uses. Actions that cover the first task, getting insights in the user's own smart rainwater buffer, are visiting the web page on a computer or smartphone on which the interface is being displayed. This web page displays several graphs on the precipitation forecast, the system's performance and history. The user can display the graphs on a specific date range by selecting this date range on the web page. Since the smart rainwater buffering system is able to function completely autonomous, the user can execute this task as frequently as they prefer.

The actions that cover the second task, also include using the interface. The user can set an amount of water that should be discharged into either the garden or the sewerage system by typing the amount in litres into a text input field on the interface and then clicking the discharge button. The discharge request can be cancelled any time by clicking the cancel button.

Finally, the actions that cover the third task involve using the faucet of the rain barrel. To re-use the harvested rainwater, the user can place a watering can or a bucket underneath the faucet or attach a garden hose to water the plants.

The municipality

For the municipality, the smart rainwater buffering system is a completely autonomous system and therefore the only task that can be executed is getting insights in the smart rainwater buffering system's total performance. Actions that cover this task are visiting the web page on a computer on which the interface is being displayed. On this web page, several graphs on the precipitation forecast, the system's total performance and history can be displayed. The user can select group of buffers to see the data from. Additionally, the user can display the graphs on a specific date range, by selecting this date range on the web page. Since the smart rainwater buffering system is an autonomous system, this task can be executed as frequently as the user prefers.

4.6.3 Context

The physical environment of the buffer is outside a citizen's home, possibly in a garden. The buffer is therefore subject to any weather condition, which means that it can be dry or wet, warm or cold, sunny or cloudy. Considering the social environment and the circumstances of the activities, this is different for both citizens and the municipality.

The citizens

The social environment of the buffer concerns the interface through which the buffer data is communicated. This interface is a website that can be accessed on a computer or mobile phone. The citizens can interact with the system during any time of the day and at any place, as long as they have their phone or computer with them. Furthermore, they can tap water from their buffer outside, if they are at home. In case the citizens need support or help with managing their buffer, they can contact the Tonnie team.

The municipality

The social environment concerns the interface of the municipality. This is also a website. The municipality employees will use the interface during working hours, in their office. It is possible for them to use the system when they are at home as well, but it is not likely that they will do so unless they are working. The employees cannot interact with the individual buffers, unlike the citizens.

4.6.4 Technologies

The technologies that are used in the smart rainwater buffering system are the same for both the citizens and the municipality.

The input of the system is the sensor data, the precipitation prediction and the user input (i.e. to discharge a certain amount of water). The output is the opening and closing of the valves, as well as the graphs and charts that are shown on the graphical user interface. The buffer communicates with a central server and with the interfaces. The user communicates by using the faucet and by using the interface, through making selections and specifying a discharging amount. The interface does not contain any sounds, but when water is pouring in the buffer, it might be that this produces some noise.

The buffers from the citizens are all connected to the main server that is situated at the municipality. The buffers are 'on' at all times, but they do not send or receive data all the time (not real-time).

4.7 PACT-FICS scenario

The results of the PACT analysis are combined with FICS in order to create a scenario that captures both the user's and the designer's perspective. One scenario is created for the citizens, and one scenario is created for the municipality.

4.7.1 The citizens

Gerard is a 42-year-old Dutch man living in a semi-detached home in neighbourhood De Bothoven with his wife and two children. He works at a software company and in his free time he likes to work in the garden and works as a volunteer in the nursing home nearby. In the past few years, it has happened several times that the street where he lives was flooded due to extreme rainfall. On the other hand, in the summer his garden can be very dry and he has to use a lot of water. Gerard heard about the smart rainwater buffering system Tonnie from his friend Diederik, who works at the municipality of Enschede. Since he already owns Toon, the intelligent energy meter, he decided to give Tonnie a try too.

Gerard receives his Tonnie in the morning and places it in the back yard next to the back door. Its dark-green colour fits quite nicely with the rest of his garden. Once installed, he opens the interface of the buffer on his laptop and looks at the current performance. He can see that the system status is fine and everything is working accordingly. There are no notifications. Furthermore, he can view the weather forecast and sees that it is going to rain within the next 2 hours. That means that his barrel will be filled. Satisfied, he goes to his work. In the lunch break, he checks the interface again, this time on his smartphone. He can see that the buffer is now filled with 50 litres of water. However, since it is going to rain again within half an hour, the buffer is scheduled to discharge 20 litres of water in order to create sufficient capacity for the predicted rainfall.

When Gerard arrives home in the evening, he finds his barrel still containing some water. As his plants need some water, he taps a few litres by using the small faucet of the barrel and waters his garden. Afterwards, he can see on the interface that the buffer contains 18 litres of water.

The next morning when Gerard wakes up, the interface shows an error message, indicating that the connection with the central server was lost. Surprised, Gerard goes downstairs and finds that the wifi connection at their home is lost. The system is now not able to retrieve the weather prediction. Luckily, a technician comes within an hour and fixes their internet connection right away. Furthermore, the whole day it is very sunny, so the buffer is not operating anyways. However, this also means that Gerard's garden is very dry. That is why he plans a discharge of 5 litres on the interface.

After a month of using Tonnie, Gerard is still very pleased with the system. It allows him to use less water from the tap, as he can now use the water that is captured by the buffer. On the interface he can see the history of the buffer's capacity over the last couple of weeks, and notices that the capacity has gone down in the last week as it has been raining a lot. For the rest, his buffer is usually filled within the range of 10-130 litres. This means that there is in general plenty of water for him to re-use.

4.7.2 The municipality

Diederik is 28 years old and started to work at the municipality of Enschede right after he finished his water management study. He recently got married to his girlfriend who he knows from tennis. At the municipality, Diederik is working in the water department,looking for solutions to reduce the strain on the sewerage system during heavy rainfall. There have been several days over the past few years where streets were flooded because the sewerage system could not handle all the rainwater at once.

Since a couple of months, a new system called Tonnie has been implemented which combined rainwater barrels in a smart communication network. These barrels have been promoted extensively and there are now around 5000 of them placed around the neighbourhoods De Bothoven and Velve-Lindenhof. The buffers are connected to a central server that is placed at the municipality. Each employee in the water department has access to the interface that shows an overview of the performance of all buffers. The system works autonomously and does not require much assistance, but Diederik likes to take a look at it at least once a day, simply because he finds it very interesting. As such, he is one of the employees at the municipality who uses the system most extensively and knows a lot about it.

On a Monday morning in April, there is a lot of rainfall predicted and Diederik is a bit worried about the situation. He checks the interface in the morning and sees that the expected rainfall is around 20 mm/u, which is quite a lot. This corresponds to bui08, a model rain shower that is the heaviest that most sewerage systems can handle. There is already 55% capacity empty, and around half of the buffers are scheduled to discharge some more water, leading to 87% empty capacity. That should be sufficient to capture all the water and there is no reason to worry.

Somewhere in the afternoon after it has rained, Diederik looks at the interface again. The system status is orange, and there is a notification stating that the buffer's capacity is lower than 20%. Indeed, there has been a lot of rain and many of the buffers are almost full, if not filled to the rim. Luckily, this also means that no water ended up on the streets, and thus flooding was prevented.

Tonnie has given Diederik a lot of insight into the fluctuations of rainfall and citizen's water usage. He can see that there is less water ending up in the sewerage system, and that the buffers actually prevent urban flooding. Furthermore, he has received a lot of feedback from the citizens which has helped the developers to make the system even better.

Chapter 5

Specification

In this chapter, the concept of the system is made more specific. First, the requirements are stated. Then, the functionalities of the system are described and visualised in a functional block diagram.

5.1 Requirements

Based on the wishes and needs of stakeholders as well as important factors identified by the developer herself, a list of requirements was created. First of all, user requirements were defined. After that, the corresponding system requirements were described. These were split into functional and non-functional requirements. The full list of requirements can be found in Table 5.1. The requirements were verified with a citizen and with the municipality during an interview. The full interview with the municipality can be found in Appendix D, section D.2.

5.2 Functional block diagram

The requirements were a starting point for creating a functional block diagram that shows an overview of the system as well as the subsystems.

5.2.1 Overview

Figure 5.1 shows the smart rainwater buffering system as a whole. The system consists of three subsystems:

1. The smart buffer system
2. Monitor and control applications
3. The central server

Each of these subsystems deal with a different part of the system. Together they transform the input ('outside world', 'time-dependent precipitation prediction' and 'end user input') into

Table 5.1: Functional requirements. (* = requirement verified with municipality, ** = requirement verified with a citizen)

Functional User requirements	Functional System requirements
Must	
The buffer is able to store and release rainwater automatically.*	
The rainwater captured by the buffer is re-usable by the citizens.	The buffer is connected to a downspout diverter. The buffer contains a faucet to retrieve water and has a sensor to measure the flow rate.
The user is able to see the weather prediction data up to 2 hours ahead.*	The system is able to fetch weather prediction data by communication with a weather station (KNMI, Buienradar). The system uses weather prediction data up to 2 hours ahead.
The user is able to see data generated by the system every 15 minutes.*	The system's sampling rate is 15 minutes. The system's synchronisation rate is 15 minutes.
The interface of the municipality shows the overall system performance consisting of the historic and current buffer volume, future discharge data and rainfall prediction.*	The buffer contains sensors that measure the water level. The data of the buffers is stored in a central database. The buffers communicate with each other and with the central server via WiFi.
The interface of the citizens shows own system performance that includes catchment history (request for one year) **, future catchment overview, current water level inside the tank and show the precipitation forecast.	The data of the citizens is stored for a month on the local node (aka. buffer system).
The buffer discharges through a pipe that is connected to the downspout.	
The buffer can be discharged independently of other buffers.*	
The citizen is able to use the roof as a catchment area for the buffer.	The buffer is connected to the downspout of the roof.
The buffer does not cause excessive rainwater in the gardens of the inhabitants.	The buffer has a downspout diverter that acts as an overflow.
Discharging the system does not result in excessive water in the sewerage system.	

The user information will be treated confidentially and anonymously.	The system anonymises the data from the citizen's buffers in the interface of the municipality, meaning that the municipality cannot see to which person which buffer belongs.
Should	
	The buffers communicate with each other and with the central server via LoRa.
The buffers notify the user in case of malfunctioning or dangerous situations.	The system should send error messages/ notifications in case of malfunctioning or dangerous situations (leakage, no contact with server, clogged, freezing).
The buffer has an overflow to the garden that will only be used between April and October.*	
The citizen is able to see recent data (almost real time) generated by the system at any time.**	Sampling rate of the sensors is lower than the synchronisation rate ($<$15 min) and higher than the sensor accuracy. The system is able to send new data to the interface of the citizen with the same rate as the sampling rate.
The rainwater captured by the buffer is not contaminated by leaves, debris (sand etc.) and insects.	The system must filter the water before it is stored in the buffer.
The citizen is able to choose whether his/her buffer data will be shared with the municipality.	
Could	
The municipality is able to test the system's performance with model rain showers.*	The system could be tested using virtual data/models.
The buffers each contain a weather station that measures local weather statistics.*	The buffers contain sensors for measuring and predicting temperature, wind speed and humidity.
The interface of the citizen only shows the data corresponding to that citizen's buffer.	The interface stores the buffer data on a local server.
Won't	
The interface of the inhabitants shows an overview on potable water savings.	
The user is able to connect an existing rainwater barrel to the system.	

Table 5.2: Non-Functional requirements.

Non-Functional User requirements	Non-Functional System requirements
Must	
The buffer network should have enough capacity to buffer a medium-large rain shower.	The joint capacity of all buffers is 1000000L of rainwater.*
The interface of the users shows the water level with a high accuracy.	The accuracy of the buffer is 1L.
The buffers discharge ahead of a predicted rain shower.*	The buffer must have a discharge of at least 67L/hour ($\sim$1L/min).
The user does not need to operate the system (manually) in order for the system to fulfill its purpose.*	The system functions autonomously and does not require intervention from the user in order to fulfill its purpose.
The citizen is able to operate the system manually.	The interface of the citizens contains buttons with which the citizen can control the buffer's capacity.
The user is able to operate the interface of the system with ease.	
The buffer fits in the garden of the citizens.	
The system is safe (does not fall over, protecting user from the electronic components).	
Should	
The system does not use a substantial amount of power.	The system is energy efficient. The sampling frequency of the system adopts to the current weather state and re-usage of rainwater by the citizen.
The sampling frequency of the system adopts to the current weather state and re-usage of rainwater by the citizen.	
The system is durable (lasts a long time).*	
The buffer's design is unobtrusive and aesthetically pleasant.	
The user needs the system to function at any given weather condition, all year round.*	The system should function whether or not it has been in contact with water.

the output ('end user output'). In the next few sections, the subsystems will be described in detail.[3]

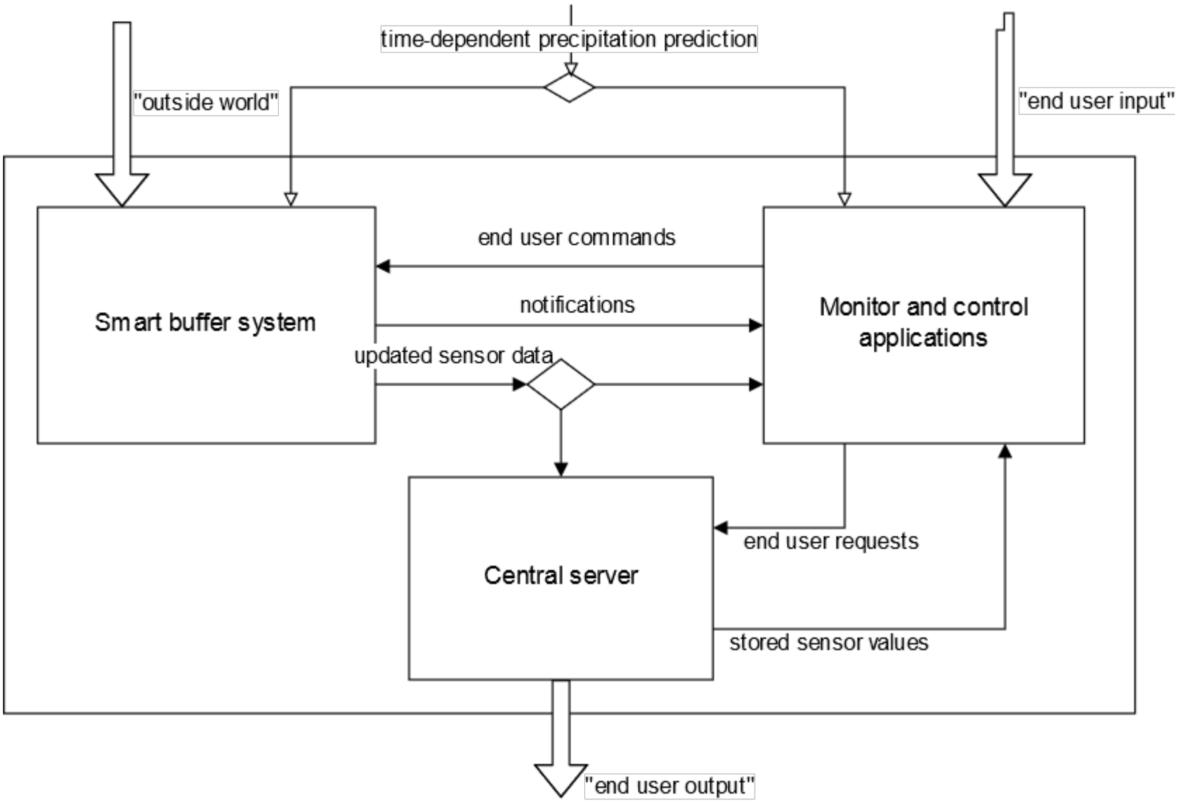

Figure 5.1: Overview of the complete smart rainwater buffering system.

Smart buffer system

The smart buffer system compromises the sensors and actuators of the buffer. The system is visualised in Figure 5.2. As input, this subsystem receives the 'outside world'. Furthermore, it receives the time-dependent precipitation prediction and the end user commands from the monitor and control applications.

This subsystem consists of four blocks. First, the sensor system, in which the water level, input/output flow and temperature are measured. Secondly, the sensor data pre-processing, in which the raw sensor data is pre-processed and filtered. Thirdly, the event handler deals with error and logic notification (if applicable). Finally, the smart buffer logic, where the sensor data is used together with the time-dependent precipitation prediction and the end user commands to make a decision regarding the valves of the buffer: will the valves be opened or closed?

Every 15 minutes, according to the requirements, the updated sensor data and the notifications are communicated to the next subsystem: monitor and control applications.

[3]An even more elaborate and detailed explanation is to be found in the report of Jeroen Klein Brinke and Dennis van der Zwet, which will be finished in August 2017.

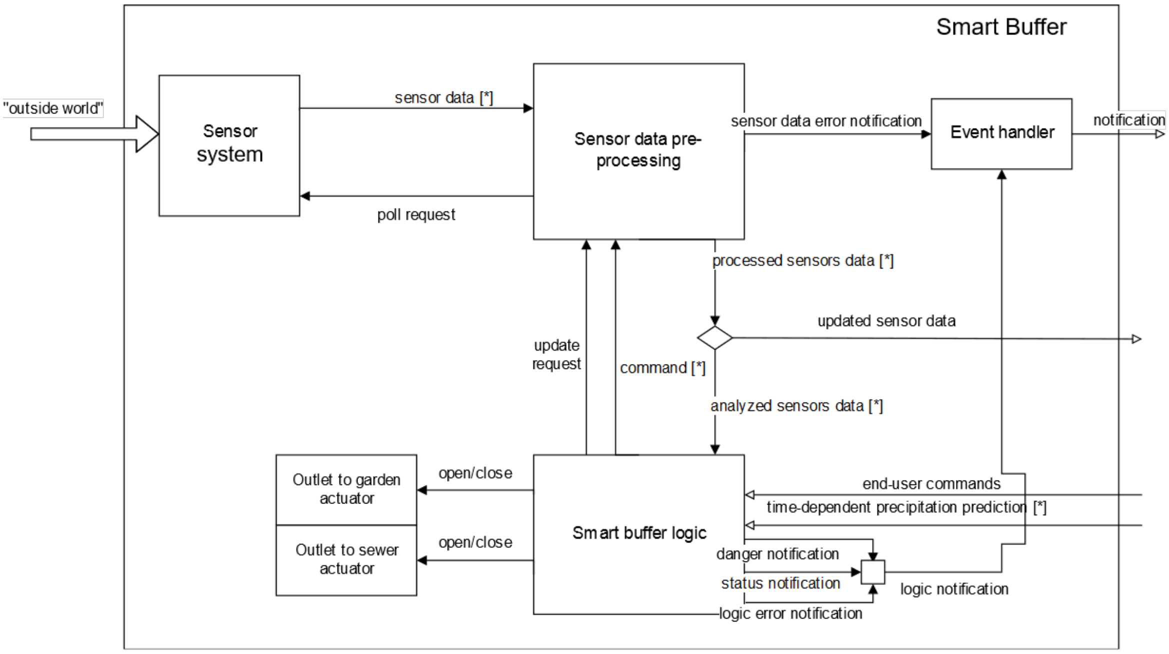

Figure 5.2: The smart buffer subsystem.

Monitor and control applications

The monitor and control applications deal with the visualisation of relevant data to the user. In order words, this subsystem describes the interface for the citizens and the interface for the municipality. The system receives notifications and updated sensor data from the smart buffer system, and stored sensor values from the central server (the latter is not specifically shown in this figure). It also receives the time-dependent precipitation prediction and the end-user input. The monitor and control applications subsystem is shown in Figure 5.3.

This subsystem consists of three blocks. First, the logger. The logger simply keeps track of all notifications and sensor data, and sends relevant historic data on to the visualiser. The visualiser shows historic data, the time-dependent precipitation prediction and updated sensor data to the user (in graphs and charts). Furthermore, the end-user can apply a selection or give input (discharge requests) here. The application logic handles discharge requests, if applicable, and sends this in the form of end-user commands to the smart buffer system.

Central server

The central server is a server located at the municipality that deals with the data storage and hosts the interface of the municipality. It receives end user requests regarding selection of data from the monitor and control applications and sends the requested sensor data to the monitor and control applications. From the smart buffer system, it receives the updated sensor data and stores this in the database.

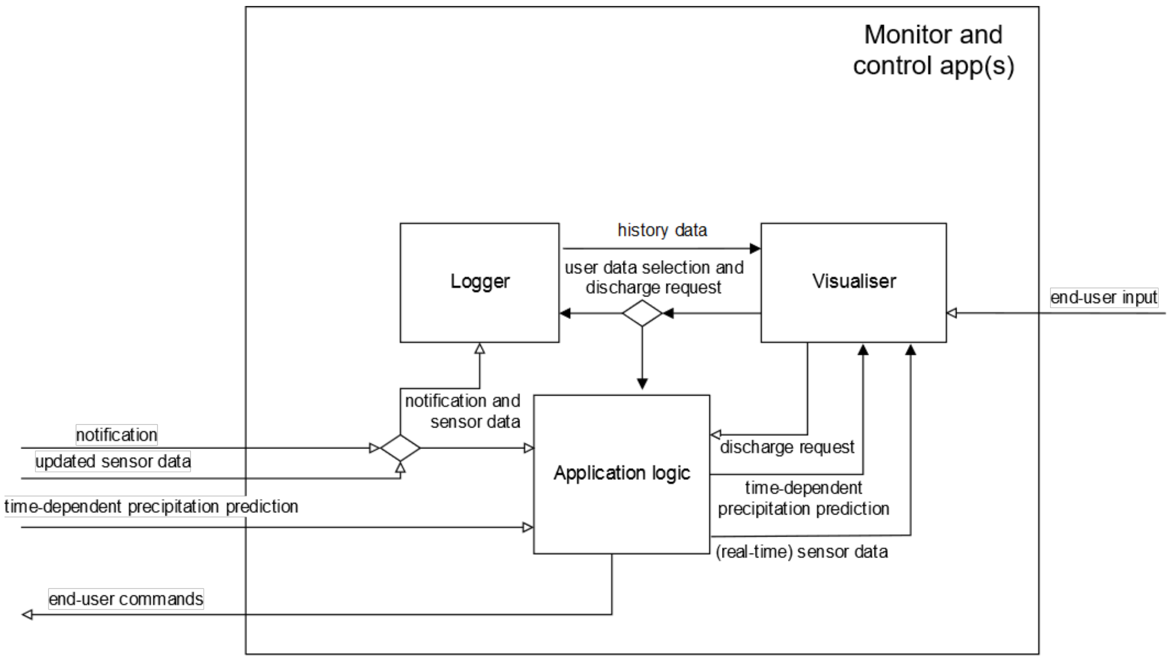

Figure 5.3: The monitor and control applications subsystem.

Chapter 6

Realisation

This chapter describes the chosen software and hardware implementation for the prototype of the smart rainwater buffering system. First, the software and hardware components are listed. Secondly, the interface design is explained and several iterations are shown. Lastly, the data storage structure of the central server is described.

6.1 Software and hardware components

In this section, the non-electronic hardware as well as electronic hardware components are listed.[4] Furthermore, the programming languages used for the software are described.

6.1.1 Hardware

Non-electronic components

The non-electronic components of the system consisted of a plastic rain barrel with a capacity of 210 litres, a faucet and several pipes and connectors to attach the rain barrel to the downspout pipe. A photo of the rain barrel is shown in Figure 6.1. The barrel was placed on the campus of the University of Twente.

Electronic components

Two microcontrollers were used: an Arduino Mega and twice the Raspberry Pi 3 model B. The Arduino Mega was used for reading out the raw sensor values and operating the valves of the buffer, it managed the sensors and actuators. The first Raspberry Pi dealt with the pre-processing of sensor values, making decisions regarding the valves and handling error events. The second Raspberry Pi served as the central server.

The sensors used were a US-100 ultrasonic sensor, two 12V solenoid valves (one for the sewers outflow, one for the garden outflow) and five water flow sensors (one for the overflow

[4] Detailed argumentation for the software and hardware choices can be found in the report by Jeroen Klein Brinke and Dennis van der Zwet, which will be finished in August 2017.

Figure 6.1: Left: the front of the barrel, with an input flow on the top and three output flows at the bottom. Right: the back of the barrel, with an overflow pipe to the sewers.

to the sewers, one for the input pipe, one for the sewers outflow, one for the garden outflow and finally one for the faucet).

The wiring of the electronics is shown in the schematic in Figure 6.2. In this schematic, every component is only shown once, but in reality some sensors were used multiple times. However, the wiring of these sensors simply stayed the same.

The Arduino, one of the Raspberry Pi's and the ultrasonic sensor were placed in a waterproof case that has been attached to the bottom of the lid of the rain barrel. Figure 6.3 shows the box and its contents. The other sensors are shown in Figure 6.4.

To measure the temperature and notify the user in case the water in the barrel is frozen, a temperature sensor was bought. However, due to time restraints, this sensor was not implemented in the final prototype.

6.1.2 Software

For the smart buffer system (see categorisation in Chapter 5), the software compromises the programming languages used for the Arduino Mega and both the Raspberry Pi's. For the Arduino, the Arduino language was used, which is based on C. For the Raspberry Pi that managed the sensor data, Java was used. The Raspberry Pi that was used for the central server was programmed with PHP.

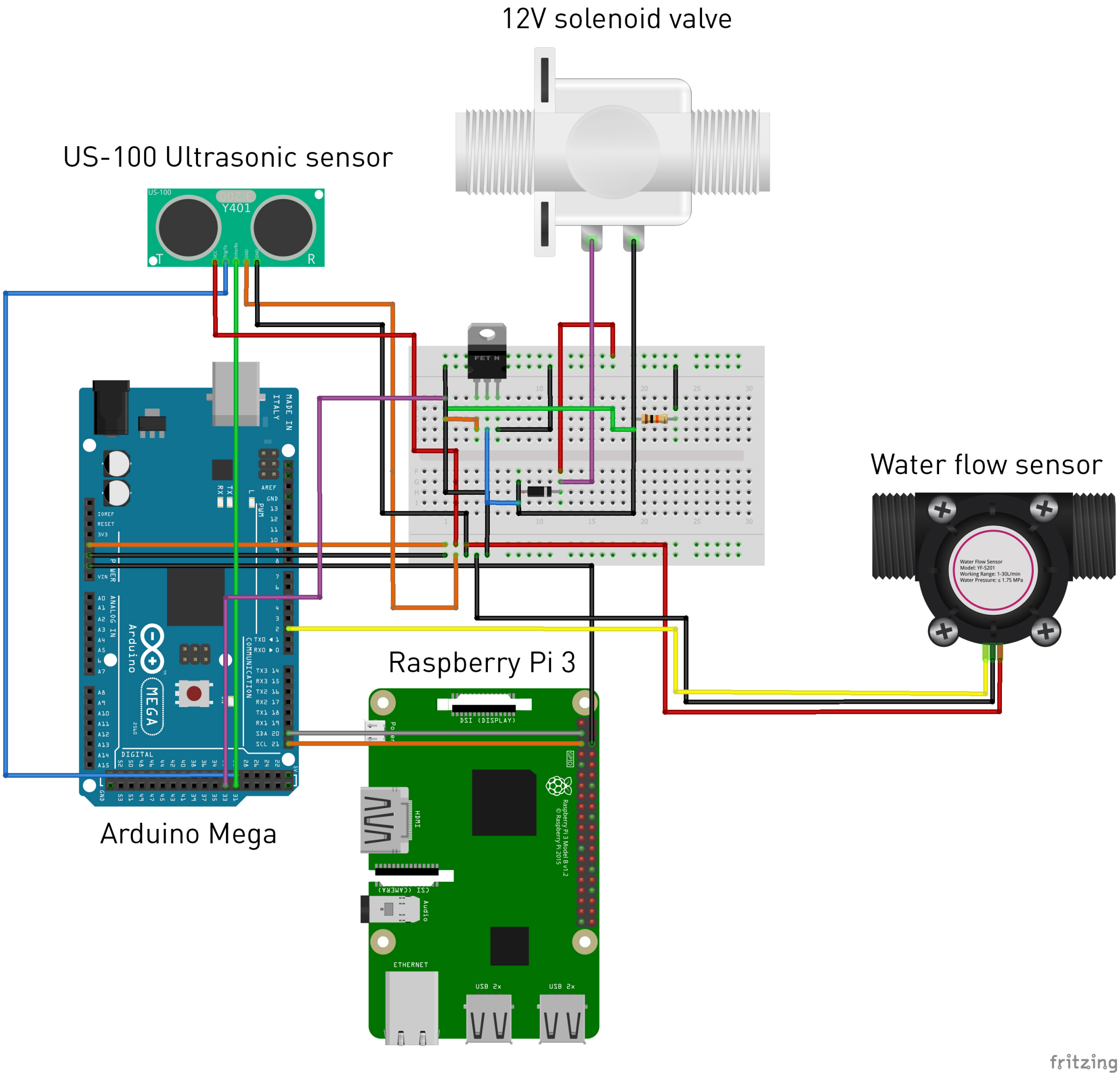

Figure 6.2: Schematic of the hardware, created in Fritzing.

For the monitor and control applications subsystem, the programming languages that were used are HTML, CSS, JavaScript, JQuery, PHP and MySQL. The graphs were created with the JavaScript library D3 version 4. The neighbourhood map was programmed with the JavaScript library Leaflet 1.0.3, using map tiles from MapBox. The CSS layout was made with Bootstrap.

All code for the interface for the municipality can be found on GitHub. [5]

6.2 Interface design

The first version of the interface design, which was a mock-up, was already referred to in Chapter 4. It can be found in Appendix C, Figure C.1. Based on the input from the

[5]The respository link of the code is https://github.com/Gelieke/srb_interface.

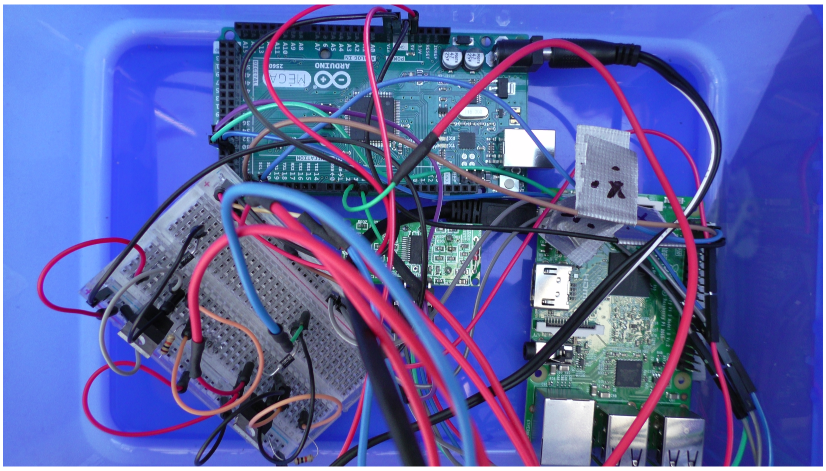

Figure 6.3: The waterproof box containing the Arduino Mega and the Raspberry Pi 3.

stakeholders and the requirements, a second and more realistic design was made. This version can be found in Appendix C. Figure C.2. It was evaluated with the municipality, and a few comments were made, according to which a final design was created. The feedback will be explained in the following section.

6.2.1 Feedback on the second design

- The block in the top left corner is called 'Buffer capaciteit' (buffer water level), while it shows how much of the buffer is filled and not how much capacity is empty. This is confusing. Therefore, this should be changed to 'Buffer vullingsgraad'.
- In the 'Buffer capaciteit' block, it now seems that you can select each buffer individually. But the municipality rather wants an overview, individual buffers are not that important. Therefore, it is better to separate the data simply according to their neighbourhood (De Bothoven and Velve-Lindenhof) and for the rest show the capacity of the whole system.
- The current water level (second graph in 'Buffer capaciteit') is shown in a bar graph, for comparison it would be more clear if the history graph (third graph) were also a bar graph.
- The block with the system status in the top right corner is now a bit too prominent, it can be made smaller and implemented in the menu bar.
- The block with 'Geplande leegloop' (planned discharge) is now without context. It would be interesting to relate it to a time frame, in order to see how this planned discharge is the result of the rain prediction on the left.
- In order to relate the planned discharge and the rain forecast to each other, it makes sense to use the same type of graph for both, i.e. an area graph, which also differentiates them from the bar graphs above them.

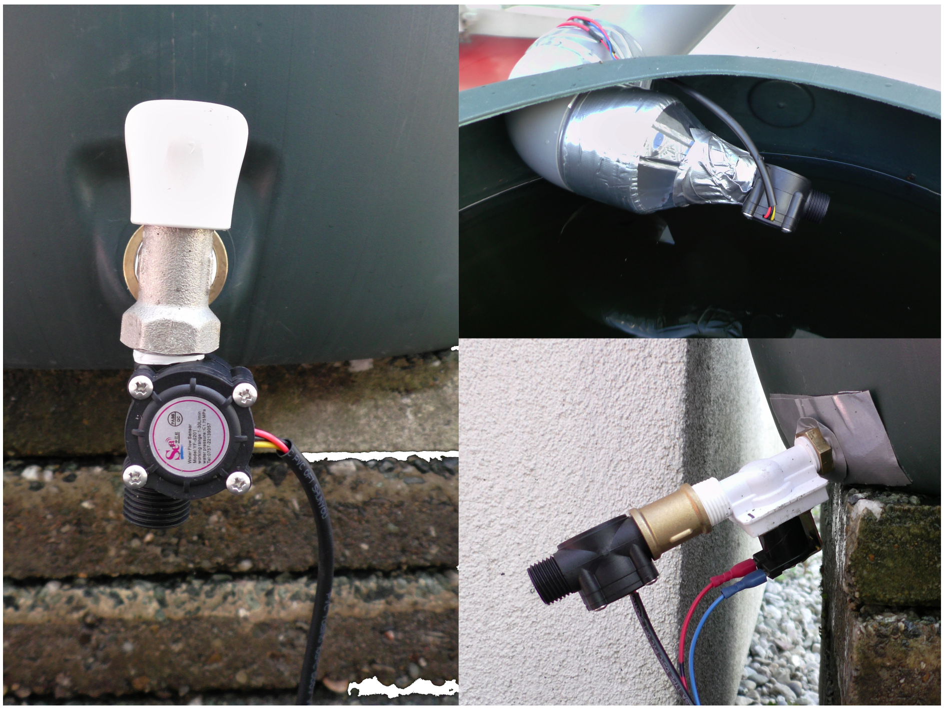

Figure 6.4: Left: the faucet with a water flow sensor underneath. Right, top: Inflow pipe with a water flow sensor. Right, bottom: Output flow to the sewers, consisting of a valve and a water flow sensor.

- The block with 'Waterafvoer' (water outflow) now only shows the water that goes to the sewer and the water that is captured from the faucet. However, it is desired to also show the outflow to the garden. To make the chart a bit more unique than a standard pie chart, it can be changed to a donut chart.
- On the bottom of the page, there should be a copyright notice. This can replace the ® sign next to Tonnie in the menu bar, as Tonnie is not actually registered.
- Aesthetically, it would be nice to add some shadow to the design, or at least something that makes the design less flat.

6.2.2 Final design

The official final design for the municipality is in Dutch, but for the explanation in this and the following sections, an English version is provided. The original Dutch version can be found in Appendix C, Figure C.3. The English version is shown in Figure 6.5. To show the interaction with the interface, a video was made.[6]

The website is designed as a dashboard interface. The interface consists of a menu bar and four blocks of charts and graphs. Each of these parts is described in more detail in the following sections. The graphs and charts are shown in different shades of blue, because blue is the colour that most people associate with water, which is what the interface is about.

[6]The video is hosted on YouTube: https://youtu.be/84Jqprqm4KE.

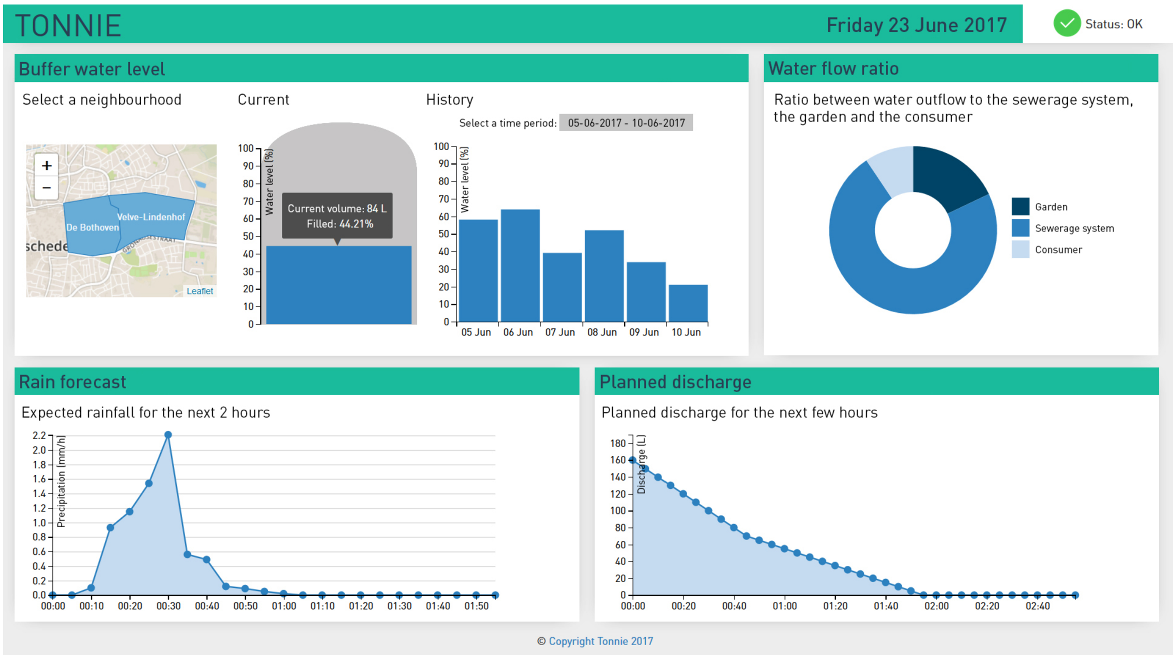

Figure 6.5: Final design of the interface for the municipality, English version.

The headers and the menu bar are coloured bluegreen to differentiate them from the data. However, this colour still fits with the blue, making sure that the layout still looks as a coherent whole with a consistent design.

The font that is used throughout the interface is DINPro, which is a sans-serif font that fits with the flat and minimalist design of the website.

Menu bar

First of all, there is a menu bar on the top of the page, shown in Figure 6.6. This bar shows the name of the system ('Tonnie') on the left, and the date and the status of the system on the right. The status of the system can have five different values, corresponding with five different icons. These values (or status names) and their icons are shown in Figure 6.7.

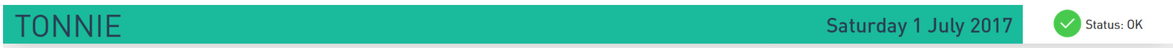

Figure 6.6: Menu bar of the interface.

Figure 6.7: The status names and their icons.

Buffer water level

The first block (see Figure 6.8) shows the current and past water level of the buffers in the system. First, the user can select a neighbourhood to see the data from (De Bothoven or Velve-Lindenhof), or see the data of the whole area. This selection is indicated in the way that a selected neighbourhood gets a dark blue colour in the map. Then, there is a bar graph that shows the current water level in the buffers in percentages (%) of the total capacity. The tooltip lists the current volume in percentages, but also in litres. Finally, there is a bar graph showing the water level in the buffers in percentages, selected over a certain time period in the past. When the user hovers over one of the bars, there is a tooltip showing the date and current water level.

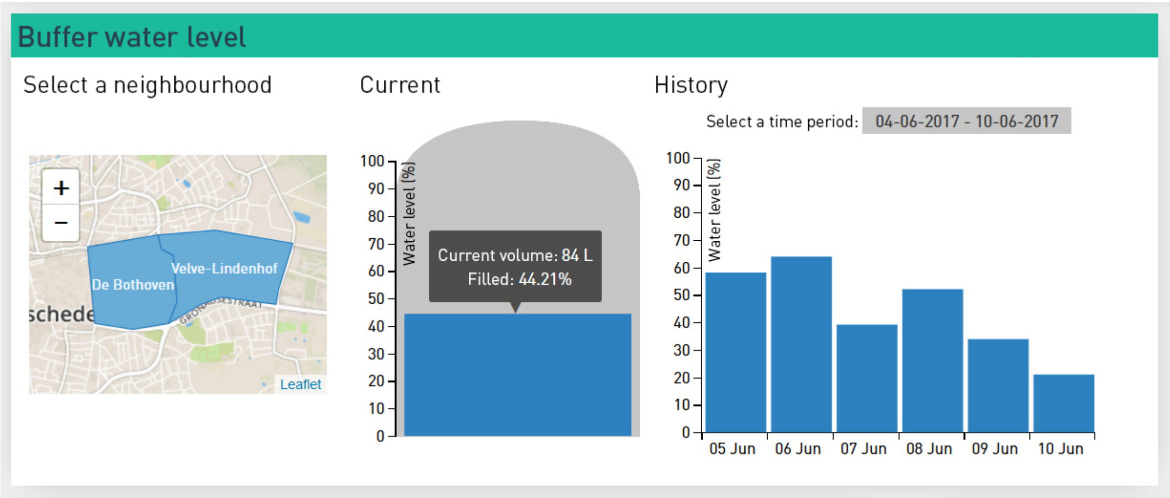

Figure 6.8: Block showing the current and past water volume in the buffers.

Water flow ratio

The second block shows the ratio between the water outflow to the sewerage system, the garden and the consumer (the faucet), see Figure 6.9. This data is shown in a donut chart, because a donut chart is suitable for showing a small amount of data points, in this case three. The data is shown for the currently selected area in the map (De Bothoven, Velve-Lindenhof or the whole area). When the user hovers over one of the donut sections, there is a tooltip stating which output it is, the flow in litres and in percentages of the total outflow.

Rain forecast

The third block shows the rain forecast for the next 2 hours in mm per hour (mm/h), see Figure 6.10. This forecast is retrieved by using the Buienradar API[7]. There are data points

[7]Buienradar provides free weather prediction data on their website: https://www.buienradar.nl/overbuienradar/gratis-weerdata

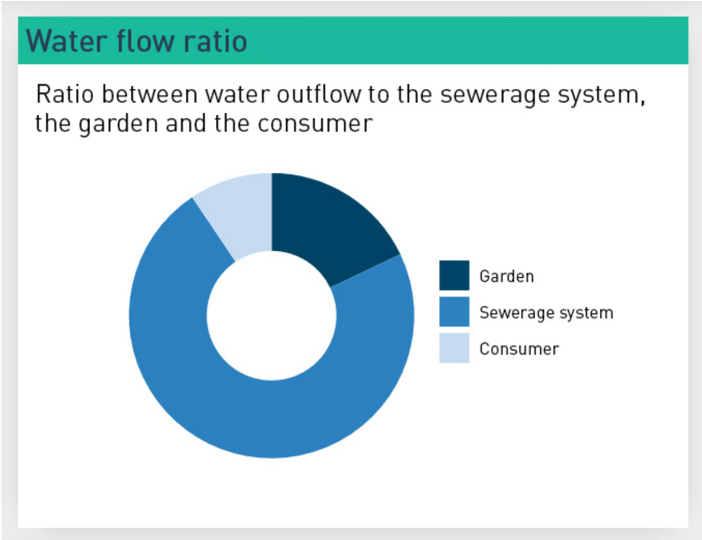

Figure 6.9: Block showing the water outflow ratio.

for every 5 minutes. When the user hovers over one of these points, a tooltip is shown with the time and the corresponding precipitation in mm/h.

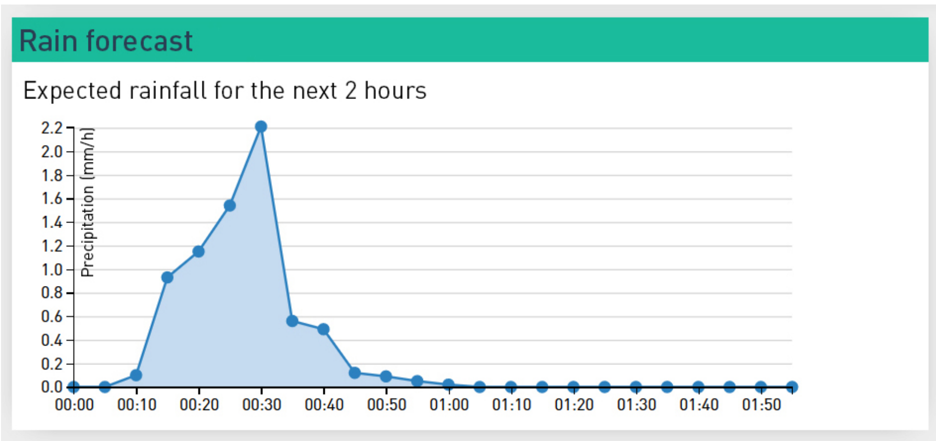

Figure 6.10: Block showing the rain forecast.

Planned discharge

The fourth and last block shows the planned discharge for the next few hours. Currently, a discharge for 3 hours is shown, but this depends on how much time the buffers need to discharge. The x-axis shows the time and the y-axis shows the water level of the buffer in litres. The data is shown fur the currently selected area in the map. There are data points for every 5 minutes, and when the user hovers over one of these, a tooltip shows the current water level in litres, the discharge speed in litres per minute (L/min) and the current time.

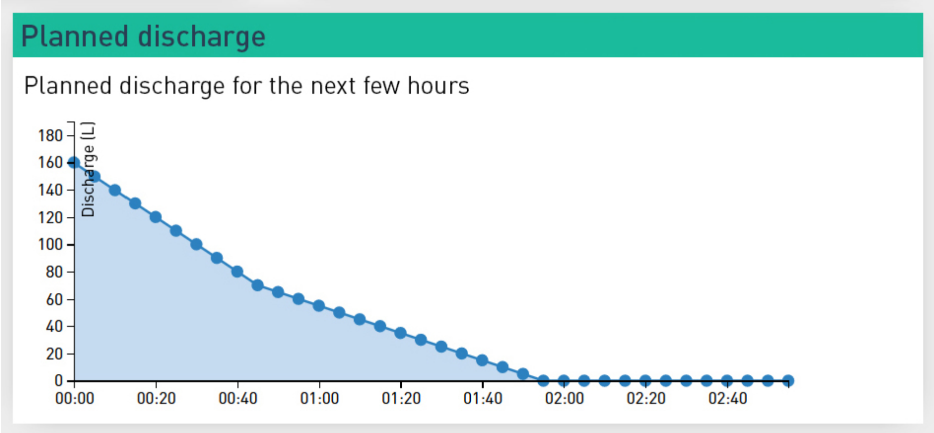

Figure 6.11: Block showing the planned discharge.

6.3 Data storage structure

The data shown on the interface is retrieved from a MySQL database of the central server. This database stores the data it gets from the Raspberry Pi in the barrel, which communicates with the Arduino Mega to retrieve the raw sensor values. The structure of the database is shown in Figure 6.12.

Every block in the diagram represents one table in the database. A row in a block corresponds with a field in the table and is built up as shown in Table 6.1. The diagram contents are discussed in more detail in the following paragraphs.

Table 6.1: Structure of a field in the database diagram.

key	name (data type)	description

First of all, the user table stores the user's id, name and address. The user id is connected to a buffer id in the water buffer table. In the water buffer table, each buffer gets a separate entry with certain information about that buffer: location, capacity, planned discharge id, last update time, default output valve and future volume refill. Every minute, the buffer sends a 'heartbeat' or last update time to the server to indicate that everything still works. The unique identifier (primary key) in this table is used as a foreign key in the discharge command table, the waterflow table, the buffer information table and the event table.

The discharge table stores the discharge id, start date and time of the planned discharge and the planned discharge amount itself in litres. The discharge command table is related to this table, but stores the discharge amount as specified by the citizen on his/her interface. In this table, it is also stored for which buffer the command is created, whether a discharge is done or not, when the discharge command was created and which output valve was indicated. For the discharge table, the valve and buffers the discharge is applied to, is decided on by the system.

The waterflow table stores the cumulative water output flow on a certain date for a certain valve, for a certain buffer. The buffer information table stores the water level of a certain

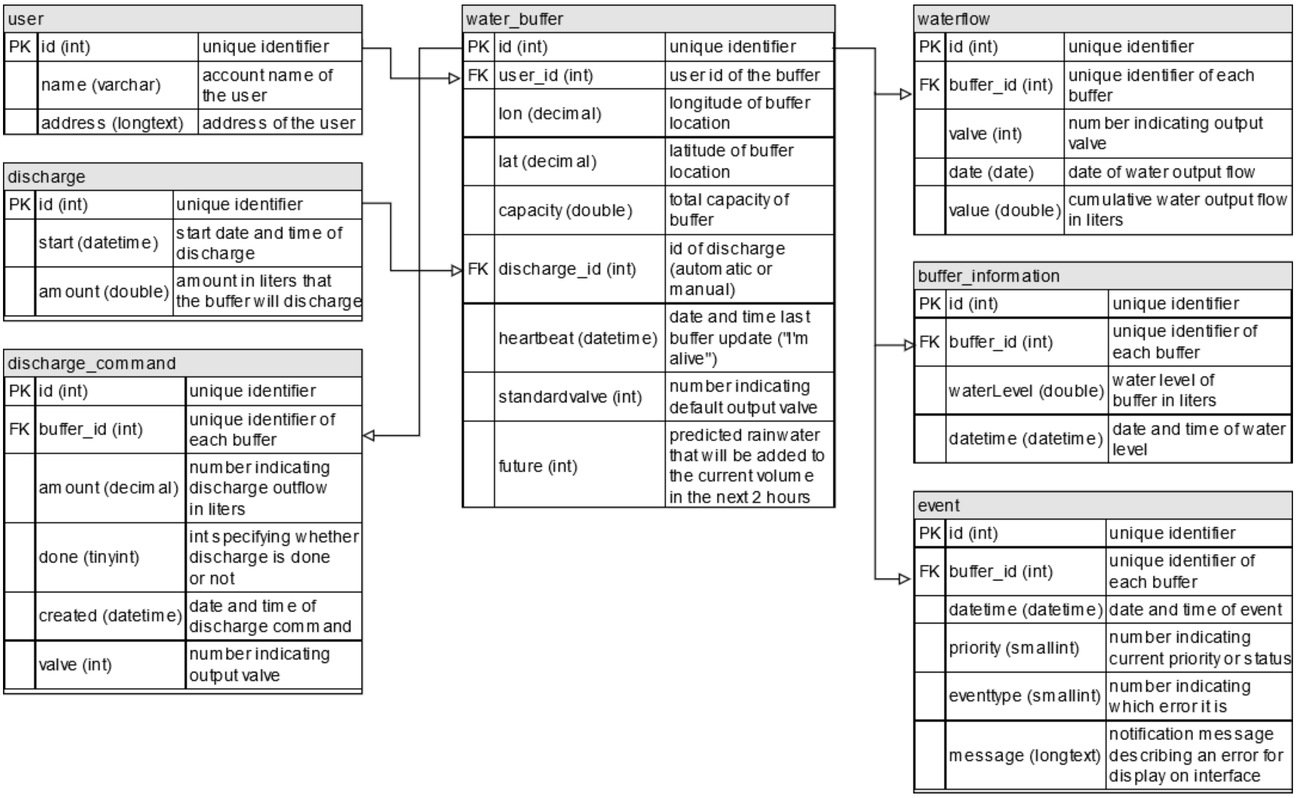

Figure 6.12: Diagram showing the tables in the database and their structure.

buffer on a certain date and time. And lastly, the event table stores the priority or status of a buffer on a certain date and time, as well as the event type and notification message that are shown on the interface in case there is something wrong.

Chapter 7

Evaluation

In this chapter, the evaluation that was carried out with the prototype of the system is described. The first section deals with the functional test for the whole system. This is followed by a description of the user test protocol for evaluating the interface for the municipality, as well as the results of the user test. Finally, a conclusion is drawn based on both the functional test and the user test, and a final iteration of the prototype was made accordingly.

7.1 Functional test

Before the user test was carried out, a functional test was done with both the smart rain buffer and the interfaces. To that end, the following question was asked for each of the requirements specified in Chapter 5: 'Does the prototype fulfill this requirement?' A new version of the requirements table was constructed, where the requirements that were met were coloured green. This table can be found in Appendix G.

For the interfaces, all 'must have' requirements were fulfilled. For this part of Tonnie, the functional test was declared a success.

For the smart rain buffer, all but two 'must have' requirements were met. Firstly, the non-functional system requirement that states *The accuracy of the buffer is 1L* was not met, as the water flow sensors turned out to be not accurate enough. Since the water flow sensors were attached to the outputs of the barrel in an angle, the water did not flow through the sensors vertically. This decreased the accuracy of the measurements. Furthermore, the sensors that were bought were cheap and therefore less reliable. Luckily, the water level in the rain barrel was not just measured with the water flow sensors, but also with the ultrasonic sensor. Also, the corresponding user system requirement simply stated *The interface of the users shows the water level with a high accuracy*, where 'high' is not further specified.

Secondly, the non-functional system requirement *The system functions autonomously and does not require intervention from the user in order to fulfill its purpose* was not met. The rain barrel was not stable enough to function entirely on its own. Intervention from the developing team was needed throughout testing. There were multiple reasons for this. Some of the wires and electronics were still shown and exposed to the outside world, as they were attached to the outside of the barrel. This setup could not be left alonen for long.

The code for the Arduino and the Raspberry Pi was not perfected yet, sometimes leading to errors. And finally, the outflow pipe to the sewerage system appeared to leak slightly.

Even though the two requirements described above were not met completely, the system was declared to be working sufficiently for the functional test. The barrel could still be used for testing in an enclosed setting as the developer would be close by to operate the barrel in case something would go wrong.

7.2 User test protocol

The user test protocol contains guidelines for carrying out the user test with the interface for the municipality. These guidelines help to make sure that testing the prototype of Tonnie happens quickly, smoothly and consistently.

7.2.1 Purpose

The purpose of the test is to find out whether the interface of Tonnie complies with the wishes and demands of the municipality of Enschede. The usability of the interface will be tested.

7.2.2 Test setup

The user test will take place in the SmartXP, room A138 in the Zilverling building on the campus of the University of Twente. The equipment that will be used are Tonnie itself, a laptop running Windows, a table and chair and pen and paper. Prior to testing, the test subjects will have to sign the consent form that can be found in Appendix H.

7.2.3 Participants

There will be three people participating in the test, representing the target group. As these participants are Dutch native speakers, the user test will be carried out in Dutch.

7.2.4 Interaction device

The interaction device used for the system evaluation for the municipality is the system's interface and buffer for the municipality. Participants will interact with a computer screen that shows the final version of the interface of the system on a website. This interface is shown in Appendix C, Figure C.3. The participants are expected to be able to get insight in the system's current performance, historic performance and precipitation prediction. For the historic performance of the system, they can select specific date ranges. Feedback to the participant will be given by updating all the graphs after date selections and after the buffer's capacity has been changed due to (extra) rainfall, automatic or manual discharges.

7.2.5 Interaction method

First, the participants will carry out a list of tasks. A task based interaction method has been chosen to test how well participants are able to interact with the system when they want to get insights on specific data and perform specific tasks. When the participant does not show any sign of understanding the system and or the task they need to perform, the test session will be interrupted and guidance will be given to the participant. A list of questions was created that guides the participants through the interface. They have to carry out certain tasks in order to find the answers to these questions. The English version of these questions can be found below.

1. What is the current status of the system?
2. What is the current volume (in litres) of the buffers in the whole area?
3. What is the percentage of the current volume of the buffers in De Bothoven?
4. What is the percentage of the volume of the buffers on 12-06 in the Velve-Lindenhof, when looking at the historic volume from 07-06-2017 until 12-06-2017?
5. The graph on the right side of the interface indicates the ratio between the water flow to the sewerage system, the water flow to the garden and the water retrieved by the citizen. Where does most of the water flow to?
6. What is the corresponding percentage?
7. Is there any rainfall predicted for the next 2 hours?
8. Finally, there is a graph showing the planned discharge for the system for the next 2 hours, based on the expected rainfall. What is the initial discharge speed in L/min of the buffers in the whole area?

After completing the tasks, the participants will give their opinion on ten statements, based on the ten usability heuristics as defined by Jakob Nielsen. A 5-point Likert scale is used for this. The English version of the statements is provided below.

1. The status of the system is easy to find.
2. The meaning of the symbols and icons that were used was completely clear to me.
3. I feel in control of my interaction with the system.
4. The design of the interface is consistent.
5. The interface does not contain any errors.
6. The interface is easy to use.
7. I am able to navigate through the interface efficiently.

8. I like the design of the interface.

9. When I select a neighbourhood, this selection is clearly indicated.

10. I can easily find help during usage of the interface, if needed.

The full survey (in Dutch) that contains both the task questions and the usability questions can be found in Appendix I.

7.2.6 Data collection method

During the test sessions, the data collection methods that will be used are the concurrent thinking-aloud method, observations and a questionnaire. These methods produce mostly qualitative data. The notes of the thinking-aloud method and the observations will be written down by the observer. Furthermore, quantitative data will be gathered on the ten usability heuristics, and on the successful completion rates for each of the task questions.

7.2.7 Results

The test took place on Friday 23 June 2017. There were three persons participating in the test. Two of them were from the water department of the municipality of Enschede, one represented water board Vechtstromen. They are all persons who might work with the system in the future.

Quantitative data

The successful completion rates of the task questions are shown in Table 7.1. As can be seen, the three participants had all questions correct, except for the last question. This might be due to the fact that they did not consciously read the part 'in the whole area', and therefore forgot to change the selection of the neighbourhoods back to the whole area.

In Table 7.2, the percentage of participants per indicated answer is shown for the ten usability heuristic statements. The statements where a majority agrees, the table cells are coloured green. On the other hand, when the majority disagrees with the statement, the cells are coloured red.

The usability heuristics where the majority disagrees concern the status of the system, whether the interface contains any errors and the indication of the selected neighbourhood. These three problems were also found in the qualitative data analysis and will be discussed later on.

The participants were generally positive about the heuristics that concerned a feeling of control, the consistency, the ease and efficiency of navigating and the design of the interface.

A complete overview of the questionnaire results can be found in Appendix J.

Table 7.1: Successful completion rates for the tasks

#	Question	Correct answer	Percentage of participants who had the question correct
1	What is the current status of the system?	OK	100 %
2	What is the current volume (in litres) of the buffers in the whole area?	61 L	100 %
3	What is the percentage of the current volume of the buffers in De Bothoven?	32.11 %	100 %
4	What is the percentage of the volume of the buffers on 12-06 in the Velve-Lindenhof, when looking at the historic volume from 07-06-2017 until 12-06-2017?	48.42 %	100 %
5	The graph on the right side of the interface indicates the ratio between the water flow to the sewerage system, the water flow to the garden and the water retrieved by the citizen. Where does most of the water flow to?	Sewerage system	100 %
6	What is the corresponding percentage?	52.6 %	100 %
7	Is there rainfall predicted for the next 2 hours?	No	100 %
8	Finally, there is a graph showing the planned discharge for the system for the next 2 hours, based on the expected rainfall. What is the initial discharge speed in L/min of the buffers in the whole area?	2 L/min	33.33 %

Table 7.2: Results of the ten usability statements

#	Question	Strongly disagree	Somewhat disagree	Neither agree or disagree	Somewhat agree	Strongly agree
1	The status of the system is easy to find.		66.67 %			33.33 %
2	The meaning of the symbols and icons that were used was completely clear to me.	33.33 %		33.33 %		33.33 %
3	I feel in control of my interaction with the system.		33.33 %		33.33 %	33.33 %
4	The design of the interface is consistent.		33.33 %		66.67 %	
5	The interface does not contain any errors.		66.67 %	33.33 %		
6	The interface is easy to use.		33.33 %		33.33 %	33.33 %
7	I am able to navigate through the interface efficiently.		33.33 %		33.33 %	33.33 %
8	I like the design of the interface.	33.33 %			33.33 %	33.33 %
9	When I select a neighbourhood, this selection is clearly indicated.		66.67 %			33.33 %
10	I can easily find help with using the interface, if needed.		33.33 %	33.33 %	33.33 %	

Qualitative data

The concurrent thinking-aloud method, the observations and the answers to the open questions of the questionnaire provided the qualitative data. The findings are described in the following paragraphs.

First of all, the participants found the status of the system hard to find. Furthermore, the actual meaning of the system status appeared to be unclear. As there was no help and documentation available on the page itself, the observer had to step in and give a hint, after which the participants were able to find the system's status.

According to the participants, the date range picker that could be used to select historic buffer data seemed to be not working all the time. The x-axis of the historic buffer graph was scaled in the wrong way. Concerning the layout, participants mentioned that they liked the looks of the interface.

Moreover, once a neighbourhood was selected, it was unclear to the participants which data changed according to this selection. It should be made clear which data every graph actually shows.

Finally, on the interface demo, the precipitation prediction graph showed real data (no rain predicted) while the planned discharge graph showed dummy data (a couple of litres planned to discharge). This was confusing for the participants. Also, one participant remarked that this prototype discharges at the start of the rain shower, while the current system at the municipality only begins to buffer at the end of a rain shower. This is not necessarily a problem, but still something to keep in mind.

7.3 Conclusion

The functional test showed that the interface for the municipality was ready to be tested. The smart rain buffer, however, was not as accurate and autonomous as desired. It worked sufficiently to demonstrate the concept, however, it seemed not to be a stable system ready for implementation in the neighbourhoods yet.

From the user test it was found that there were only some minor errors in the interface. The status of the system could be fixed by making it more prominently visible in the interface, as well as adding notification messages to clarify the status' meaning. A help and documentation guide could be provided to help out users of the interface. The date range picker and x-axis of the historic buffer graph could be fixed by making sure that the code does not contain any errors anymore. Finally, the neighbourhood selection could be made more clear by indicating the selected neighbourhood in every block it applies to, giving different neighbourhoods a different colour and changing the graphs to that colour as well.

As the sample size in this user test is very small (n=3), no general claims can be made on the usability of the interface for municipalities. However, it can be said that for the water department of the municipality of Enschede, the interface fulfilled their needs and wishes. The main contact person of the project, Hendrik-Jan Teekens, indicated that he was very pleased with the end result.

7.4 Iteration on the final interface design

Based on the feedback provided by the test results, some small changes were made to the final design of the interface. The neighbourhood selection was made more clear and the historic buffer graph code was fixed. The iteration on the final design is shown in Appendix C, Figure C.4.

Chapter 8

Conclusions and recommendations

In this chapter, a conclusion is given by discussing to what extent the research questions are answered and the goal of the project is reached. Furthermore, recommendations for future work are given.

8.1 Conclusions

This graduation project dealt with the development of a smart rainwater buffering system, commissioned by the municipality of Enschede. The goal was to reduce the strain on the sewerage system of the Oldenzaalsestraat. At the beginning of the project, a main research question was formulated: *How to develop a monitoring and control infrastructure for a smart rainwater buffering ecosystem that will be placed in the neighbourhoods De Bothoven and Velve-Lindenhof?* Two subquestions were created accordingly. The first subquestion was: *How can rainwater buffers be made 'smart', so they adapt their performance and capacity according to the anticipated rainfall?* and the second subquestion was: *How can the system's monitoring data be processed and presented to the municipality of Enschede?*

In order to answer these questions, literature research was carried out as well as an analysis of the state of the art. It was found that integrating different water buffers is a viable approach. Furthermore, smart technology (such as sensors or the Internet of Things) can be a valuable addition to existing rainwater management practices. The use of technology allows authorities to get more insight in their water management practices. However, there was a lack of documentation on real-life examples. After doing literature research, stakeholders were involved in the design process and the local conditions in the neighbourhoods De Bothoven and Velve-Lindenhof were investigated. Then, the following concept was created: Tonnie, a system of smart rainwater buffers, which will be placed on the private property of citizens in De Bothoven and Velve-Lindenhof. The buffers can measure their water level and flow by using ultrasonic and water flow sensors. The rain forecast for the next 2 hours is retrieved using an internet connection. Based on this forecast, the buffers open or close their valves, which lead towards the sewerage system and the garden.

Unfortunately, not all buffer types are suitable for measuring and adapting their performance. Taking into account practicality and costs, a rain barrel was considered to be the most feasible option. Due to the scope of the project, it was chosen to use only one type of buffer for the project, and not a combination of different ones. Besides, for the municipality the underlying system was more important than the buffer's actual form. This concept of smart rainwater barrels is the answer to the first subquestion: rainwater buffers, in this case barrels, can be made smart by using sensors to measure their performance and capacity, and adapt these factors by using controllable valves. A server is used to retrieve the anticipated rainfall.

In order for the municipality to get insight into the system, the data produced by the rain barrels and their overall performance should be presented to them in a clear way. Through brainstorming and meetings with the municipality, it was decided that the data would be shown on a website dashboard using charts and graphs. After a design of the interface was created, it was approved of by the municipality. As such, an answer to the second subquestion can be formulated: the system's monitoring data can be processed and presented to the municipality in graphs and charts, where the municipality can select a neighbourhood or a time period for which they want to see the data. The data shown on the interface is the current and historic water level, the discharge ratio between different outflows, the rain forecast and the planned discharge.

A prototype of the system was realised and tested on the campus of the University of Twente, consisting of a single 210 L rain barrel with sensors, actuators and an interface. The evaluation showed that the water flow sensor used in the barrel was not as accurate as desired. This was partly due to the sensor's construction, and partly due to how the sensor was attached to the buffer. Furthermore, Tonnie was not yet able to operate fully autonomously. Nonetheless, the interface was generally positively received. However, as there were only three participants taking place in the test, no general claims could be made on such an interface.

Combining the results discussed above, the answer to the main research question can be given. A monitoring and control infrastructure for a smart rainwater buffering ecosystem can be developed by implementing a system of various buffers with sensors and actuators throughout the neighbourhoods. The overall buffer performance can be monitored by the municipality. (The individual buffers can be monitored and controlled locally by the citizens, which is a part of the project worked on by Felicia Rindt.[8]) A rain barrel was found suitable as a buffer for such an ecosystem, but other buffer types are potentially feasible as well.

Nevertheless, the question remains whether the smart rainwater buffering system would actually reach the goal of reducing the strain on the sewerage system. After all, the developed prototype consisted of only one rain barrel, not a combination of different buffer types. To be able to buffer as much water as was specified in Chapter 4 (1 million liters), almost 5000 of these barrels would be needed, which is not realistic. That is why a combination of different buffer types is crucial. The system was not tested in situ. Also, the performance of the system during actual severe rainfall was not researched. To really find out the effectiveness of the concept, more research is needed, as will be discussed in the next section.

[8]More information on the citizen's role in the project can be read in the report of Felicia Rindt, which will be finished in August 2017.

To conclude, this graduation project served as an exploration and early development of the concept of a smart rainwater buffering system. An actual implementation was not yet done, but the results are promising for the future.

8.2 Recommendations

There are several recommendations for the future development of Tonnie, the smart rainwater buffering system. Concerning the developed prototype of the rain barrel, the water flow sensor would be more accurate if it was attached to the buffer in a vertical way, which could have been done by using a gooseneck pipe. On the same note, the buffer's software and hardware should be developed further in order to guarantee stable performance. The interface of the system should be tested with more (representatives of) municipalities, in order to verify the workings of the interface and improve its design. Furthermore, the interface could be expanded in its use to other cities, and not just Enschede.

There were several improvements identified for the interface for the municipality. The system's status and neighbourhood selection could be made more clear in the interface, as pointed out during the evaluation. The interface should be made responsive, so it can be viewed in different browsers and with different screen sizes. The design of the interface could be improved by adding animations to the graphs and charts. Custom date ranges could be added to the date range picker, so a user can easily compare different months and years of historic buffer data with each other. Also, the map could be constructed as a heatmap, where buffers have a different colour depending on how full they are.

The weather data was now solely retrieved from Buienradar. In order to improve the accuracy of the rainfall prediction, multiple weather stations could be used and compared with each other. From the interview with housing corporation Domijn, it appeared that housing corporations could get a role in the project later on. They should be considered as a stakeholder when the project is developed further.

Co-developer Felicia Rindt looked at the role of the citizens in the development of a smart rainwater buffering system. She found that it was hard to reach the citizens and get them to participate in the design process. They did not always see the need for the system, or simply were not interested in being involved. In order to make it attractive for them to acquire a buffer, it would help if these citizens would receive subsidies and if they could re-use the water from the buffer. In order to facilitate promotion of Tonnie, a logo could be created. However, this is something to consider only in the future, when the system is ready for implementation and distribution in De Bothoven and Velve-Lindenhof.

Finally, there are some recommendations for the system as a whole. Most importantly, the system should be implemented with various buffer types of different sizes, not just rain barrels of 210 L. This means that a buffer type can be chosen according to the local possibilities and the needs and wishes of the user, allowing for a lot of flexibility. After all, the chosen rainwater barrels were not the most popular buffer type among the citizens. Another recommendation is to implement the system not only on the private property of citizens, but in industrial areas or around shops and offices, as this allows for buffers with a bigger capacity. In the future, when Tonnie is developed further, the strain on the sewerage system will hopefully be reduced, leading towards a solution to urban flooding.

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Appendix A

Categories and measures of treating rainwater

Table A.1 shows the four categories of treating rainwater and their measures.

Table A.1: Treating rainwater categories and measures (Niemczynowicz, 1999; Palla et al., 2017; Schuetze & Chelleri, 2013; Ellis et al., 2006; Saraswat et al., 2016; van Hattum et al., 2016; atelier GROENBLAUW, 2014).

Category	**Measure**
Rainwater harvesting	Rain barrels
	Gutter
Rainwater infiltration	Wetlands and open water fields
	Ponds
	Permeable asphalt
	Soil infiltration
	Green(-blue) roofs
	Rain gardens
	Water squares
	Bioswales/wadi's
	Dwelling mound
	Tree pit
	Active/passive evapotranspiration (by using plants)
	Vegetative strips (along roads)
	Geocellular systems
	Infiltration zones/trenches
	Water crate
Rainwater storage (above/below ground)	Rain barrels
	Cisterns
	Rain 'walls'/green walls

	Green(-blue) roofs
	Water squares
	Rainwater retention basins ('bergbezinkbassins')
Rainwater drainage	Pipes
	Canals ('geulen/grachten') and rivers
	Green(-blue) roofs
	Hollow roads
	Open gutters
	Prefab fluted gutter

Appendix B

Pictures of De Bothoven and Velve-Lindenhof

Figure B.1: Pictures taken in the focus area. There are playgrounds, little front yards, apartment buildings and mostly houses with sloped roofs.

Figure B.2: Pictures taken in the focus area. There are a few houses with green roofs, many downspouts that are directly at the front of the house, and some unused patches of land that offer opportunities.

Appendix C

Iterations of the interface design for the municipality

Below, all versions of the interface design for the municipality are shown. They are in Dutch.

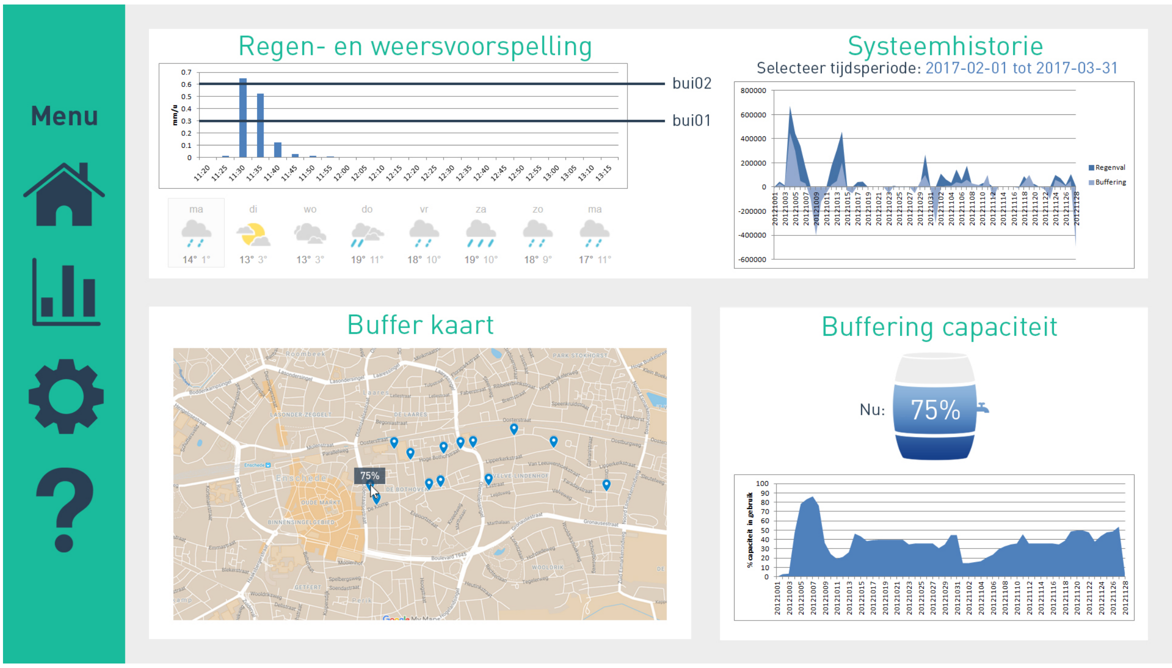


Figure C.1: Interface design for the municipality, version 1.

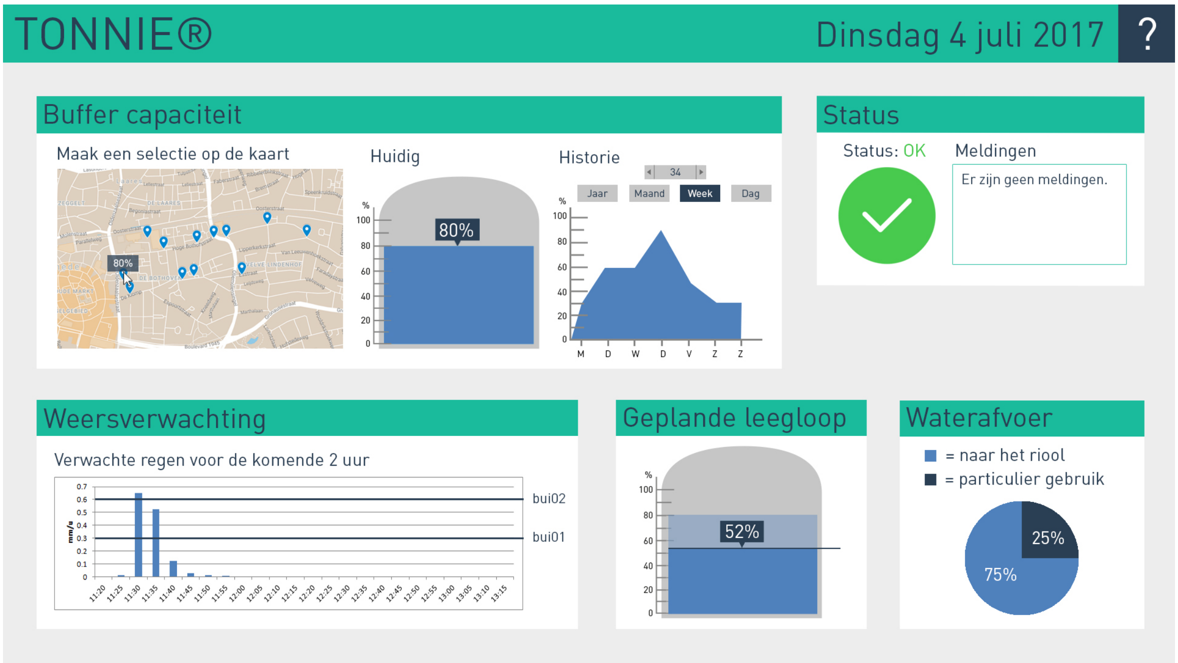


Figure C.2: Interface design for the municipality, version 2.

Figure C.3: Interface design for the municipality, final version.

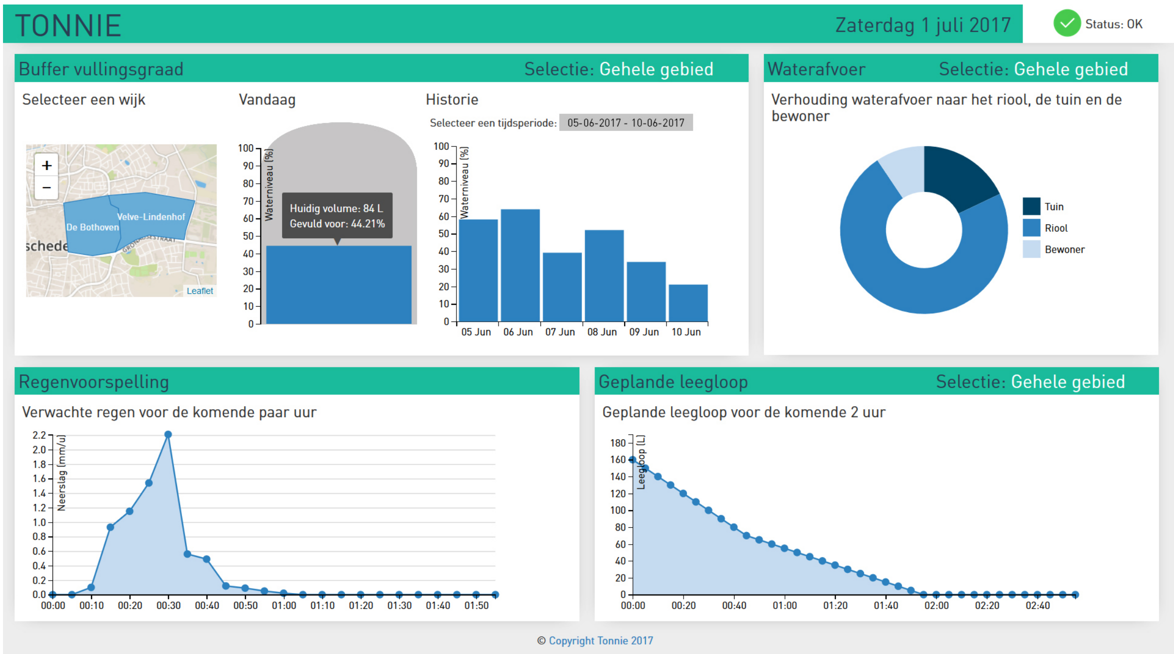


Figure C.4: Interface design for the municipality, final version after evaluation.

Appendix D

Notes of meetings with the municipality

Several meetings were conducted with Hendrik-Jan Teekens. He works as a water designer for the municipality of Enschede and is therefore the designated client of this graduation project. The questions and notes of the answers are listed in this appendix (in Dutch only).

D.1 Monday 8/05/2017

On 8 May 2017, some basic questions regarding the system design were asked in order to guide the brainstorming process and select the most promising ideas. This was a semi-structured interview that allowed for exploration of other (related) topics.

1. **Welke tools en programma's op het gebied van waterbeheer gebruiken jullie al?**
   We gebruiken RainTools, daarmee kun je verschillende buien simuleren met de huidige riolering en eventuele waterberging.

2. **Hoe werken jullie huidige regenwaterbuffers?**
   We hebben nu gewoon een watertank waarbij je kunt zien hoe die zich vult en leegloopt. Dat systeem werkt met telemetrie, met inbellen. De klep naar het riool wordt handmatig bediend door een persoon, die de weersvoorspelling checkt en aan de hand daarvan bepaalt of de klep open of dicht gaat (en het water dus in de tank blijft of wegstroomt).

3. **Als ik een slim regenwaterbuffersysteem zou ontwerpen, welke data willen jullie dan hebben? (Bijv. het waterniveau of het weer.)**
   We zouden de totaalcapaciteit van het systeem willen weten, dus een gezamenlijk getal van alle buffers bij elkaar. En hoeveel water er opgevangen is van de bui: als er bijvoorbeeld 40 mm regen is gevallen, hoeveel daarvan is er dan in de buffer gekomen? Details omtrent de waterkwaliteit, zoals de pH-waarde en mineraalgehalte zijn minder belangrijk voor ons (de gemeente). Het gaat ons om het totaalplaatje.

4. **Wat zouden jullie willen kunnen controleren en beheren in het systeem?**
   We hoeven zelf niet per se actief iets te controleren, als het systeem gewoon goed werkt dan gaat dat automatisch. Aan de hand van de verwachte regenval kan het systeem bepalen welke buffers water opvangen en hoeveel, het verdeelt de pijntjes. We willen het niet afzonderlijk per huis aansturen, dus niet specifiek gaan kijken wat we doen met de buffer van mevrouw Jansen. Qua privacy is dat ook geen goed idee.

5. **Welk onderhoud aan het systeem zijn jullie bereid te plegen, en wat verwachten jullie van de bewoner?**
   We willen de garantie dat het gewoon werkt. We kunnen de bewoner subsidie geven (betalen uit de rioolbelasting) voor het aanschaffen van de buffer, maar dan moeten ze wel zelf aantonen dat ze die buffer hebben staan. We kunnen eventueel wel eens in de zoveel tijd (bijvoorbeeld om de 4 jaar) een controle uitvoeren.

6. **Welke eigenschappen moet het systeem zeker hebben?**
   Het moet vooral een simpel en robuust systeem zijn. Eenvoudig en overzichtelijk, en het moet gewoon werken.

   Het mooiste zou zijn als het werkt van april tot oktober, wanneer de meeste regen valt. Dat er dan gegarandeerd overloop is en er water wordt opgevangen bij de mensen (en eventueel de tuin in gaat). In de winter is het wat anders, dan wil je het water niet in de tuin infiltreren omdat de grond dan al verzadigd is en het grondwater vrij hoog staat.

7. **Wat vindt je van de mock-up voor de interface?**
   Ziet er al goed uit, dit is wel iets wat we zouden kunnen gebruiken als je de werking van het systeem op een simpele manier inzichtelijk kunt maken.

8. **Wat zou de voertaal van de interface moeten zijn, Nederlands of Engels?**
   Nederlands is handiger voor de interne communicatie, omdat dat ook in het Nederlands gaat.

9. **Heb je verder nog toevoegingen of opmerkingen?**
   Gebruik de neerslag duurlijnen om de werking van je systeem aan te geven. Een wadi kun je tekenen als een aflopende lijn, eerst alles opvangen en daarna afvoeren. Bij jullie buffer, die werkt met geknepen afvoer, laat je direct een deel weglopen en vang je een deel op. Dit resulteert dan juist een stijgende lijn.

   Misschien kunnen jullie ook nog kijken naar waar in de wijken de kansen het gunstigste zijn. Sommige gebouwen en huizen zijn al erg oud en daar kun je simpelweg niet zo veel meer mee. Kijk of je de beste plekken, de interessantste mogelijkheden eruit kunt halen. Een scan van de wijk met getallen, waar kun je hoeveel water bufferen? Je kunt ook woningcorporaties meenemen in je onderzoek.

   Het is handig om de werking van het systeem te testen met standaardbuien, ddat zijn buien die echt gebeurd zijn, zoals bui Herwijnen, Kopenhagen of Apeldoorn.

D.2 Thursday 18/05/2017

On 18 May 2017, the first iteration of requirements was verified with the municipality. Therefore, the questions were quite specific, so this was a structured interview. A few questions in this interview were answered by Hans Koetsier, who works for the municipality of Enschede as well but is specialised in the sewerage system.

1. **Requirement: The capacity of the buffer is around 200L.**
   Hoeveel procent van de huishoudens zouden potentieel een regenwater buffer willen en hoe groot zouden deze moeten zijn?
   Dat is lastig te zeggen, je kunt het beste een soort kansenkaart maken van het gebied waarbij je verschillende straten en huizen in kaart brengt. Je kunt dan categorien toewijzen op basis van de mogelijkheden die er op de kavels zijn, bijvoorbeeld of het heel moeilijk gaat worden, of dat er juist wel veel opties zijn. Daaruit kun je dan een soort percentage of getal van de hoeveelheid huishoudens afleiden. De grootte van de buffer hangt heel erg af van de mogelijkheden op de kavel, dus ook dan kom je weer bij een soort overzichtskaartje terecht. Bij het ene huis kun je nu eenmaal meer opvangen dan bij het andere huis.

2. **Requirement: The user is able to see the weather prediction data up to a certain time ahead.**
   Hoe lang van tevoren moet de buffer leeglopen? Wat is de tijd die er nodig is om de buffer(s) te legen?
   Voor het leeglopen van de buffer heb je twee opties:

   - Geknepen afvoer naar het riool
   - Eerst de buffer laten vollopen, daarna nood overflow naar het riool.

   Dat laatste is waarschijnlijk het handigste voor jullie. De tijd die nodig is om een buffer te legen zal pakweg 10 minuten zijn, afhankelijk van hoeveel water erin zit.

   Hans Koetsier: de looptijd van het rioolstelsel van het hoogste punt van de stad naar de rwzi is ongeveer 2-3 uur. Dus je zou de buffer ook 2-3 uur van tevoren kunnen laten leeglopen. 3 uur kun je nemen om aan de veilige kant te zitten, maar 2 uur geeft meer accurate weerdata.

3. **Requirement: The user is able to see recent data generated by the system at a certain time.**
   Hoe vaak zouden jullie de data in willen zien?
   Het is voldoende om elke 15 minuten nieuwe data te krijgen, real-time is niet nodig. Eventueel elke 10 minuten.

4. **Requirement: The interface of the municipality shows historic, current and future data on rainfall (prediction) and system performance.**
   Zouden jullie nog meer informatie willen zien of is het goed zo?
   Het is prima zo.

5. **Requirement: The buffer discharges at a certain rate (litres per time)**
   Maakt het uit hoe snel een buffer leegloopt? Hoe snel/langzaam?
   Hans Koetsier: Bij bergbezinkbassins is het zo dat de vulsnelheid en ledigingssnelheid afhankelijk zijn van metingen in het riool. Je kunt daar dus niet n getal aan vastplakken dat voor elke situatie geldt. Om aan de veilige kant te blijven kun je de buffer zeker wel laten leeglopen 24 uur na een bui, want dan heeft het rioolstelsel genoeg kans gehad om te stabiliseren.

6. **Requirement: The buffer has an overflow to the garden.**
   Is dit te realiseren?
   Een overflow naar de tuin is niet verplicht, maar wel zeer gewenst. Dit kun je weer aangeven in een overzichtskaartje, waarin je kunt zien waar er een tuin is met infiltratiemogelijkheden en waar er betegeling is (of geen tuin). Je kunt een beeld schetsen van waar de overflow wel en niet mogelijk is op basis van:

   - Verhouding verhard/niet verhard oppervlak.
   - Hoogteverschil (AHN hoogtebestand), is het huis hoger dan de tuin? (niveau bouwpeil)

   In het geval van een tuin kun je aangeven hoeveel % in de tuin terecht komt naast wat de buffer opvangt. Dat schept mogelijkheden voor extra opvang.

7. **Requirement: The system fulfils its purpose between April and October.**
   Wat moet het daarbuiten doen?
   De rest van het jaar moet je het water niet in de tuin laten lopen, omdat de grondwaterstand dan erg hoog is. Het mag wel gewoon het riool in. Je kunt dit mooi zien aan de statistieken van de grondwaterstand in Enschede.

Appendix E

Survey for citizens living in De Bothoven and Velve-Lindenhof

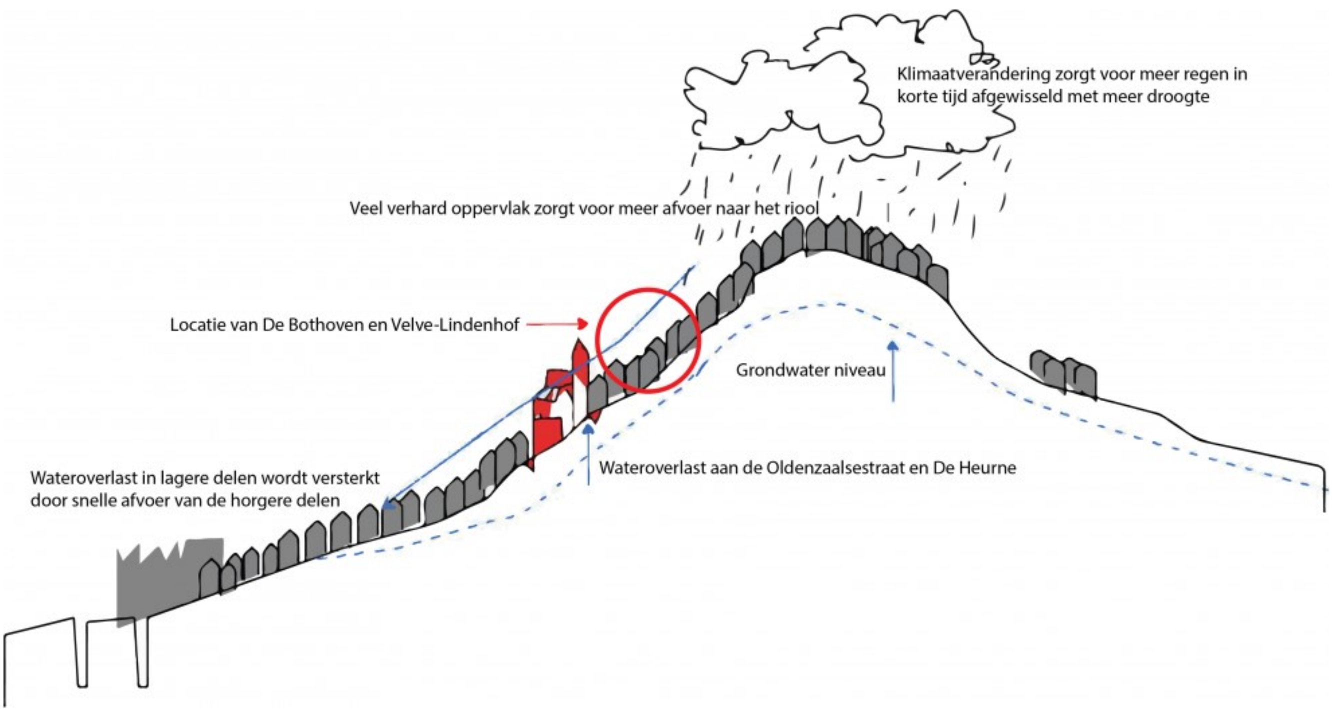
Default Question Block

. Enquête slimme regenwater buffer

.
Wij zijn Gelieke en Felicia, twee studenten van de Universiteit Twente en we doen momenteel onze bacheloropdracht bij de studie Creative Technology. Dit is een studie die zich richt op het ontwerpen en maken van slimme, technische oplossingen voor alledaagse problemen. In opdracht van de gemeente Enschede gaan we kijken naar de regenwaterproblematiek in Enschede. De riolering kan op sommige plekken in de stad de regen niet aan en overstroomt. Het water stroomt dan door de oostelijke wijken De Bothoven en Velve-Lindenhof naar de Oldenzaalsestraat en het centrum. Om de waterproblematiek te verminderen, moet het rioleringsstelsel ontlast worden. Dit kan door regenwater op te vangen ('bufferen') in De Bothoven en Velve-Lindenhof. De figuur hieronder geeft het probleem goed weer.

Wij willen daarom een systeem van 'slimme' regenwater buffers maken, die water opvangen en laten wegstromen afhankelijk van de weersvoorspelling. Als er een bui aankomt, dan loopt zo'n buffer langzaam leeg zodat er capaciteit vrijkomt voor de verwachte regenval. De buffers kunnen met elkaar communiceren, zodat dit allemaal zo efficiënt mogelijk gaat. Een buffer kan verschillende vormen aannemen, bijvoorbeeld een regenton, een regenschutting of een regenopvangend dak. We willen dit systeem van buffers voor en met de bewoners en de gemeente ontwikkelen, zodat het zo goed mogelijk aansluit op ieders behoeften. Natuurlijk is dit een proces dat jaren in beslag gaat nemen, maar wij willen u vanaf het begin bij het project betrekken. Daarom hebben we voor u een aantal vragen. Het invullen van de enquête duurt maar 5-10 minuten.

Uw gegevens worden volstrekt vertrouwelijk behandeld. Invullen gebeurt volledig anoniem.



Algemeen

. Algemeen

1. Wat is uw geslacht?

- ◯ Man
- ◯ Vrouw
- ◯ Anders

2. Wat is uw leeftijd?

- ◯ 0-19
- ◯ 20-39
- ◯ 40-59
- ◯ 60-79
- ◯ 80+

3. In welke wijk woont u?

- De Bothoven
- Velve-Lindenhof
- Andere wijk

4. Wat voor woning heeft u?

- Koop woning
- Huur woning

5. Heeft u wel eens last gehad van regenwateroverlast in uw tuin of straat?

- Ja
- Nee

6. Heeft u wel eens last gehad van regenwateroverlast in het centrum van Enschede?

- Ja
- Nee

7. Kent u andere mensen in uw buurt die last hebben gehad van regenwateroverlast?

- Ja
- Nee

8. Hoe zou u uw tuin omschrijven?

- Klein
- Gemiddeld
- Groot
- Geen (eigen) tuin aanwezig

9. Heeft uw huis een plat dak?

- Ja
- Nee
- Ik woon in een flat/gedeelde woning

10. Heeft uw garage een plat dak?

- Ja
- Nee
- Geen garage aanwezig

11. Heeft uw tuinhuis een plat dak?

- Ja
- Nee
- Geen tuinhuis aanwezig

Block 1

. Ontwerp regenwaterbuffer

12. Zou u een regenwaterbuffer in uw huis of tuin willen?

- Ja
- Nee
- Misschien

13. Waarom wel of niet?

14. Stel nou dat u een regenwaterbuffer (bijv. een regenton) in uw tuin kunt zetten om bij te dragen aan een oplossing. Zou u hier zonder tegenprestatie toe bereid zijn?

- ◯ Ja
- ◯ Nee
- ◯ Misschien

15. Zo nee, wat zou er voor u tegenover moeten staan? U kunt hierbij denken aan minder kosten voor water, of subsidie van de gemeente.

16. Stel dat u het gefilterde regenwater dat u opvangt kunt hergebruiken, bijvoorbeeld voor uw tuin, uw wasmachine of het doorspoelen van het toilet en hierbij leidingwater kunt besparen. Zou u dan wel een regenwaterbuffer willen?

- ◯ Ja
- ◯ Nee
- ◯ Misschien

17. Welke buffer zou u aanspreken? Een regenton, regen plantenbak, regenschutting of regendak? Meerdere antwoorden zijn mogelijk.

- ☐ Regenton
- ☐ Regen plantenbak
- ☐ Regenschutting
- ☐ Regenwater bufferend dak/groendak

Block 3

. Ontwerp systeem

18. Het systeem is 'slim', het verzamelt data. Welke informatie over uw regenwaterbuffer systeem zou u het liefste kunnen inzien? Meerdere antwoorden zijn mogelijk.

- ☐ Huidige waterniveau in buffer (bijv. 60% gevuld)
- ☐ Lokaal weerbericht
- ☐ Historie van opslag en leegloop (bijv. wat het waterniveau in de afgelopen dagen was)
- ☐ Aanbevolen leegloop (bijv. laat het met 20% leeglopen voor optimale prestatie)
- ☐ Hoeveel regenwater hergebruikt is voor eigen doeleinden (bewateren van de tuin etc)

19. Hoe zou u deze informatie het liefste kunnen inzien? Meerdere antwoorden zijn mogelijk

- ☐ Via een app op de mobiele telefoon
- ☐ Via een website of programma op de computer
- ☐ Een scherm in uw huis vergelijkbaar met een thermostaat

20. Zou u (sommige van) deze informatie anoniem ter beschikking willen stellen aan de gemeente? Om hiermee regenwateroverlast in het centrum te beperken?

- ◯ Ja
- ◯ Nee
- ◯ Misschien

21. Waarom wel of niet?

22. Zou u ermee akkoord gaan als de gemeente deze data gebruikt om het systeem zo efficiënt mogelijk te besturen? U heeft er dan zelf geen omkijken meer naar. Dit kunt u vergelijken met slimme energiemeters, die op afstand worden uitgelezen door energiemaatschappijen.

- Ja
- Nee
- Misschien

23. Waarom wel of niet?

24. Welk onderdeel van de buffers spreekt u aan om zelf te willen besturen? Meerdere antwoorden zijn mogelijk.

- [ ] Hoeveel water er maximaal opgevangen kan worden in de buffer
- [ ] Wanneer het water in de buffer leegloopt in het riool
- [ ] Hoeveel water in de buffer leegloopt in het riool
- [ ] Hoeveel water in de buffer wordt gebruikt voor andere doeleinden

25. Wat lijkt u aantrekkelijker, een plug-en-play product waar u zelf niks aan hoeft te doen, of een product dat u zelf kunt monitoren en besturen?

- Plug-en-play
- Zelf monitoren en bestuderen
- Beide opties zijn mogelijk

Block 4

. **Tot slot**

26. Zou u binnenkort eventueel mee willen werken met een vervolgonderzoek? Zo ja, laat dan hier uw e-mailadres achter.

27. Heeft u nog verdere opmerkingen of vragen voor ons? U kunt ons ook een mailtje sturen: regenwaterbuffer@gmail.com

Appendix F

Interview with housing corporation Domijn

F.1 Monday 22/05/2017

On 22 May 2017, a semi-structured interview was held with Arno Weppel, who works as water manager at housing corporation Domijn. Domijn owns several buildings in De Bothoven and Velve-Lindenhof. The questions and notes of the answers are listed below (in Dutch).

1. **Heeft Domijn wel eens klachten gehad over wateroverlast? Zo ja, in welke mate?**
   Ja, voornamelijk over vochtige kelders/vloeren, maar dat is meer een grondwaterverhaal. Toen hebben we wel eens maatregelen moeten nemen, met betrekking tot de drainage.

2. **Heeft Domijn zelf al maatregelen genomen tegen wateroverlast? Zo ja, welke? Kunt u deze toelichten?**
   Zijn er al mee bezig, ook met de gemeente Enschede en Vechtstromen (Watervisie):

   - Waterretentie op hellend groendak bij Transburg (gedeelte in De Bothoven, zie afbeelding), pilot project. Met hellende daken is dit nog niet echt gedaan, dus vrij nieuw. Al sinds 1982 groendak boven de parkeerplaats hier.

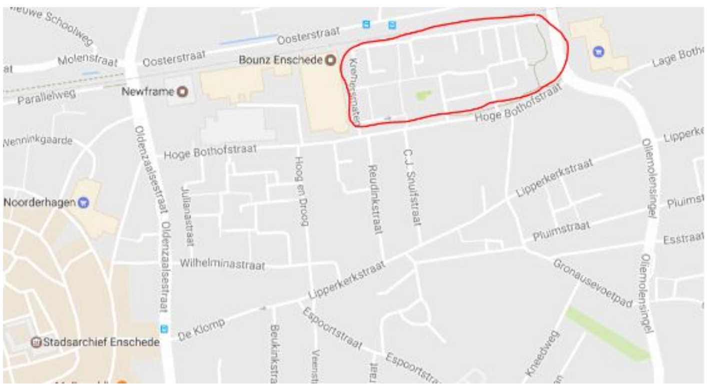


Figure F.1: Location of the Transburg area in De Bothoven.

- Sterrenbuurt afkoppelen hemelwater (in Twekkelerveld)

  Proefprojecten staan er al sinds 2011 Regenton in bak met grind (i.p.v. klei) zodat het water goed kan weglopen

3. **Gebruiken jullie ook (slimme) technologie in die maatregelen?**
   Er wordt wel gemeten bij het pilot project van de groene daken (STOWA doet dat), zoveel kan er opgevangen worden op zon groot dak, berekeningen.

4. **In hoeverre zouden huurwoningen een regenwaterbuffer mogen hebben?**
   Huurders mogen gewoon een regenton aansluiten, dat is geen probleem.

5. **Zouden jullie betrokken willen worden bij ons project?**
   Misschien in verband met als je een bestaande huurwoning op-plust, dus hoger energielabel eraan geeft, dat je dan direct ook zon systeem aanlegt. Hergebruiken in de tuin. Ik zie het nog niet zo 1-2-3 bij bestaande woningen op grote schaal in de nabije toekomst. We staan er wel zeker open voor.

   Hergebruik van water e.d. voor wasmachine is meer voor nieuwbouw of grootse renovatie. Dan krijg je energieneutrale woningen, die hun eigen grijswatercircuit opslaan.

6. **Zou Domijn bereid zijn hieraan mee te betalen op het terrein van huurwoningen?**
   Dat is wel heel vroeg om nu te zeggen. Maar stel je wil meer isolatie dan kun je als bewoners naar Reimarkt en die leggen dan uit wat je kunt verbeteren aan je woning om je energielabel omhoog te halen. Dus het gaat met name om energiemaatregelen. Evt. kun je hier het afkoppelen van hemelwater bij halen. Overzichtsplaatje waar je regenwater voor kunt gebruiken, niet alleen de plantjes maar het grijswatercircuit.

7. **Er is een bedrijf, Optigroen, dat een systeem bedacht heeft voor een retentiedak. Dit systeem kijkt naar de weersvoorspelling en bepaalt aan de hand daarvan of er water opgevangen kan worden of af wordt gevoerd. Wat denkt u van zon systeem?**
   Dat kan alleen bij platte daken, en dan moet je het platte dak ook zo voor ingericht hebben. Want de meeste daken hebben allemaal grind erop, dus dan moet je naar een heel ander daksysteem.

   Meestal kan een dak de ballast wel aan, 70kg/m dus 70L water zou wel moeten kunnen voor een normaal bestaand plat dak. Maar je moet naar een ander daksysteem, het mooiste is een daksysteem met EPDM, dat is een soort rubber. Dan kun je dus echt water gaan bufferen op je dak. Want grind ligt er zo los op. Je zou hiernaar kunnen kijken bij de vervanging van je daklaag.

8. **Wat vinden de mensen in de wijk van groene daken en dergelijke maatregelen, voor zover u weet?**
   Oude mensen en buitenlandse mensen hebben er vaak nog wat problemen mee, maar jonge mensen zijn er vaak wel enthousiast over. Maar die begrijpen het ook water beter en die kennen het principe al wel.

9. **Heeft u nog tips/suggesties voor onze regenwaterbuffers?**
   Het mooiste zou zijn als je het water gewoon tijdelijk vast kunt houden op het gebouw zelf. Daar zijn niet zo heel veel mogelijkheden voor, dat zou dan gaan om een groendak of opslaan bij de woning zelf.

   Je hebt ook blauwe daken, die zijn wat simpeler, die slaan alleen water op (zonder groen dus).

   Het zou wel heel mooi zijn om een kaart te hebben om te weten waar wat allemaal mogelijk is qua waterbuffering, waar platte daken zijn en zo. Het zou wel mooi zijn om te weten bij welke complexen je zon (slim) systeem toe kan passen.

Appendix G

Functional test

Table G.1: Functional requirements. (* = requirement verified with municipality, ** = requirement verified with a citizen)

Functional User requirements	Functional System requirements
Must	
The buffer is able to store and release rainwater automatically.*	
The rainwater captured by the buffer is re-usable by the citizens.	The buffer is connected to a downspout diverter. The buffer contains a faucet to retrieve water and has a sensor to measure the flow rate.
The user is able to see the weather prediction data up to 2 hours ahead.*	The system is able to fetch weather prediction data by communication with a weather station (KNMI, Buienradar). The system uses weather prediction data up to 2 hours ahead.
The user is able to see data generated by the system every 15 minutes.*	The system's sampling rate is 15 minutes. The system's synchronisation rate is 15 minutes.
The interface of the municipality shows the overall system performance consisting of the historic and current buffer volume, future discharge data and rainfall prediction.*	The buffer contains sensors that measure the water level. The data of the buffers is stored in a central database. The buffers communicate with each other and with the central server via WiFi.
The interface of the citizens shows own system performance that includes catchment history (request for one year) **, future catchment overview, current water level inside the tank and show the precipitation forecast.	The data of the citizens is stored for a month on the local node (aka. buffer system).
The buffer discharges through a pipe that is connected to the downspout.	
The buffer can be discharged independently of other buffers.*	
The citizen is able to use the roof as a catchment area for the buffer.	The buffer is connected to the downspout of the roof.
The buffer does not cause excessive rainwater in the gardens of the inhabitants.	The buffer has a downspout diverter that acts as an overflow.
Discharging the system does not result in excessive water in the sewerage system.	

The user information will be treated confidentially and anonymously.	The system anonymises the data from the citizen's buffers in the interface of the municipality, meaning that the municipality cannot see to which person which buffer belongs.
Should	
	The buffers communicate with each other and with the central server via LoRa.
The buffers notify the user in case of malfunctioning or dangerous situations.	The system should send error messages/ notifications in case of malfunctioning or dangerous situations (leakage, no contact with server, clogged, freezing).
The buffer has an overflow to the garden that will only be used between April and October.*	
The citizen is able to see recent data (almost real time) generated by the system at any time.**	Sampling rate of the sensors is lower than the synchronisation rate ($<$15 min) and higher than the sensor accuracy. The system is able to send new data to the interface of the citizen with the same rate as the sampling rate.
The rainwater captured by the buffer is not contaminated by leaves, debris (sand etc.) and insects.	The system must filter the water before it is stored in the buffer.
The citizen is able to choose whether his/her buffer data will be shared with the municipality.	
Could	
The municipality is able to test the system's performance with model rain showers.*	The system could be tested using virtual data/models.
The buffers each contain a weather station that measures local weather statistics.*	The buffers contain sensors for measuring and predicting temperature, wind speed and humidity.
The interface of the citizen only shows the data corresponding to that citizen's buffer.	The interface stores the buffer data on a local server.
Won't	
The interface of the inhabitants shows an overview on potable water savings.	
The user is able to connect an existing rainwater barrel to the system.	

Table G.2: Non-Functional requirements.

Non-Functional User requirements	Non-Functional System requirements
Must	
The interface of the users shows the water level with a high accuracy.	The accuracy of the buffer is 1L.
The buffers discharge ahead of a predicted rain shower.*	The buffer must have a discharge of at least 67L/hour ($\sim$1L/min).
The user does not need to operate the system (manually) in order for the system to fulfill its purpose.*	The system functions autonomously and does not require intervention from the user in order to fulfill its purpose.
The citizen is able to operate the system manually.	The interface of the citizens contains buttons with which the citizen can control the buffer's capacity.
The user is able to operate the interface of the system with ease.	
The buffer fits in the garden of the citizens.	
Should	
The system is safe (does not fall over, protecting user from the electronic components).	
The system does not use a substantial amount of power.	The system is energy efficient. The sampling frequency of the system adopts to the current weather state and re-usage of rainwater by the citizen.
The system is durable (lasts a long time).*	
The buffer's design is unobtrusive and aesthetically pleasant.	
The user needs the system to function at any given weather condition, all year round.*	The system should function whether or not it has been in contact with water.

Appendix H

Consent form (in Dutch)

Titel onderzoek: Smart Rainwater Buffer - Tonnie
Verantwoordelijke onderzoekers: Gelieke Steeghs, Felicia Rindt
Datum: ....

In te vullen door de deelnemer

Ik verklaar op een voor mij duidelijke wijze te zijn ingelicht over de aard, methode, doel en belasting van het onderzoek. Ik weet dat de gegevens en resultaten van het onderzoek alleen anoniem en vertrouwelijk verwerkt zullen worden en al mijn vragen zijn naar tevredenheid beantwoord. Ik begrijp dat film-, foto, en videomateriaal of bewerking daarvan uitsluitend voor analyse zal worden gebruikt. Ik stem geheel vrijwillig in met deelname aan dit onderzoek. Ik behoud me daarbij het recht voor om op elk moment zonder opgaaf van redenen mijn deelname aan dit onderzoek te beindigen.

Naam deelnemer:	**Handtekening deelnemer:**
....	....

In te vullen door de uitvoerende onderzoeker

Ik heb een mondelinge en schriftelijke toelichting gegeven op het onderzoek. Ik zal resterende vragen over het onderzoek naar vermogen beantwoorden. De deelnemer zal van een eventuele voortijdige beindiging van deelname aan dit onderzoek geen nadelige gevolgen ondervinden.

Naam onderzoeker:	**Handtekening onderzoeker:**
....	....

Appendix I

Survey for user testing

Default Question Block

Voor ons afstudeerproject hebben wij een systeem van slimme regenwater buffers gemaakt, genaamd Tonnie. Hierover hebben we een enquête gemaakt. Eerst moet je enkele eenvoudige taken uitvoeren met onze interface, en daarna stellen we je er een aantal vragen over. Het invullen duurt slechts enkele minuutjes. Alvast bedankt voor de moeite!

Druk op » om door te gaan.

Block 1

In het eerste gedeelte stellen we je een 7 korte vragen, die je moet beantwoorden door de interface te gebruiken. Als je er echt niet uitkomt, kun je één van ons even om een hint vragen. Veel succes!

Wat is de huidige status van het systeem?

- ○ OK
- ○ Melding
- ○ Waarschuwing
- ○ Error
- ○ Kritiek

Wat is het huidige volume (in liters) van de buffers in het gehele gebied?

- ○ 50 L
- ○ 400 L
- ○ 61 L
- ○ 20 L

Voor hoeveel procent zijn de buffers in "De Bothoven" op dit moment gevuld?

- ○ 23.66 %
- ○ 89.78 %
- ○ 4.45 %
- ○ 32.11 %

Voor hoeveel procent waren de buffers gevuld op 12-06 in de Velve-Lindenhof wanneer er gekeken wordt naar de periode 07-06-2017 t/m 12-06-2017?

- ○ 48.42 %
- ○ 23.1 %
- ○ 9.78 %
- ○ 50.01 %

De grafiek in het rechterblok van de pagina geeft aan hoeveel water er naar het riool stroomt, hoeveel de tuin in gaat en hoeveel er afgetapt wordt door de bewoner. Waar gaat het meeste water naartoe?

- ○ Tuin
- ○ Riool
- ○ Bewoner

Hoeveel procent is dit?

- ○ 52.6 %
- ○ 50.0 %
- ○ 12.45 %
- ○ 43.56 %

Is er regen voorspeld voor de komende 2 uur?

- ○ Ja
- ○ Nee

Tot slot is er een grafiek waarin je kunt zien wat de geplande leegloop is voor het systeem voor de komende 2 uur, gebaseerd op de verwachte regenval. Met hoeveel liter per minuut loopt het systeem in het gehele gebied aanvankelijk leeg?

- ○ 10 L/min
- ○ 5 L/min
- ○ 2 L/min
- ○ 1 L/min

Block 2

Nu gaan we de taken die je zojuist volbracht hebt langs aan de hand van 10 design principes ("heuristics"). Geef voor elke stelling aan in hoeverre je ermee (on)eens bent.

	Volledig mee oneens	Mee oneens	Neutraal	Mee eens	Volledig mee eens
Ik vind de status van het systeem duidelijk zichtbaar.	○	○	○	○	○
De betekenis van de gebruikte iconen en symbolen waren voor mij volstrekt helder.	○	○	○	○	○
Ik heb het gevoel dat ik controle heb over mijn interactie met het systeem.	○	○	○	○	○
Het ontwerp van de interface is consistent.	○	○	○	○	○
Er zitten geen fouten in de interface.	○	○	○	○	○
De interface is eenvoudig in gebruik.	○	○	○	○	○
Ik kan efficiënt navigeren door de interface.	○	○	○	○	○
Ik vind de interface mooi.	○	○	○	○	○
Wanneer ik een wijk heb geselecteerd, wordt dit duidelijk weergegeven.	○	○	○	○	○
Als ik hulp nodig heb bij het gebruik van de interface, kan ik die gemakkelijk vinden.	○	○	○	○	○

Bij de vorige vraag heb je bij ten minste één stelling "neutraal", "mee oneens" of "volledig mee oneens" ingevuld. Kun je deze keuze uitleggen?

Block 3

Dit is het einde van de enquête. Heb je nog andere feedback voor ons? Zo ja, schrijf je opmerkingen dan in het veld hieronder.

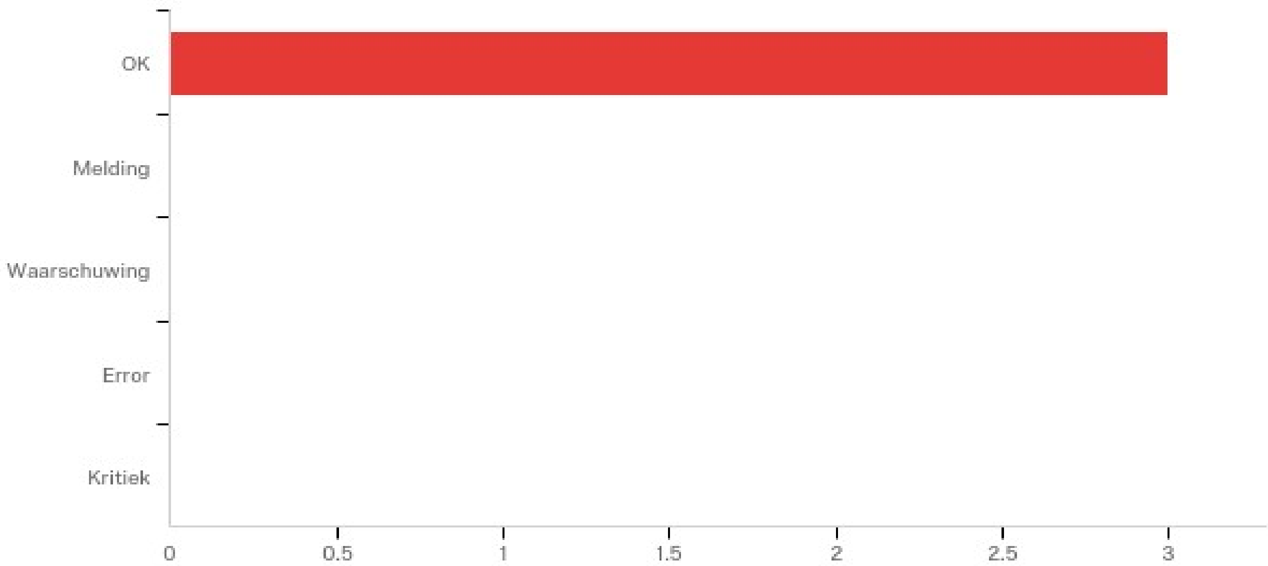
Appendix J

Results user testing

Enquête over Tonnie

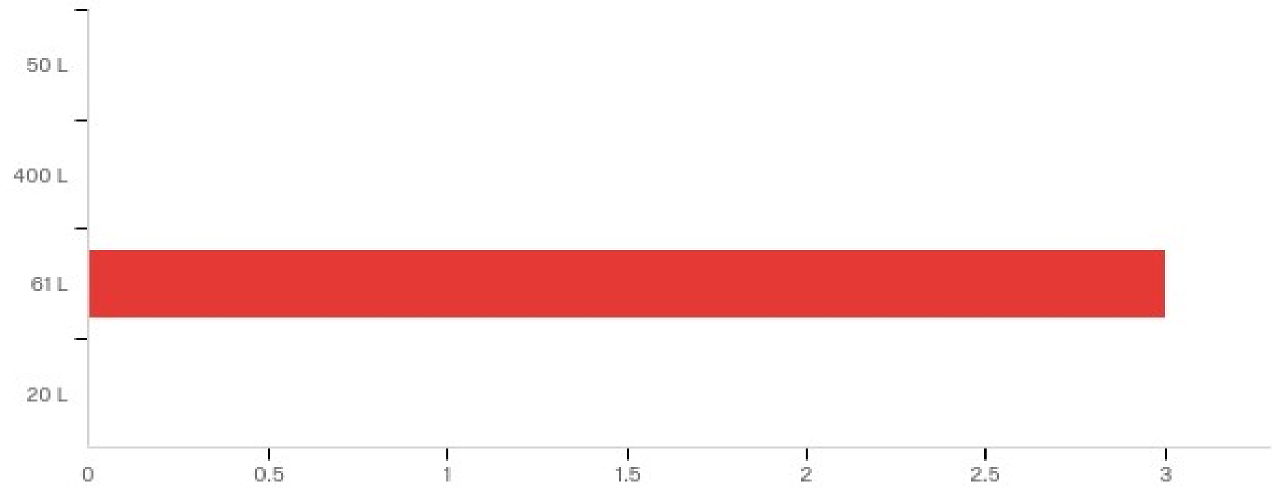
June 26th 2017, 10:00 am CEST

Q1 - Wat is de huidige status van het systeem?



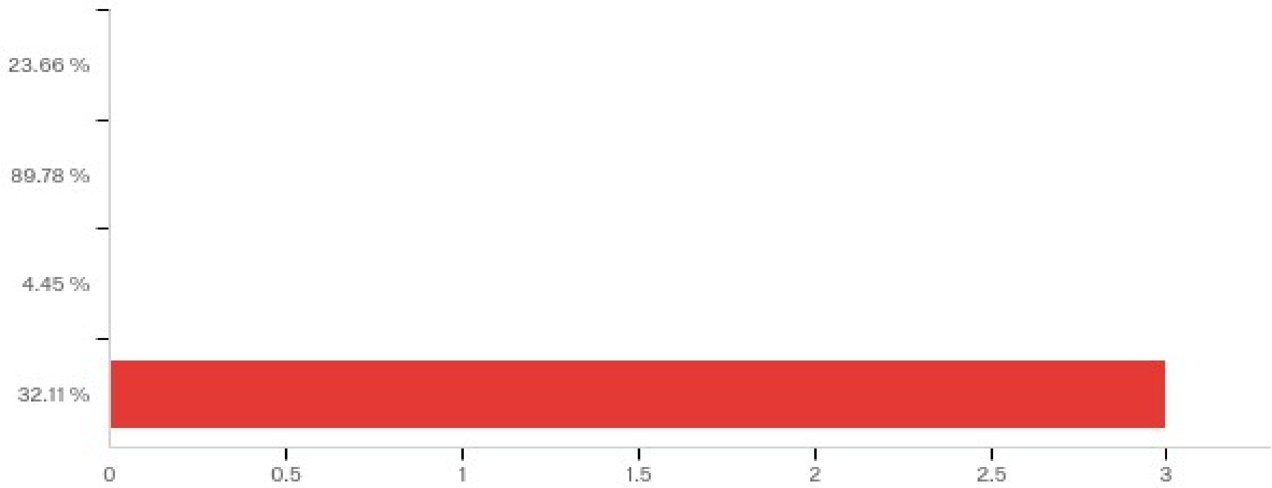
#	Answer	%	Count
1	OK	100.00%	3
2	Melding	0.00%	0
3	Waarschuwing	0.00%	0
4	Error	0.00%	0
5	Kritiek	0.00%	0
	Total	100%	3

Q2 - Wat is het huidige volume (in liters) van de buffers in het gehele gebied?



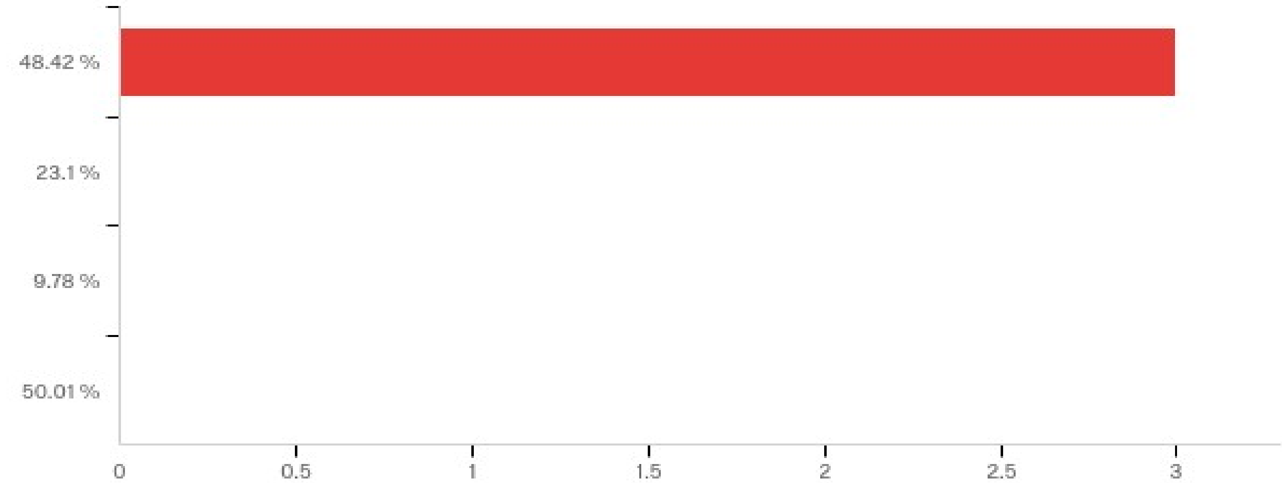
#	Answer	%	Count
1	50 L	0.00%	0
2	400 L	0.00%	0
3	61 L	100.00%	3
4	20 L	0.00%	0
	Total	100%	3

Q3 - Voor hoeveel procent zijn de buffers in "De Bothoven" op dit moment gevuld?



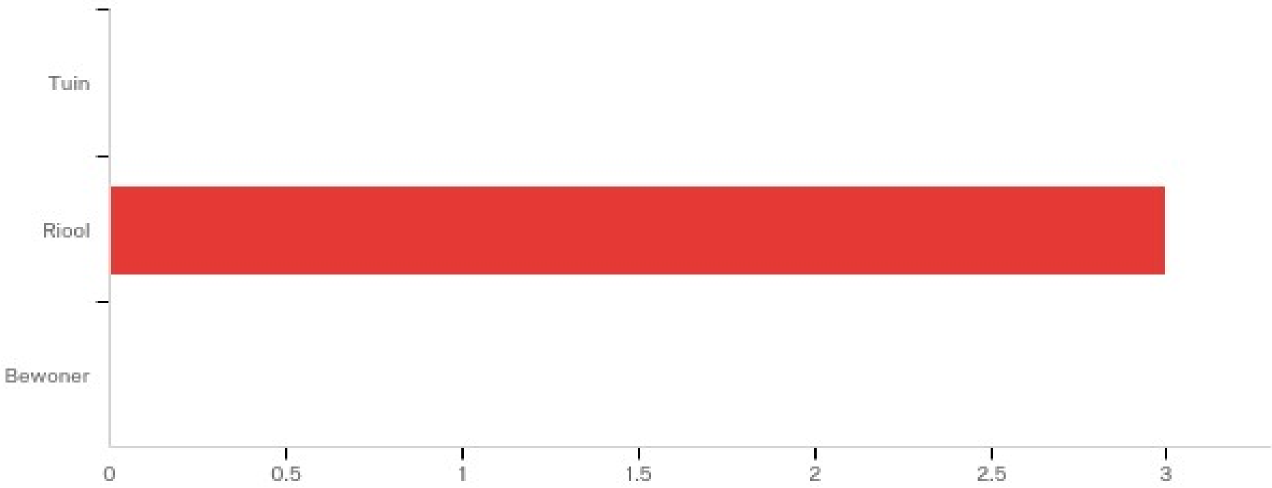
#	Answer	%	Count
1	23.66 %	0.00%	0
2	89.78 %	0.00%	0
3	4.45 %	0.00%	0
4	32.11 %	100.00%	3
	Total	100%	3

Q4 - Voor hoeveel procent waren de buffers gevuld op 12-06 in de Velve-Lindenhof wanneer er gekeken wordt naar de periode 07-06-2017 t/m 12-06-2017?



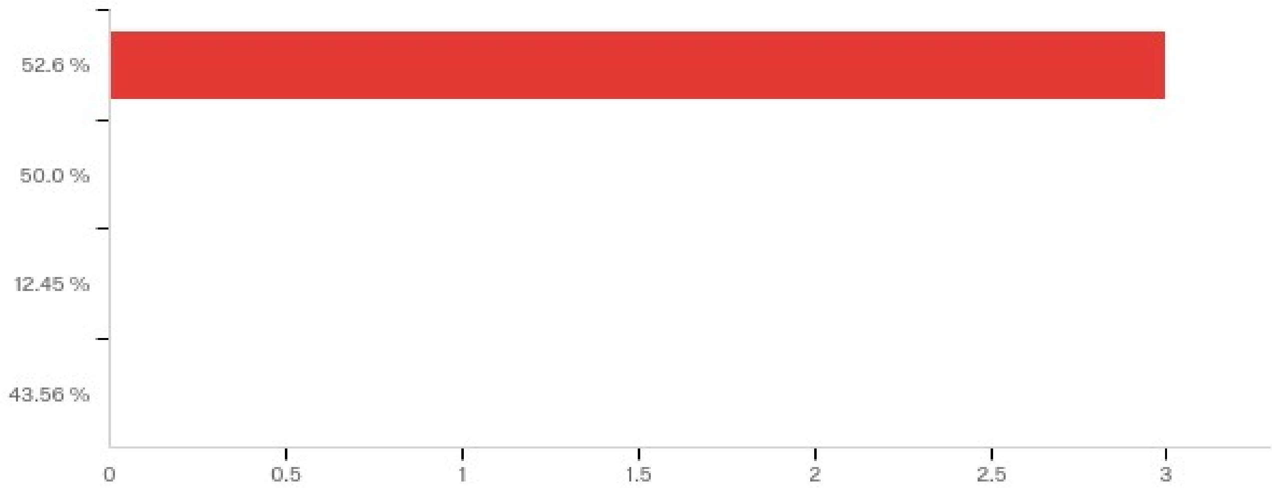
#	Answer	%	Count
1	48.42 %	100.00%	3
2	23.1 %	0.00%	0
3	9.78 %	0.00%	0
4	50.01 %	0.00%	0
	Total	100%	3

Q5 - De grafiek in het rechterblok van de pagina geeft aan hoeveel water er naar het riool stroomt, hoeveel de tuin in gaat en hoeveel er afgetapt wordt door de bewoner. Waar gaat het meeste water naartoe?



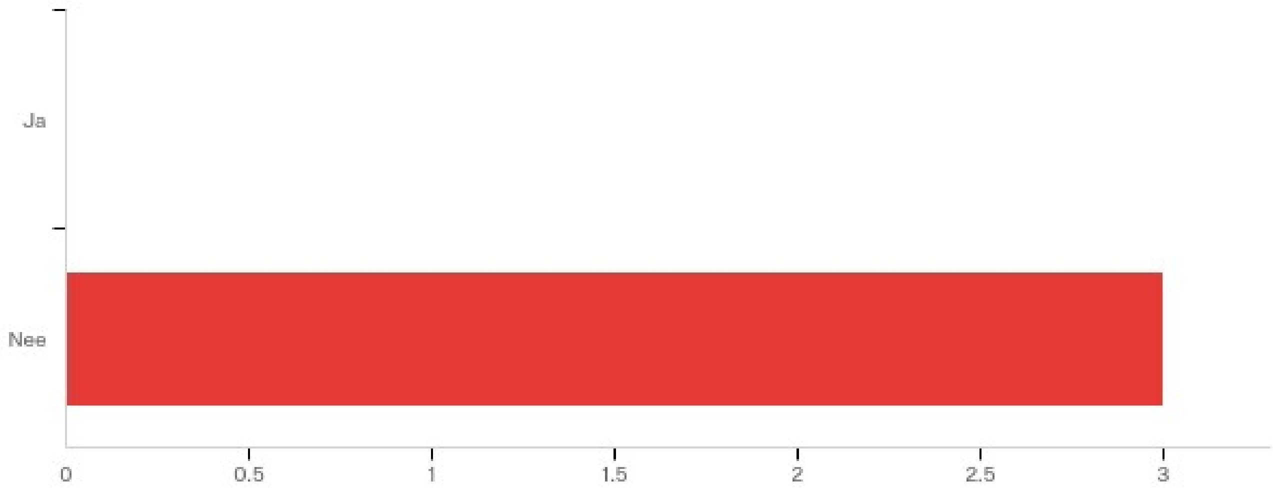
#	Answer	%	Count
1	Tuin	0.00%	0
2	Riool	100.00%	3
3	Bewoner	0.00%	0
	Total	100%	3

Q6 - Hoeveel procent is dit?



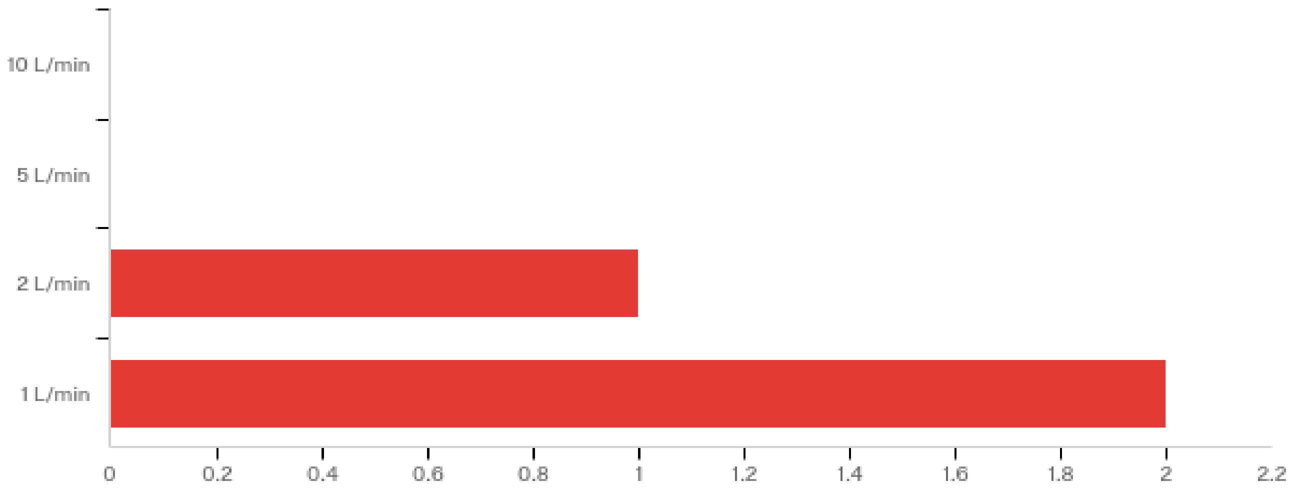
#	Answer	%	Count
1	52.6 %	100.00%	3
2	50.0 %	0.00%	0
3	12.45 %	0.00%	0
4	43.56 %	0.00%	0
	Total	100%	3

Q7 - Is er regen voorspeld voor de komende 2 uur?



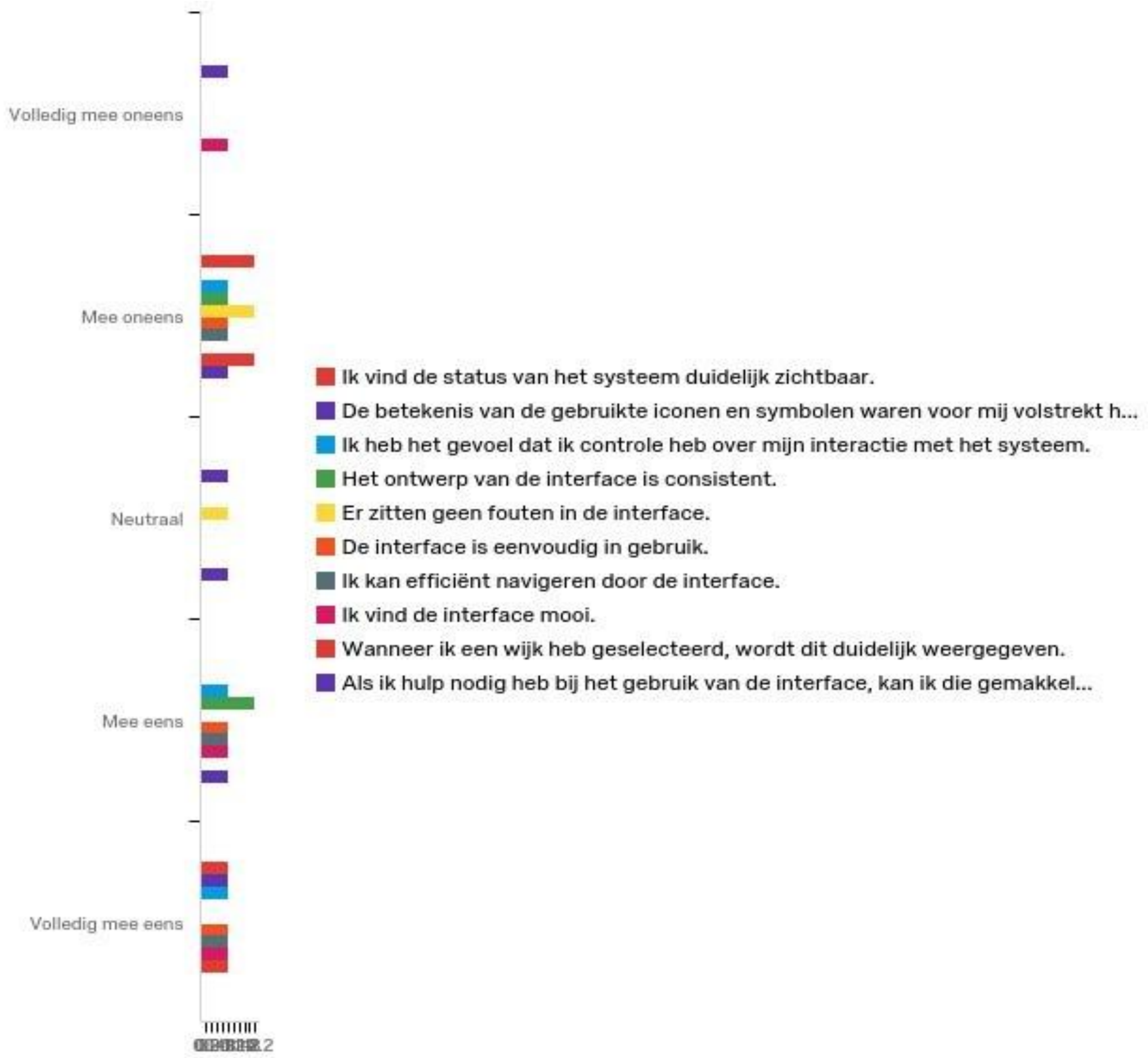
#	Answer	%	Count
1	Ja	0.00%	0
2	Nee	100.00%	3
	Total	100%	3

Q8 - Tot slot is er een grafiek waarin je kunt zien wat de geplande leegloop is voor het systeem voor de komende 2 uur, gebaseerd op de verwachte regenval. Met hoeveel liter per minuut loopt het systeem in het gehele gebied aanvankelijk leeg?



#	Answer	%	Count
1	10 L/min	0.00%	0
2	5 L/min	0.00%	0
3	2 L/min	33.33%	1
4	1 L/min	66.67%	2
	Total	100%	3

Q9 - Nu gaan we de taken die je zojuist volbracht hebt langs aan de hand van 10 design principes ("heuristics"). Geef voor elke stelling aan in hoeverre je ermee (on)eens bent.



#	Question	Volledig mee oneens		Mee oneens		Neutraal		Mee eens		Volledig mee eens	
1	Ik vind de status van het systeem duidelijk zichtbaar.	0.00%	0	18.18%	2	0.00%	0	0.00%	0	14.29%	1
2	De betekenis van de gebruikte iconen en symbolen waren voor mij volstrekt	50.00%	1	0.00%	0	33.33%	1	0.00%	0	14.29%	1

	helder.										
3	Ik heb het gevoel dat ik controle heb over mijn interactie met het systeem.	0.00%	0	9.09%	1	0.00%	0	14.29%	1	14.29%	1
4	Het ontwerp van de interface is consistent.	0.00%	0	9.09%	1	0.00%	0	28.57%	2	0.00%	0
5	Er zitten geen fouten in de interface.	0.00%	0	18.18%	2	33.33%	1	0.00%	0	0.00%	0
6	De interface is eenvoudig in gebruik.	0.00%	0	9.09%	1	0.00%	0	14.29%	1	14.29%	1
7	Ik kan efficiënt navigeren door de interface.	0.00%	0	9.09%	1	0.00%	0	14.29%	1	14.29%	1
8	Ik vind de interface mooi.	50.00%	1	0.00%	0	0.00%	0	14.29%	1	14.29%	1
9	Wanneer ik een wijk heb geselecteerd, wordt dit duidelijk weergegeven.	0.00%	0	18.18%	2	0.00%	0	0.00%	0	14.29%	1
10	Als ik hulp nodig heb bij het gebruik van de interface, kan ik die gemakkelijk vinden.	0.00%	0	9.09%	1	33.33%	1	14.29%	1	0.00%	0
	Total	Total	2	Total	11	Total	3	Total	7	Total	7

Q10 - Bij de vorige vraag heb je bij ten minste één stelling "neutraal", "mee oneens" of "volledig mee oneens" ingevuld. Kun je deze keuze uitleggen?

Bij de vorige vraag heb je bij ten minste één stelling "neutraal", "mee one...
is al besproken veel succes met vervolg!

Q11 - Dit is het einde van de enquête. Heb je nog andere feedback voor ons? Zo ja, schrijf je opmerkingen dan in het veld hieronder.

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laat ook bij de andere grafieken zien welke selecties gelden (gebied/periode enz.) de status is mij onduidelijk. wat zegt het? waarom is er een leegloop gepland, als er geen regen wordt voorspeld?