



# Designing a Smart Rainwater Buffer

Bachelor thesis for Creative Technology by  
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BSc Project Report  
5-8-2017

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## Abstract

The morphology of the terrain of Enschede is a hill, together with impermeable soil and paving this results in regular floods as a consequence of heavy rainfall. The municipality of Enschede is looking for a solution to be implemented on the premises of the inhabitants of the most affected areas. The aim of the system is to buffer up to 7000 m<sup>3</sup> for the whole affected area; it is to be implemented within the property of the inhabitants. In this thesis, a solution to the problem is proposed: A Smart Rainwater Buffer. This solution uses the principles of hollow fences to create a buffer in which rainwater is stored during heavy downpour. The stored water can be used to water the garden, and is released via a weather-aware smart valve in response to buffer capacity and expected rainfall. The system can be monitored with a webpage that automatically updates in response to changes to the system. A total of four prototypes were presented to the municipality of Enschede and the regional waterboard Vechtstromen. The result is an intelligent weather-aware buffering system that empties itself before heavy rainfall, which is installed in the garden of house owners. In order to improve the prototype, long-term testing is required to assess system performance and stability over periods of time. In conclusion, a functioning prototype was developed and tested, which if implemented by 3500 households could effectively buffer the required 7000 m<sup>3</sup> of rainwater.

## Acknowledgements

I would like to thank several people that helped or supported me during this project.

First of all, I would like to thank my supervisor, Richard Bults. Richard has given me lots of advice and feedback throughout the span of this project. His hands-on approach helped me during development of my prototypes.

Secondly, I would like to thank Hendrik-Jan Teekens. He was my contact person at the municipality of Enschede, who visited the campus of the University of Twente countless times to provide feedback on this project.

Finally, I would like to thank Gloria Carta for assisting with structuring and reviewing my work.

## Table of Contents

|                                                             |    |
|-------------------------------------------------------------|----|
| Abstract.....                                               | 2  |
| Acknowledgements.....                                       | 3  |
| 1 Introduction .....                                        | 6  |
| 2 State of the Art.....                                     | 7  |
| 2.1 Problem analysis .....                                  | 7  |
| 2.2 Rainwater harvesting advantages.....                    | 9  |
| 2.3 Literature research method .....                        | 9  |
| 2.4 Currently available solutions.....                      | 10 |
| 2.5 Infiltration systems .....                              | 11 |
| 2.6 Buffering systems.....                                  | 13 |
| 2.7 Concluding problem analysis and literature review ..... | 18 |
| 2.8 Novelty of the research question .....                  | 18 |
| 3 Methods and techniques .....                              | 19 |
| 3.1 Creative Technology Design Process .....                | 19 |
| 3.2 Requirements Elicitation .....                          | 20 |
| 3.3 MoSCoW.....                                             | 20 |
| 3.4 Stakeholder Analysis.....                               | 21 |
| 3.5 Concept generation .....                                | 21 |
| 3.6 iPact analysis .....                                    | 21 |
| 3.7 Demonstrating the prototypes .....                      | 22 |
| 3.8 Evaluation .....                                        | 22 |
| 4 Ideation.....                                             | 23 |
| 4.1 Stakeholder identification and analysis .....           | 23 |
| 4.2 Functional and non-functional requirements.....         | 24 |
| 4.3 Concepts .....                                          | 25 |
| 4.4 Conclusion .....                                        | 29 |
| 4.5 iPACT analysis.....                                     | 30 |
| 5 Specification .....                                       | 32 |
| 5.1 Proposed setup .....                                    | 32 |
| 5.2 Functional Architecture.....                            | 35 |
| 5.3 Specifying the prototypes .....                         | 36 |
| 5.4 Requirements, second iteration .....                    | 38 |

|     |                                                               |    |
|-----|---------------------------------------------------------------|----|
| 6   | Realization .....                                             | 40 |
| 6.1 | Decomposition of system components.....                       | 40 |
| 6.2 | Development of lo-fi prototype 1.....                         | 40 |
| 6.3 | Development of lo-fi prototype 2.....                         | 42 |
| 6.4 | Development of hi-fi prototype 3.....                         | 43 |
| 6.5 | Development of hi-fi prototype 4.....                         | 46 |
| 7   | Evaluation and Discussion .....                               | 47 |
| 7.1 | Functional and non-functional requirements evaluation .....   | 47 |
| 7.2 | Feedback on prototype .....                                   | 48 |
| 8   | Conclusion .....                                              | 50 |
| 9   | Recommendations.....                                          | 51 |
| 10  | References.....                                               | 52 |
| 11  | Appendices.....                                               | 54 |
|     | Appendix A – Map displaying locations extreme runoff .....    | 54 |
|     | Appendix B – Results brainstorm session.....                  | 55 |
|     | Appendix C – Baseline and satellite stakeholders.....         | 56 |
|     | Appendix D – Material list .....                              | 57 |
|     | Appendix E – Smart Rainwater Buffer python code .....         | 58 |
|     | Appendix F – Informational poster Smart Rainwater Buffer..... | 63 |

# 1 Introduction

Last year's Little Prince's Day main theme has been about flooding [1]. The heaviest downpours based on the most recent KNMI prediction models for 2050 have already occurred prematurely [2]. The past ten years the water boards have invested 1,5 billion euros to fight stormwater runoff, but it has become clear an extra effort has to be made from other parties: the municipality and the inhabitants of their cities.

With its 160,000 inhabitants Enschede is the urban heart of East Netherlands. The geographical situation in Enschede makes rainwater management a daunting task. Enschede lays on a moraine, has been built on a hill and the area has been paved through the years. Due to these factors, in weather conditions with a large volume of rainfall in a short time the strain on the existing sewerage system of the city of Enschede is too high. At spikes of heavy rainfall over time, parts of the city might flood as result. The geographical factors inducing flooding are further elaborated on in chapter 2.

Stormwater runoff causes damage and health hazards directly to the inhabitants situated in lower areas, to shops and to the municipality. Appendix A shows the area with stormwater runoff in the streets as well as some of the most extreme flooded areas at yearly peak rainfall moments in Enschede. The municipality of Enschede targeted a problem area, marked purple on this map. The municipality reached out to the University of Twente to design a solution for this expanding problem. The main focus lies primarily on providing a smart solution for large volume rainwater buffering in the aforementioned target area of the Oldenzaalsestraat, which has a surface runoff of roughly 7.000 m<sup>3</sup> of rainwater. The main research question for this project is defined as:

*"How to develop a rainwater buffering system that reduces the strain on the sewerage system of Enschede and is distributed over the premises of its inhabitants?"*

This report gives an overview of the project and its outcomes. Firstly, the problem is further analyzed in chapter 2. The geographical factors from which flooding originates are described and contextualized. Furthermore, the chapter includes an overview of current systems used to tackle rainwater and flooding. In chapter 3 the methods and techniques of the project are described, this includes the literature study strategy, the stakeholder analysis, the elicitation of the system's requirements and the design process. Chapter 4 describes the ideation of the prototype which includes the characterization of requirements as well as the proposition of prototype concepts. One final concept is then chosen. Chapter 5 gives an account of the results of different iterations of the prototype, both low and high-fidelity. In chapter 6 the realization of the prototypes is shown, including a material list and a step-by-step guide to reproduce the final prototype. Chapter 7 follows, which includes an evaluation of the prototype based on feedback received during the different iterations and on the system's requirements. This report ends with a conclusion in chapter 8 and a recommendations section in chapter 9 for further work.

## 2 State of the Art

In this chapter, the causes of flooding specific to the city of Enschede are analysed. Relevant buffering- and infiltration systems are explored in order to understand currently available solutions, including their advantages and disadvantages.

### 2.1 Problem analysis

The origin of flooding in the city can be attributed to Enschede's geographical and morphological situation. Enschede is situated on a moraine: the land was pushed up by big chunks of land ice in the glacial age. This implies that Enschede lies on mixed soil as shown in figure 1.

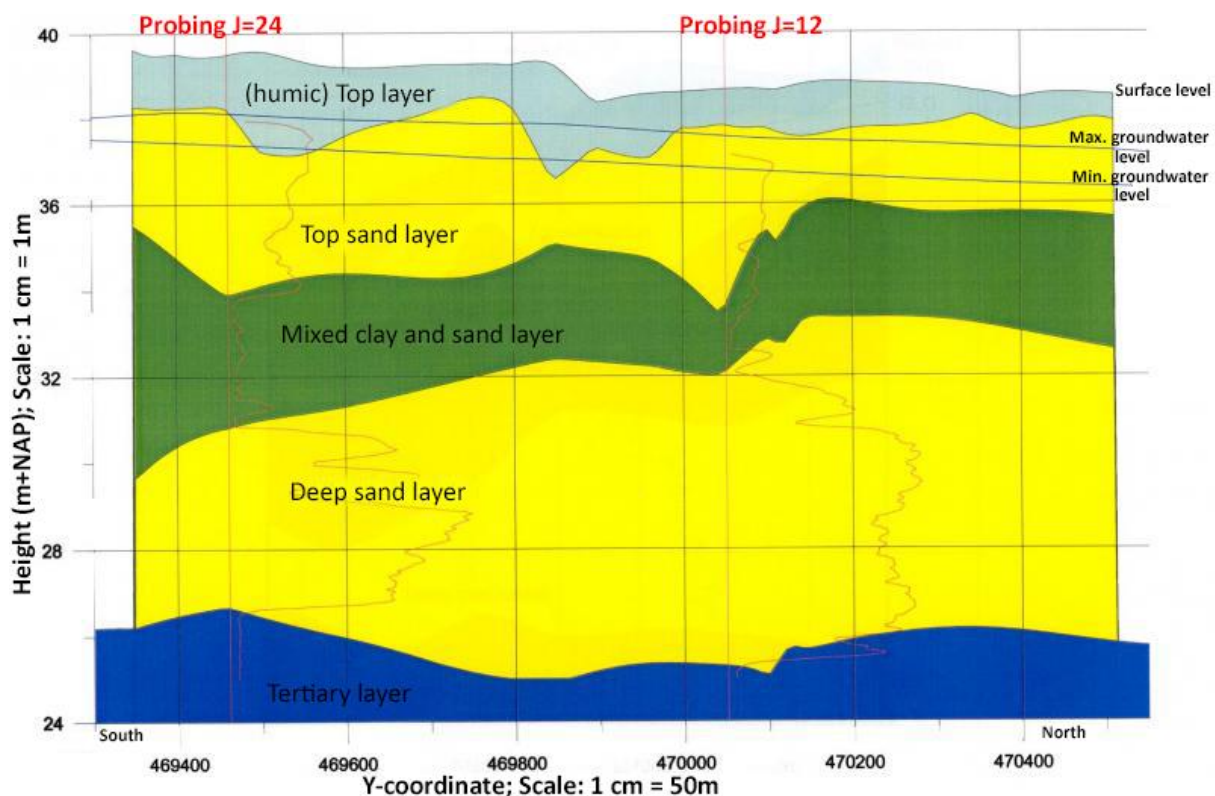


Figure 1: Composition of the soil in Enschede

Soil, at the surface level consists of mixed ground: fine sand, a layer of loam, raw sand, and a layer of clay. This poorly pervious deep clay layer is situated at a depth of 12 to 20 meters [3]. Depicted in figure 1, the probed bearing capacity of the soil has a measured coefficient of friction of  $J=12$  or  $J=24$ . It can be concluded that Enschede's soil is rather impervious, considering clay usually has a coefficient higher than 5, and peat has a coefficient of over 8. As a result of impervious soil, Enschede has problems with high ground water levels. This contributes to material damage due to flooding [4]. This factor not only contributes to contextualizing the problem, but also shows that the soil of Enschede is not ideal for water buffering systems relying on infiltration systems.

Contributing to the problem, Enschede has been heavily paved over the years. Enschede is built on 1400 hectares of land which has been partially hardened as a result of road paving, premises and shops [5]. This situation and the developments as Enschede as a city are

depicted in figure 2. Because of the high amount of paved surface area, not all the water gets absorbed into the soil during peak rainfall moments.

The altitude at which the city of Enschede is built also contributes to the risk of water runoff in particular areas. Figure 2 shows a height map of Enschede. The eastern part of the city is roughly 44 meters higher compared to the lowest part of Enschede in the west. This slope in the city causes water to naturally flow and settle towards the western area of Enschede, making it a high-risk zone for floods.

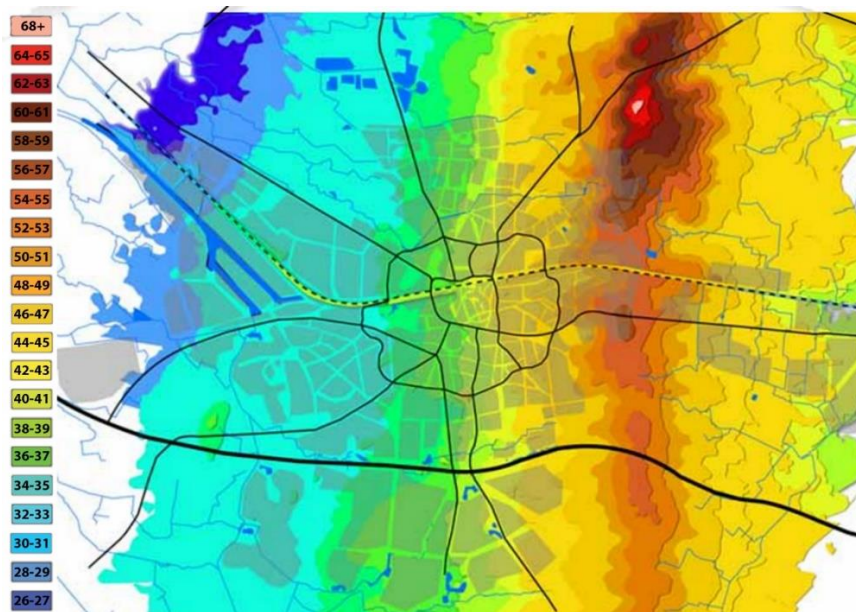


Figure 2: Height map of Enschede indicated in metres

Stormwater runoff causes significant negative impact to homeowners, the municipality of Enschede and (insurance) companies. Aside from property damage, urban stormwater runoff increases health risks to homeowners and inhabitants. Damage of property includes seal cracks or damage in foundation walls, windows, doors, basement flood damages, loss of irreplaceable items or plumbing failures [6]. Moreover, stormwater runoff erodes soil, ditches and stream channels leading to degraded water quality. As a result, aquatic habitats in nearby ecosystems can be adversely altered [7, 8, 9]. Lastly, stormwater runoff carries continued mobility issues for vulnerable areas of Enschede.

Appendix A shows a map of Enschede with the problem areas during heavy downpour marked. Red indicates water inside the houses of residents and companies. As it can be seen on the map, more than half of Enschede's streets are flooded during a storm. The only areas not flooded are the areas not in the center and the higher-up eastern area of Enschede. The focus for this project is on the area of the "Oldenzaalsestraat", marked purple on the map. An interview with the client showed that in this area, during a TS100-situation<sup>1</sup>, approximately 7.000 cubic meters of surface runoff floods the streets.

Rainfall is expected to be more extreme than in the past, leading to more cases of flooding with material damage as a result [10]. The goal in this project is to think of a buffering

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<sup>1</sup> Situation with the heaviest downpour in a period of a hundred years

solution for this problem. The surface of the targeted area comprises 154 hectares. Interviews with the client showed that roughly two-thirds of this area has been paved, which means about 100 hectares is paved. A solution has to be created that goes beyond the existing sewerage system as it is incredibly expensive to replace [11, 12]. Currently, every 70 years the sewerage system is replaced. The last time Enschede replaced its sewage system was 40 years ago, therefore with 30 years to go a more time-efficient solution needs to be employed.

## 2.2 Rainwater harvesting advantages

The first and foremost important aspect of buffering rainwater in Enschede is to reduce the threat of runoff. However, buffering rainwater is also an environmentally conscious action and can save the inhabitant of Enschede on their monthly water bill. Figure 3 shows a possible reduction in use of sanitized water by up to 57% [10], by reusing rainwater for different purposes in and around the house.

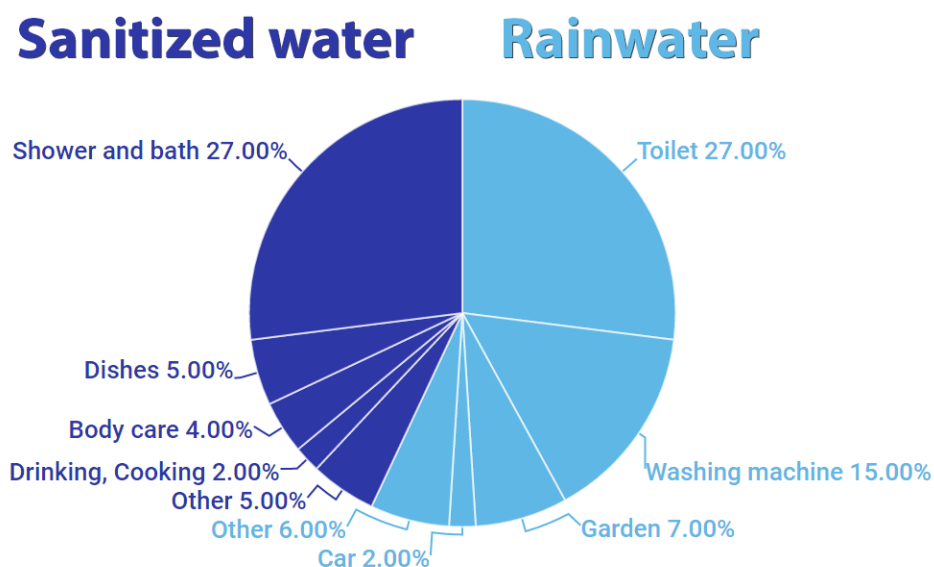


Figure 3: Sanitized water reduction [10]

## 2.3 Literature research method

In the following section, literature review is performed to explore the design space of relevant stormwater management solutions. Literature research terms were elicited by performing a brainstorm session and by conducting semi-structured interviews with the client.

The image described in figure 4 displays these search terms in a word cloud. Literature research was conducted using Scopus and Google Scholar. Additionally, the same key words translated to Dutch have been used to find more relevant papers to this projects' main research question.



*Figure 4: Wordcloud displaying used key words in literature research*

The matrix method of literature was a popular research method in the domain of health sciences [13]. This literature review method has been adapted since (R. Klopper et. Al, 2007), known as the concept matrix. The latter method was used in this project as the concept matrix is more flexible from an epistemological point of view, which benefits problem-based research in other domains where knowledge is of a conscious incompetence. The goal of literature review using this matrix is to refine knowledge on the subject, present to the reader a clear idea of the nature context of this research, to convince the reader of knowledge in the field and lastly to build a case for the empirical part of this study.

#### 2.4 Currently available solutions

This section introduces and explores solutions that are currently employed in tackling flooding. Two groups of solutions were identified, infiltration systems and buffering systems. Infiltration systems allow harvested water to slowly soak into the soil, and buffering systems are designed to retain rainwater. A conceptual checklist matrix [14], shown in figure 5, was used to analyze and link relevant literature in this section. Central themed search terms in this literature research have been listed in the top column to identify similarities and relevance between studies.

| Concepts                        | Stormwater / Rainwater / Rainfall | Homeowner | Drainage | Infiltration | Harvesting / Buffering / Retention | Runoff / Overflow / Flooding | Permeability / Filter / Porous | Soil | Paved / Pavement | Garden / Parcel | Urbanization / Residential | (LID) Low Impact Dev. | Cistern / Tank / Barrel | Roof(top) | Water management | Storm Water Management Model |
|---------------------------------|-----------------------------------|-----------|----------|--------------|------------------------------------|------------------------------|--------------------------------|------|------------------|-----------------|----------------------------|-----------------------|-------------------------|-----------|------------------|------------------------------|
| References                      |                                   |           |          |              |                                    |                              |                                |      |                  |                 |                            |                       |                         |           |                  |                              |
| (Trieu et al., 2000)            | X                                 |           |          |              |                                    | X                            | X                              |      |                  |                 | X                          | X                     | X                       | X         |                  |                              |
| (Smullen et al., 2005)*         | X                                 |           |          |              | X                                  | X                            |                                |      |                  |                 | X                          |                       | X                       |           | X                |                              |
| (Litofsky et al., 2014)         | X                                 |           |          |              |                                    | X                            |                                |      |                  | X               | X                          |                       | X                       | X         |                  |                              |
| (Steffen et al., 2013)          | X                                 |           | X        |              | X                                  |                              |                                |      |                  |                 | X                          |                       | X                       | X         | X                | X                            |
| (Jennings et al., 2012)         | X                                 | X         | X        |              |                                    | X                            |                                | X    |                  | X               | X                          |                       | X                       | X         |                  | X                            |
| (Chenevey and Buchberger, 2013) |                                   |           | X        |              |                                    |                              | X                              | X    | X                |                 | X                          |                       | X                       | X         |                  | X                            |
| (Schlüter and Jefferies, 2004)  | X                                 |           | X        | X            |                                    |                              | X                              |      | X                |                 |                            |                       |                         |           |                  | X                            |
| (Scholz, 2015)                  |                                   |           | X        |              |                                    |                              |                                |      |                  |                 | X                          |                       | X                       |           |                  |                              |
| (Monaghan et al., 2016)         | X                                 | X         |          |              |                                    |                              |                                |      |                  |                 | X                          |                       | X                       |           |                  | X                            |
| (Sandink, 2015)                 | X                                 | X         |          |              |                                    | X                            |                                |      |                  |                 | X                          |                       | X                       |           | X                |                              |
| (Jennings and Baker, 2015)      | X                                 | X         |          | X            | X                                  | X                            | X                              | X    |                  | X               | X                          | X                     |                         |           | x                |                              |

Figure 5: Conceptual checklist matrix showing literature with overlap

## 2.5 Infiltration systems

The first category of systems used against flooding comprises rainwater drainage, also known as infiltration systems. These solutions reduce rainwater runoff by allowing underlying soil to soak up as much of the rainwater as possible. By separating drainage of dirty water and rainfall, the water stress on the existing sewerage system is reduced [15].

### Permeable Pavement Systems (PPS)

Permeable pavement systems (PPS) use a base and subbase of sustainable materials that allow water to flow through this surface. An example is depicted in figure 6. These systems are designed not only to reduce runoff, but also filter pollutants from the water.



*Figure 6: Grass concrete tiles: a form of permeable pavement system*

Even though PPS are designed to collect and infiltrate surface runoff to support recharge of groundwater levels, PPS can be used solely for storm management purposes as well. These systems are cost-efficient, easily mouldable to tailor needs and have been applied in a wide variety of places. Permeable Pavement Systems can be found in car parking lots, on roads and other public spaces. However, such a system heavily relies on the permeability of the soil, therefore, it is not a suitable solution for Enschede

As a part of the European Union's climate adaptation project, Dutch, Flemish and British governments started an international cooperation project, Sponge2020. The goal and ambition of this project is to make densely populated cities fully capture or infiltrate all the rainwater. As a result of this project the municipality of Rotterdam installed a very similar system to the permeable pavement system: water buffering street tiles in Rotterdam's Agniese neighbourhood [16]. These permeable tiles allow water to pass through but instead of letting the water infiltrate, the tiles capture and buffer the rainwater. Installing a similar system would be a possible solution to tackle the intrinsic disability of Enschede's soil to absorb water.

### Infiltration Gallery

An infiltration technique used on private property is the residential infiltration gallery, depicted in figure 7. This effective stormwater management technique can be applied by homeowners [17] to reduce storm runoff.

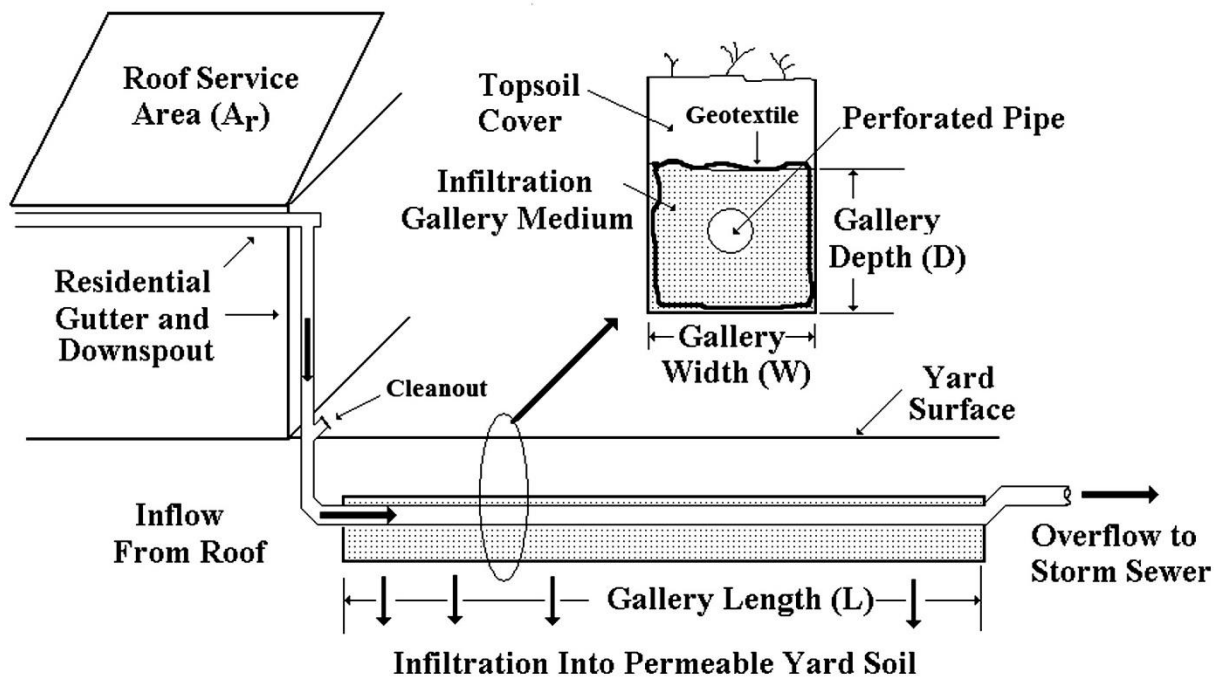


Figure 7: Schematic illustration of a residential infiltration gallery used to reduce stormwater runoff [17]

As can be seen in figure 7, the residential downspout is connected to a sub-surface perforated pipe. This pipe is situated in an infiltration medium, which also functions as a buffer. Lastly the overflow of this gallery setup leads to a storm sewer. One advantage of this system is the low-key nature of this system; it is placed below the surface which means there are no aesthetical drawbacks. Albeit more powerful, this system also relies on a relatively permeable yard soil. Such a system is ineffective in soil types comprised of clay and peat [18], therefore this is not an applicable solution in Enschede given its impermeable soil. Furthermore, this system requires digging out a garden to install it, which results in high installation costs and an inability to perform maintenance.

## 2.6 Buffering systems

Buffering systems can be used as an alternative to infiltration systems. These types of solution allow for the collection of rainwater. In rainwater harvesting scenarios for stormwater management benefits, the larger the volume of the buffering cistern, the higher the stormwater control potential [19]. Therefore, volume capacity is an important factor when looking at these types of systems.

### Downspout disconnection system

One way to buffer rainwater using a physical container is to disconnect the downspout from the sewerage system. Depending on the application and possibilities, this can be used as an infiltration system or as a buffering system by connecting a rain barrel to it. Figure 8 shows this system as an infiltration system using the homeowners' grass garden. Disconnecting the downspout connected to the roof gutter from the city's sewerage system provides a solution for reducing strain on existing infrastructures and redirects rainfall to a rain barrel or soil instead.

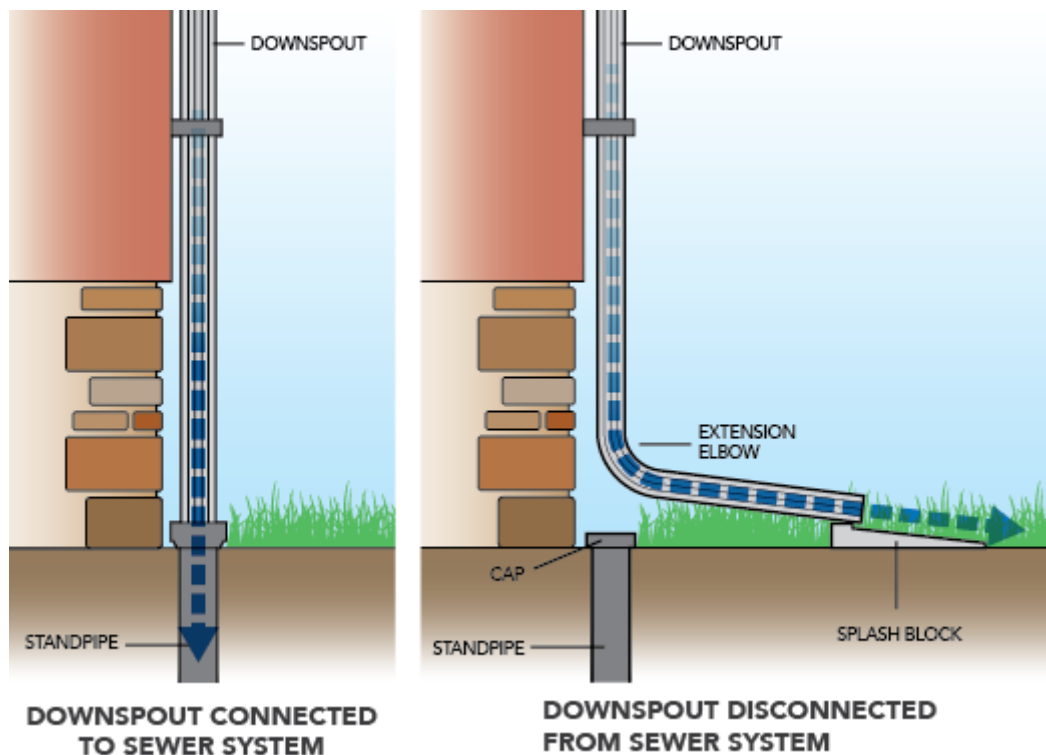


Figure 8: A connected downspout versus a disconnected downspout

One advantage of such a system is the moderate cost, but many home owners are reluctant to install such a system because this often merely shifts the problem: after heavy downpour, the home owner might be left with wet yards or leakage and mouldy basements [20].

Applicability to homes in Enschede and urbanized areas in general is limited. In the past decades, it became a trend for home owners in urban environments in The Netherlands to pave their garden with bricks, stones or other impermeable material, making this system unusable. Moreover, this system requires intervention of the homeowner. In case of heavy storm, the homeowner would need to switch the downspout manually once the garden is saturated, making it not an ideal or smart solution.

An intelligent disconnected downspout system was designed in 2015 by a group of Creative Technology students of the University of Twente called the Enskéton during a 24-hour brainstorm competition. This is essentially a smart disconnected downspout system that checks the local weather forecast and empties itself before heavy rainfall [21]. Such a system can be cost-efficient and controllable, but lacks high buffering capacity.

#### Stormwater ponds

Stormwater ponds are a way to buffer excess water. Installed in both urban environments and coastal areas, these ponds are made to provide flood control and water treatment. In coastal areas, these ponds drain directly to local estuaries such as ditches or streams in case of overflow. These ponds divert runoff not only by buffering water but also by means of evapotranspiration, evaporation and infiltration. Stormwater ponds differ from regular buffer systems applicable to homeowners' property as they serve an aesthetical function as well. Figure 9 shows an example of a stormwater pond in West Seattle in the United States.



*Figure 9: Example of a stormwater pond in West Seattle, United States*

According to Monaghan et al. [7], local residents' receptivity to such a system depends on age, attitude about water quality and whether their home is adjacent to a pond. It was concluded that awareness of the ecological function of stormwater ponds is present, however merely knowing this was not enough to convince homeowners to adopt such a system. Furthermore, homeowners seemed unwilling to go against the social norms of landscaping. These ponds are not a viable option as most home owners are not situated nearby a pond. A similar solution would be for farmers to create separation ditches that are able to temporarily buffer in cases of overland flow. However, both of these systems would only be applicable in the outskirts of Enschede. Furthermore, it is important to take note that homeowners are not seeking an intrusive system that might negatively alter the opinion that neighbours have of them [7].

#### Green roof

Green roofing is a hot topic in the Netherlands right now, and is promoted from various municipalities. Considered a hybrid buffering and infiltration solution, a green roof consists of a thin layer of substrate with a good buffering capacity, respectively covered by a layer of plants. About 50% of the rainwater can be buffered by this soil and it is eventually evaporated by the plants. An example of such a system is shown in figure 9. Using a 25 cm soil with thick plantation will buffer roughly 70 litres of water per square meter [22].



*Figure 10: Model of a series of apartments with a green roof installed*

Green roofing is sometimes applied to houses with an angled rooftop, but is considered highly inefficient because it loses its buffering function. On a flat roof, this is an effective solution, however there are considerable disadvantages to such a system. Because a green roof system weighs a lot, often modifications need to be made to a roof structure to improve the carrying capacity before it can be installed. A green roof also requires regular maintenance and safety modifications for the gardener that maintains these roofs [23]. Overall, the installation and maintenance of green roofs comes with substantial costs. Homeowners that do choose to install a green roof system often receive subsidy [24], lowering installation costs. The limited applicability makes this system unsuitable for the problem area in Enschede targeted by the municipality.

#### Water fence

This system is a commercial product which functions by redirecting water that pours on the roof to a hollow fence through the downspout and allows for its retaining [25]. Developed with the purpose of storing water in dry areas, hollow fences can also be used as buffering elements to capture and store storm runoff. Figure 11 shows an example of a hollow fence.



*Figure 11: Display of a hollow water-holding fence*

It is estimated that the service area of the average downspout includes 50% of the total roof area [26, 27]. This solution can be applied to any household with a garden without much effort. Furthermore, installation and maintenance costs are relatively low. However, this system is unsuited for stormwater management purposes unless water is allowed to flow out of the fence in case of overflow. The disadvantage of this system is the fact that it needs to be able to let water out, which can be tackled by implementing an intelligent system that empties the buffer when it's full.

### Wadi

A wadi is a mixed buffering and infiltration system designed in Enschede [28]. Wadis comprise of a grassy area, situated lower than the environment which retains water and a connection to this area. Water is often transported to a wadi using sewerage pipes. Figure 12 shows a wadi in action.



*Figure 12: A wadi retaining water in Enschede*

Water captured by a wadi infiltrates in the soil or water is transported to surface area water located nearby. A wadi is a sustainable system, as it prevents clean water to be transported to a sanitation facility. A wadi cannot be implemented on the premise of Enschede's inhabitants, though this is considered relevant as it is possible to connect a downspout to a wadi. Effectiveness depends on multiple factors, namely distance from premise to wadi and height difference between the premise and wadi. This can lead to high installation costs of connecting a downspout to an existing wadi, and issues with regulations concerning constructing in the public space.

## 2.7 Concluding problem analysis and literature review

Periodically, the strain on the sewerage system of the city is too high. Impermeable soil and the gardens of homeowners commonly being paved make the infiltration solutions explored in this chapter unsuitable for the city of Enschede. Existing buffering solutions are either not applicable to premises of inhabitants, are tough to implement or simply do not provide the buffering capacity required to solve the problems during downpour.

The Enskéton does not buffer nearly enough runoff to be applied, however it has the added value of being an intelligent solution that responds to external factors. On the other hand, the water fence has a higher buffering capacity but it lacks intelligence to function as a resilient adaptive system, as it does not have the means to let water flow out autonomously. Buffering water captured from a disconnected downspout in underground basins is effective but requires a considerable amount of labour to implement.

## 2.8 Novelty of the research question

The analysis of the problem leads to the goal of this project. This project aims to bridge the gap in research and practical work by offering a smart solution to flooding caused by rainwater. Thus, the research question for this project is formulated as follows:

*“How to develop a rainwater buffering system that reduces the strain on the sewerage system of Enschede and is distributed over the premises of its inhabitants?”*

In conclusion, it can be said that the main research question is novel, considering no solutions have been provided that are to be installed on the premises of the inhabitants and function as a resilient rainwater buffering system with sufficient buffering capacity. Using a disconnected downspout system combined with intelligent storing of the water could provide the smart, adaptive solution the client asks for.

### 3 Methods and techniques

This section describes methods and techniques used in the ideation, specification, realization and evaluation phases of this project.

#### 3.1 Creative Technology Design Process

The creative technology design process [29] served as a guideline for this graduation project in terms of planning, implementation and documentation. As can be seen in figure 13, this design process consists of four larger phases: Ideation, Specification, Realization and Evaluation. These four phases are further elaborated on, in chapter 4 to 7 in this report.

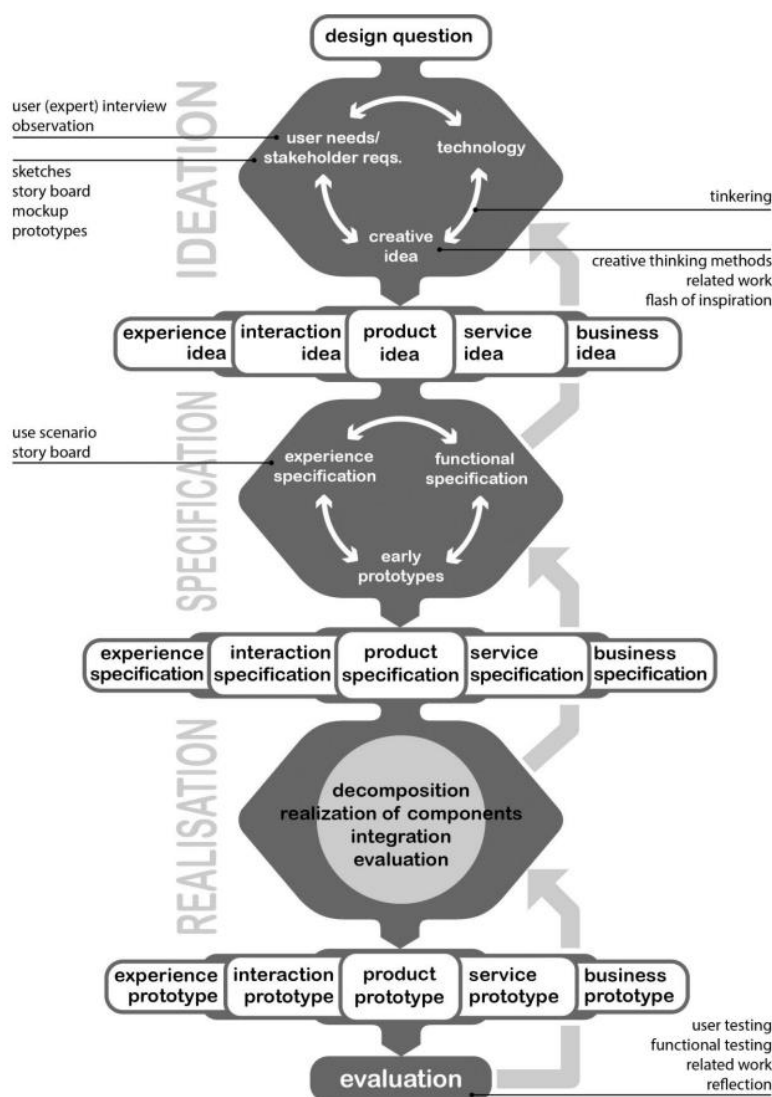


Figure 13: Illustration of the Creative Technology design process

The general design question of this project was determined through initial interviews with the municipality and the regional water authorities and an intensive technological background research, found in chapter 2 – State of the Art.

For the ideation phase the starting point was an order from the client, the request for a smart rainwater buffer that is distributed over the premises of Enschede's inhabitants. After

brain storm sessions and concept generation, a design idea was decided on in the ideation phase (chapter 4). To converge, the five most promising ideas have been visualized and presented to the municipality of Enschede, which then chose a single idea to elaborate on. This convergent phase set the transition point to the specification phase.

In the specification phase, a number of low-fidelity (lo-fi) and high-fidelity (hi-fi) prototypes has been made to explore the design space, and realise a feedback loop through a short evaluation with the client and relevant stakeholders.

In the ideation phase, system requirements, stakeholder elicitation and a PACT analysis are described, following a description of the realization of the prototypes mentioned in the specification phase. Next, these prototypes are presented to the client, the municipality of Enschede. Based on this assessment and evaluation, changes might have to be made, features discarded or improved upon, resulting into a transition into a high-fidelity prototype.

A high-fidelity (hi-fi) prototype is built in the realization phase (chapter 6) using proven methods of engineering design. Iterative and incremental development was used to design and improve this prototype, allowing for backtracking in the case of faulty decisions. Initial evaluation should show whether the end product met the specification.

In the evaluation phase, functional testing and user testing is performed to assess whether the final prototype meets the system requirements.

### 3.2 Requirements Elicitation

Both functional and non-functional requirements for the intended system have been collected using two methods and techniques: interviews and literature research.

Multiple interviews with the most important stakeholders led to a draft of the functional and non-functional requirements. The most important stakeholders for eliciting these requirements are listed in the influence-interest matrix under chapter 4 - stakeholder analysis.

These stakeholders are: the municipality of Enschede, regional water authorities Vechtstromen and the University of Twente. The most important requirements of the system are reliability, low-maintenance, low cost in that particular order as specified by the client.

Several system requirements have been listed as a result of literature research, described in chapter 2 – State of the Art. Additionally, the author gave his expert opinion in the field to set clear boundary conditions and add requirements that were deemed missing after performing aforementioned methods for requirements elicitation.

### 3.3 MoSCoW

In new design projects, there is always more to do than is possible in the set timeframe or funding. In order to assess which functional and non-functional requirements are most vital and distribute work accordingly, the MoSCoW method [34] was used. All requirements for

this project are divided in one of the following categories, in order of importance.

**Must** have: Non-negotiable critical must-have attributes or features. Even if one must-have requirement is not included, the project delivery should be considered a failure.

**Should** have: Important and if possible, these features should be included.

**Could** have: Less critical, “nice to have” features that could be added to improve user experience or satisfaction.

**Won’t** have: Least critical, lowest payback attributes, or ‘Would like to have in the future’.

After eliciting the initial functional and non-functional requirements in chapter 4 – Ideation, system requirements have first been re-evaluated by means of review and expert opinion and, following this, subdivided in order of importance using the MoSCoW method in chapter 5 – specification.

### 3.4 Stakeholder Analysis

The development of a new product for a client starts with a good understanding of the requirements for this product. Requirements elicitation is the process of making explicit the (latent) requirements for a new product preferably with their priorities. However, requirements elicitation may not be limited to the client, there may be more parties involved in the development process.

Every party (including the client) involved in the requirements elicitation process is a stakeholder. The challenge is to identify stakeholders relevant for the development of the product. Therefore, we adopt the stakeholder identification in the requirements engineering process from Sharp et al. [31].

### 3.5 Concept generation

Two brainstorm sessions were performed by the author to think of as many concepts as possible. The author chose to use the technique of making mind maps, to explore the design space using associations that branch off from a central idea. This map can be found in appendix B. Brainstorming as a way of concept generation defers judgment and reaches for divergence, stimulating idea generation and creativity.

Next, in order to diverge, the author made a choice to narrow down the concepts to five concepts. These concepts were drawn digitally as mock-ups, as visualizing concepts helps create a clear mental image. Moreover, it is a powerful tool to convey ideas during concept presentations to the client.

### 3.6 iPact analysis

An iPACT analysis was made in order to work out a typical user perspective scenario, considering Intended use, People, Activities, Context and Technology [32, 33].

Intended use describes to what problem the intended system is applicable to. People describes the background and competence of the user(s). Context describes the environment in which the intended system will be applied to, in this case the average household is described. Activities describes how the user intends to apply the system.

Technology describes the features of the technology and how the users will interact with the technology.

### 3.7 Demonstrating the prototypes

Demonstrations of the system were split up in two parts. First, the system is shown running in the background, which showed the system in an equilibrium situation. Secondly, a run-through of the system in an emergency situation was presented. In this scenario, heavy rainfall is expected and the system will adjust itself accordingly. Only 50 litres of water will be discharged by the system to simulate how it works.

### 3.8 Evaluation

Evaluation is performed using client and stakeholder feedback from demonstrating the final prototype of the intended system, and by assessing the functional and non-functional requirements in a demonstration setting by the author. These two techniques should give an insight whether all the original requirements identified are met, and whether the decisions taken by the author satisfy the interests of client.

## 4 Ideation

Chapter 2 – State of the Art concludes there is a need for a novel system that can buffer rainwater, that reduces the strain on the existing sewerage system of Enschede and is also distributed over the premises of its inhabitants. Methods include setting (preliminary) requirements, brainstorming, visualizing concepts, decision making through the use of interviews and lastly an iPACT analysis.

### 4.1 Stakeholder identification and analysis

The influence and interest analysis of each stakeholder in this project have been analysed using an interest-influence matrix, shown in figure 13. The inhabitants of Enschede are rated highest in terms of influence and interest because these end-users are to operate and maintain the intended system. The primary contact person from the municipality of Enschede is Hendrik-Jan Teekens. Meetings with the client showed that the municipality has plans to use financial stimuli in the form of subsidy or lower taxes to the inhabitants of Enschede in order to encourage the adoption of the intended system, therefore they are rated high on terms of influence. As they are the initiators of this project, with responsibility of solving the problem of regular stormwater runoff, the municipality scores maximum on the scale of interest.

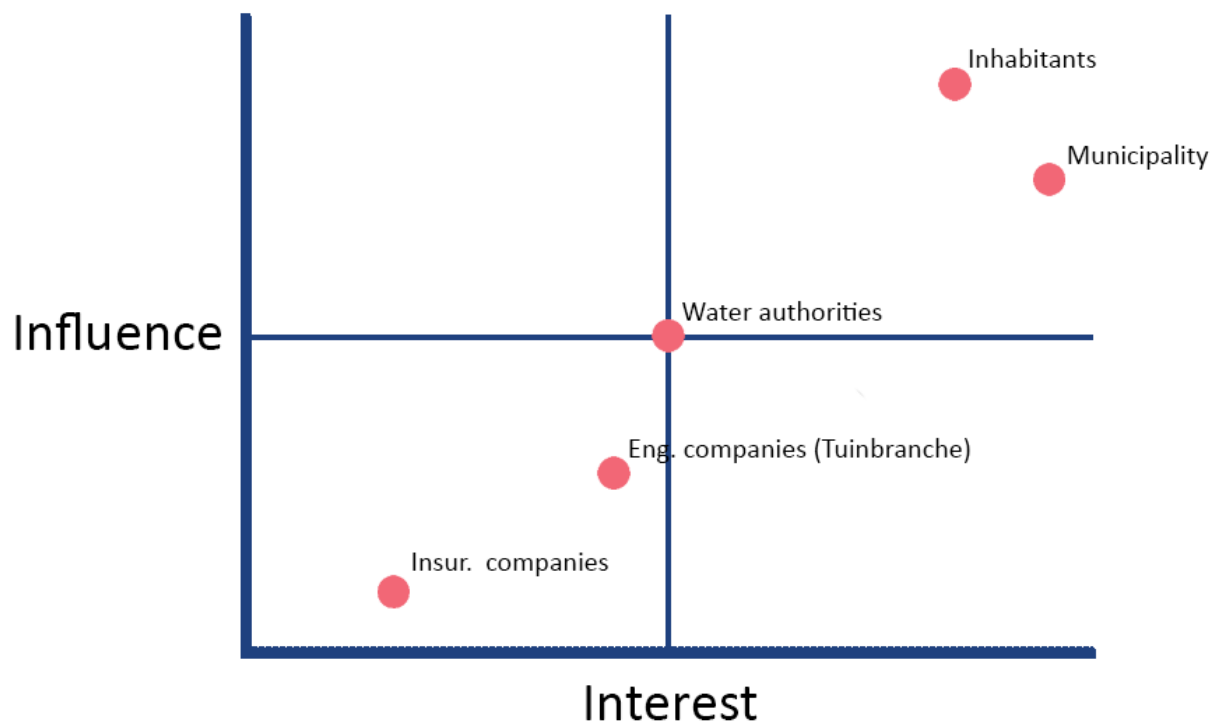


Figure 13: Influence-interest matrix showing roles of different stakeholders in this project

Sharp et al. [31] separate between two types of stakeholders: baseline stakeholders and satellite stakeholders. Sharp et al. identified four groups of baseline stakeholders: users, developers, legislators and decision-makers, as can be found in appendix C. The primary focus lies with baseline stakeholders in this project; satellite stakeholders are not expected to have an effective impact on the outcome of this project.

## 4.2 Functional and non-functional requirements

As described in chapter 3 – Methods and Techniques, these preliminary requirements have been elicited as a result of interviews and literature review. System requirements have been split in two categories: functional requirements and non-functional requirements. In the second iteration of system requirements, listed in chapter 5 – specification, requirements will also be categorised in order of importance using the MoSCoW method [34].

### Functional requirements

- The system should be able to buffer rainwater
- The system should be automatically regulated
- The system should be able to empty the buffer autonomously
- The system should be able to handle a throughput of a least 2000 litres per hour (see specification)
- The system should be modular
- The system should be adjustable from a distance
- The system should drain buffered rainwater without the possibility of damaging land or property

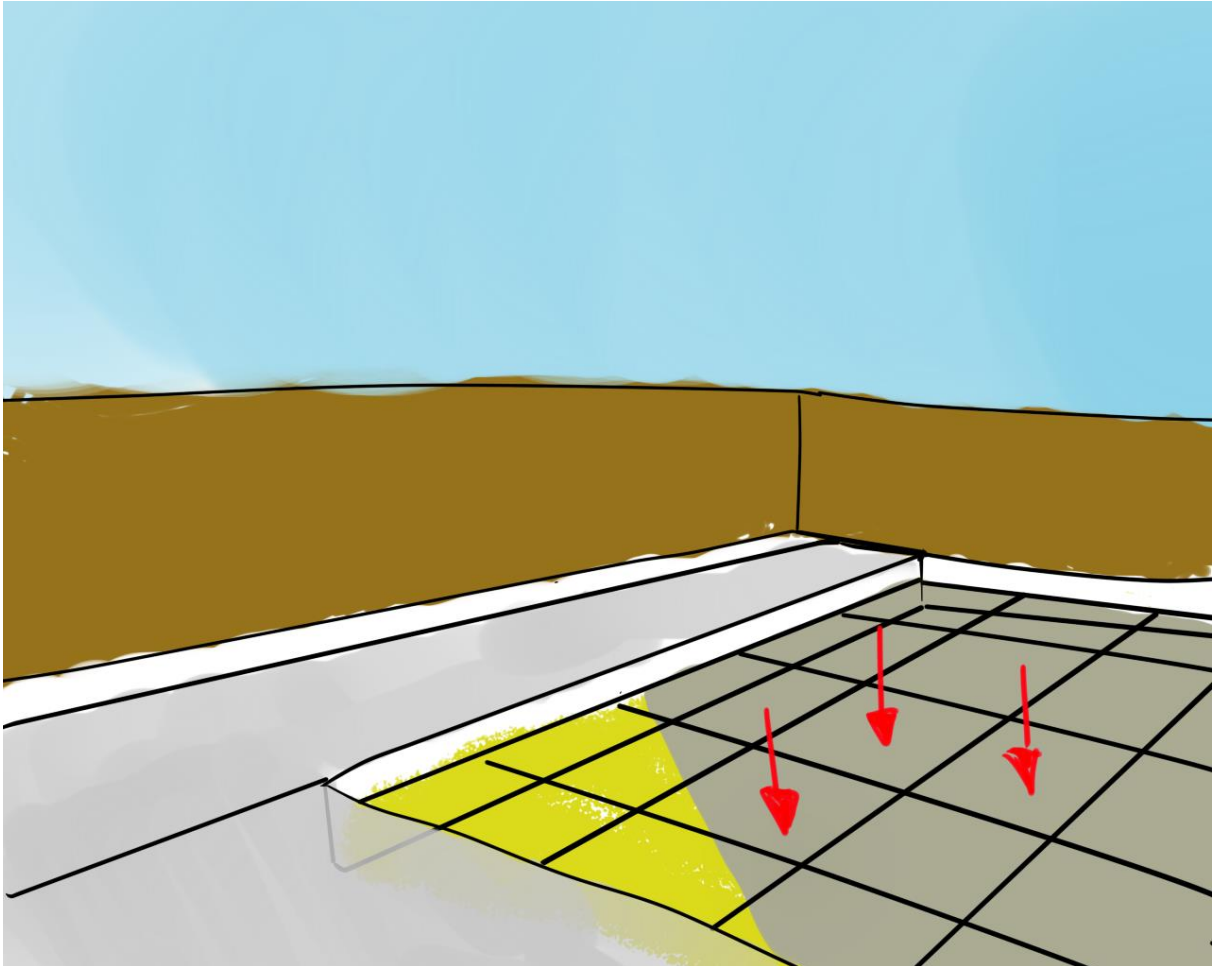
### Non-functional requirements

- The system should be scalable
- The system should be weather proof (ip65+)
- The system should be durable
- The system should require low maintenance
- The system should be economically efficient
- The system should control the water flow using valves
- The system should make use of a network in order to receive weather updates and to be regulated externally
- The system should buffer rainwater without leaking
- The system should be able to control water flow
- The system could make use of the LoRa network [35] to communicate

### 4.3 Concepts

Before developing concepts, a two-part brainstorm session took place. The result of this brainstorm can be found in Appendix B. Next, five of these brain storm ideas have been developed into concepts. These concepts are further described in this section.

#### 4.3.1 Garden sponge

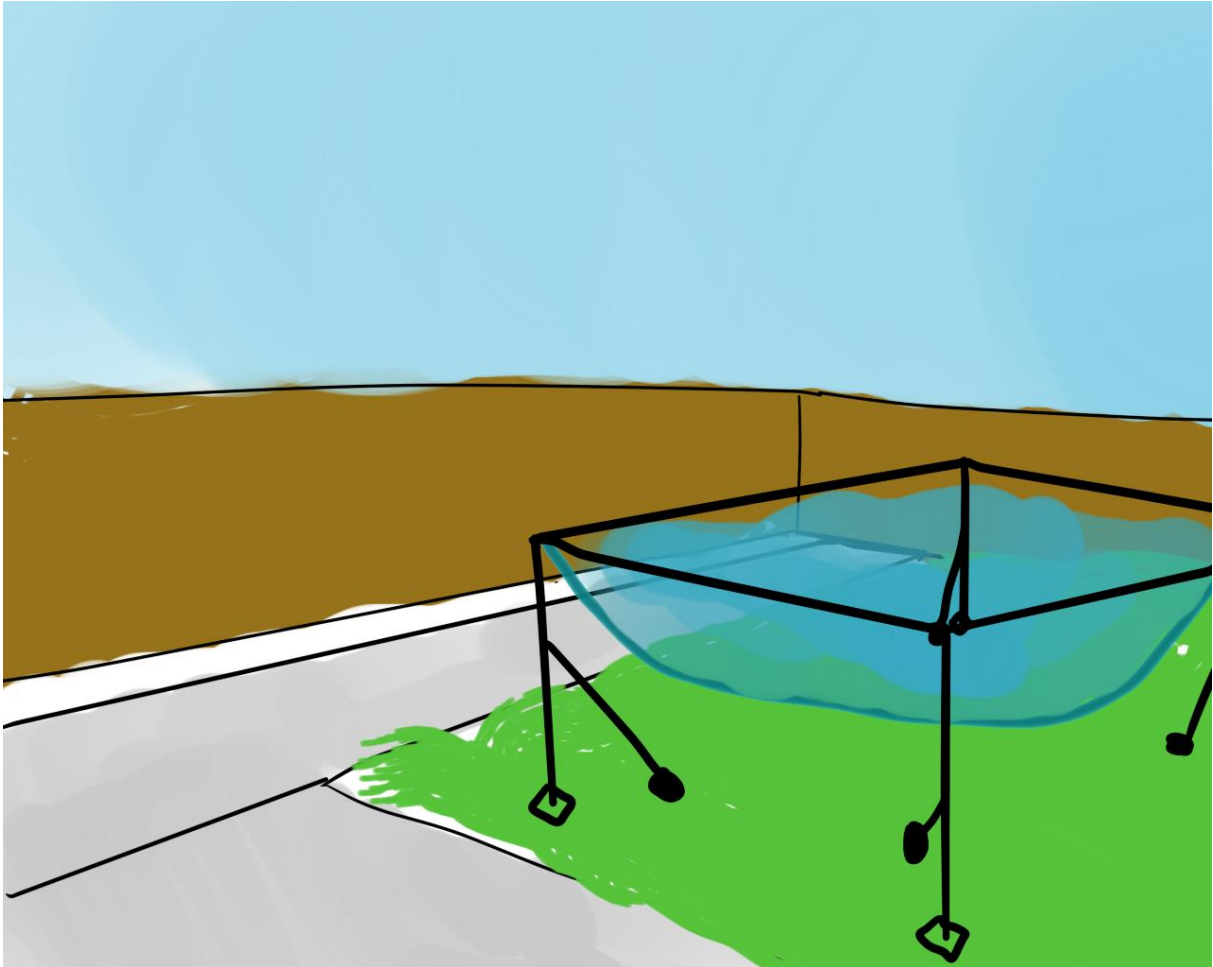


*Figure 14: First concept, displaying a garden holding a massive sponge*

Figure 14 displays a mock-up of the first concept. This solution is a hybrid buffering and infiltrating solution. Rainwater flowing along garden tiles is absorbed by a large sponge under the garden tiles. The garden needs to be dug out first, after which a large shallow sponge gets placed and tiles can be place on top of the sponge with holes in them. During rainfall, the sponge will absorb the water and slowly infiltrate this into the soil below.

Considering the average garden in the targeted problem area is 40 square meters, a 10 cm thick sponge installed throughout the whole surface of the garden could buffer roughly 4000 litres.

#### 4.3.2 Emergency balloon



*Figure 15: Second concept, inspired by the idea of a foldable party-tent*

Figure 15 describes the second concept. This second concept shows a portable, deployable solution in the form of an inverse party tent that buffers rain water.

Right before or during expected downpour this foldable system can be taken out of the shed and quickly set-up. The design is similar to a party tent, with a rubber material that stretches under the pressure of the water weight that it catches. The basic construction consists of four poles, a rubber material in between and a tap at the middle or bottom of the material. The advantage is that this solution is cheap and doesn't require any adaptation or space.

An average sized emergency balloon is 3x3x1 meters. The volume of a cuboid yields a maximum buffering capacity of roughly 9000 litres.

#### 4.3.3 Hollow plastic trees

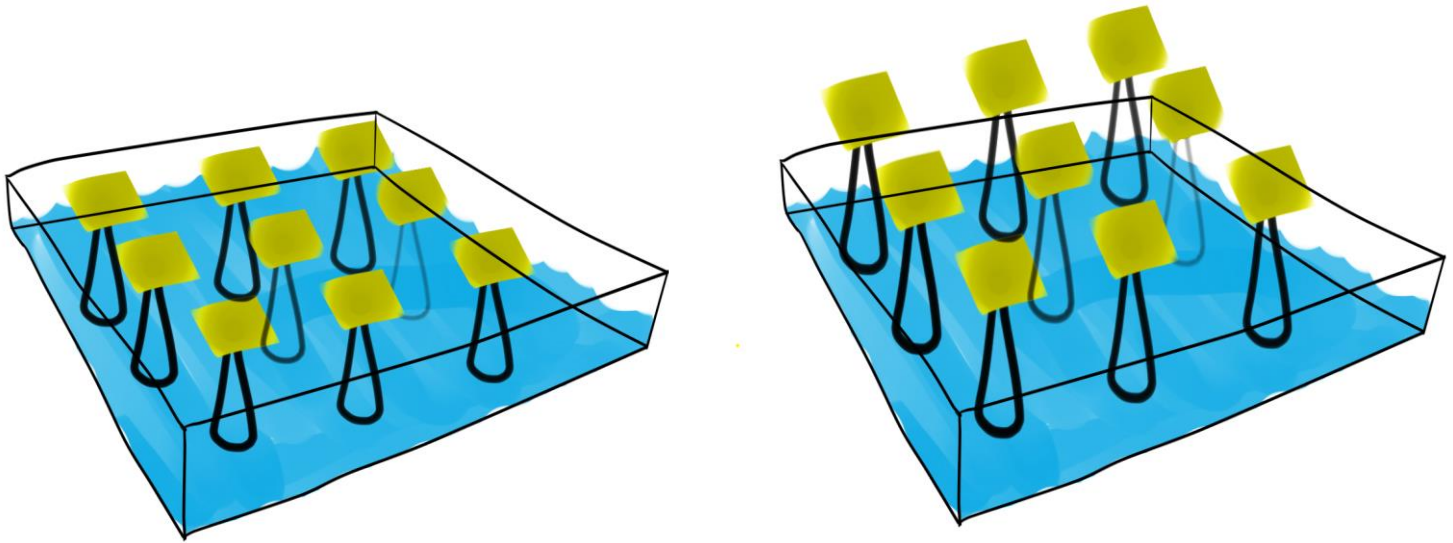


*Figure 16: Third concept, displaying an artificial tree that harvests water*

Figure 16 displays a plastic tree that uses the width of its branches to harvest water. An assortment of hollow plastic trees and bushes can be placed in the garden which catch rainwater. A fake tree with branches that reach out and a thick hollow base can store a substantial amount of water. Water flows from the branches, hanging plants and other type of real plants can be hung from the branches of the hollow tree which also absorb some of the water and might give the tree more of a natural appeal.

A hollow tree with a height of two meters and a diameter of one meter is able to buffer roughly 1570 litres of water.

#### 4.3.4 "Bed of nails" buffering tiles



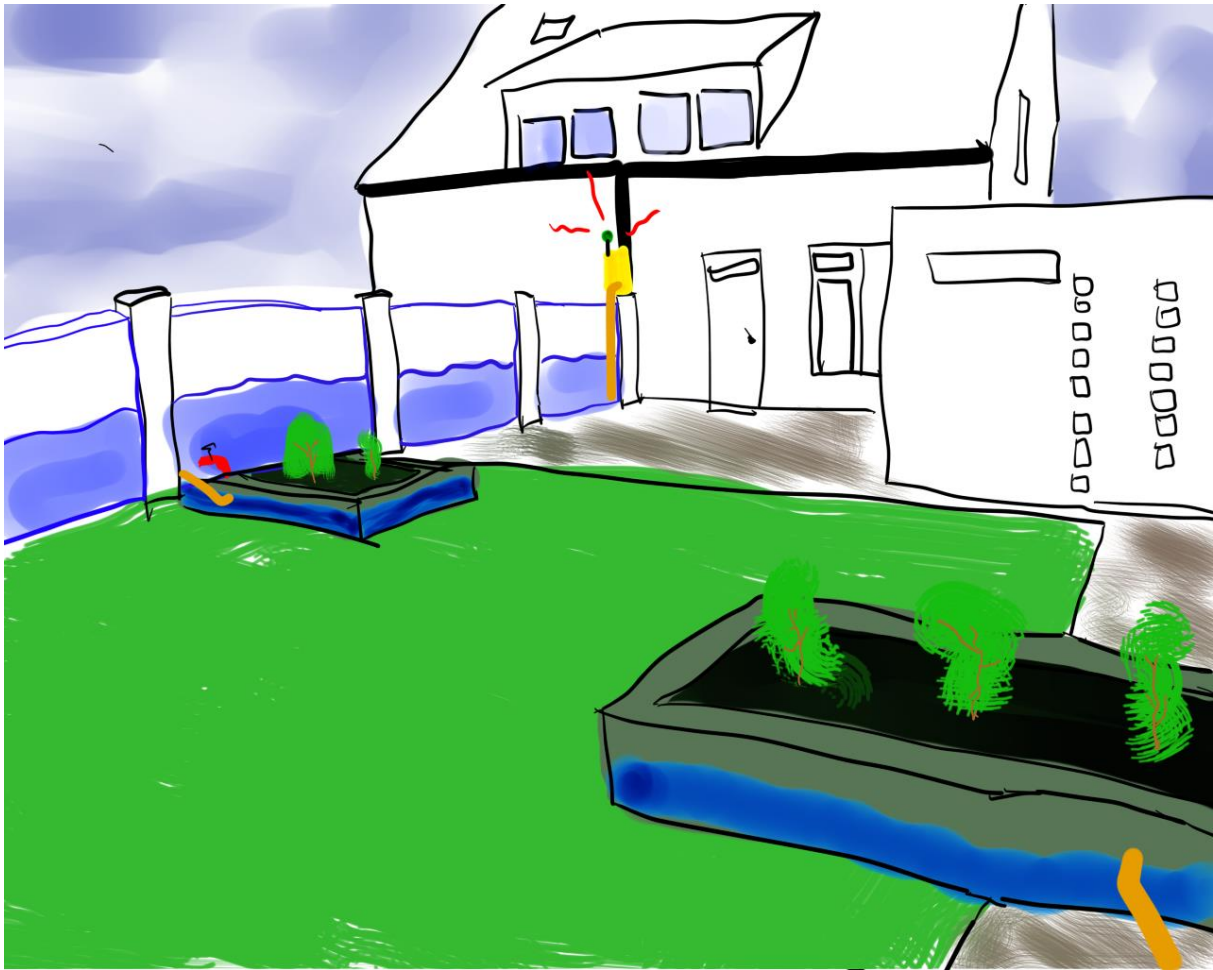
*Figure 17: Fourth concept, displaying concept buffering tiles in two conditions: down and up*

Figure 17 shows tiles that buffer rainwater. These tiles have nine retractable elements that pop up in times of heavy rainfall. This way, the garden can be submerged in water, but homeowners can still walk in their garden by stepping on these yellow elements.

These yellow elements are plastic elements able to withstand force, as they are meant for walking on. A requirement is for the garden to have a border around the outer edge of the tiles, to be able to submerge the tiles. The tiles have holes in the bottom for the buffered water to infiltrate into the soil after a downpour.

As a result of measurement, the average garden in the targeted problem area in Enschede counts 40 square meters. With a buffering capacity of 10 cm per tile, a fully paved garden with this system could buffer up to 4.000 litres of rainwater.

#### 4.3.5 Smart Rainwater Buffer



*Figure 18: Fifth concept, displaying a garden with buffering elements in the form of a fence and plant holders, and a control system near the downspout*

A final concept is displayed in figure 18. This is a modular system which buffers water that falls on the roof of a house in containers with different shapes. A core element is the hollow fence. Elements can be linked together to create one big buffer. Ponds, garden furniture, bases for plants, hollow trees can all be connected to this system. The intelligence for this system is within the automated regulation at the downspout.

Instead of a standard-sized wooden fence, a hollow fence can be placed with the same dimensions between the industry standard pillars already present on the premise. Each fence element with standard dimensions of 14x180x180 can buffer roughly 450 litres of water. Using solely fence elements, the average garden of 40 square meter could hold up to 4050 litres of water.

#### 4.4 Conclusion

These concepts have been presented at the municipality of Enschede. The client decided the Smart Rainwater Buffer concept has the most potential, as it offers ease of use and a great buffering capacity. Another advantage about this design is the fact that it allows for easy drainage of the buffered water.

#### 4.5 iPACT analysis

As described in 3 – Methods and Techniques, an iPACT analysis has been applied to demonstrate a typical use case scenario in the intended context.

Figure 19 displays an iPACT analysis for the intended system. “People” have been described by comparing house prices in Enschede. It can be concluded the average household consists of a family from middle to upper-middle class. “Activities” has been described by looking at system functionality. “Context” has been described by looking at houses in the targeted problem area, marked purple in appendix A. The typical home in this targeted area is either a terraced house or a semidetached house with an average garden size of 40 square meters. This lower area in Enschede has been defined by the municipality of Enschede because there’s a large runoff of 7000 m<sup>3</sup> during heavy downpour. Using google maps it has been determined these houses mainly have pointy roofs. “Technology” has been described from the end-user perspective in this scenario.

| Scenario title                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Heaviest downpour of 2016</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| <b>Scenario Type</b><br>Use case scenario                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Rationale</b><br>This scenario has been developed as a part of the design process of this thesis. It is intended to give a rich description of a general context use case scenario of the proposed Smart Rainwater Buffer (SRB) system. The intention of this system is to buffer rainwater, in order to reduce stress on the existing sewerage system during times of peak rainfall. Homeowners in targeted problem areas in Enschede experience damage to property and safety hazards during a downpour. Homeowners are looking for a solution on their property which is not intrusive to their garden. Moreover, homeowners might appreciate the possibility of living more sustainable: tapping buffered rainwater to water the plants or the car.                                                                                                                                                  |
| <b>PACT analysis</b><br><u>People</u> – A starter family of four in their mid-thirties, well educated, able-bodied. The family members are not technically inclined, but know how to operate a computer and smartphone.<br><br><u>Activities</u> - Using the system to buffer all the rainwater that falls on their roof during the heaviest downpour of the year. Then, buffered rainwater is used to water the garden.<br><br><u>Context</u> – Living in the Willem Alexanderstraat in Enschede. This area is well-known to have had issues with water flooding the streets periodically in the past, because this street is situated in a lower part of Enschede. Their garden measures 8 by 5 meters, about the same as their neighbours’ garden. They have a pointy roof with a downspout in the front and in the backyard. An industry-standard wooden fence shields off the backyard from outsiders. |

Technology – The Smart Rainwater Buffer (SRB) envisaged as a standalone system that requires little to no interaction to function properly.

At the core of the intended system is a controller that autonomously opens and closes the buffer by means of a valve, based on the weather forecast. The homeowner can interact with the intended system in several ways: he can remotely empty the buffer from a pc or tablet, he can manually open the side taps of the buffer to water the plants and lastly, he can set the idle water threshold – the amount of water stored for gardening purposes.

### **Scenario**

Petra and Jos are a couple in their mid-thirties with a daughter of eleven and a son of eight. Petra is a social worker and Jos is a teacher of a high school. They live in a problem area concerning rainfall in Enschede, the Willem Alexanderstraat. They moved there five years ago and every year they had problems with stormwater runoff into their house. This year they decided to purchase the Smart Rainwater Buffer (SRB), which Jos placed himself on a Saturday afternoon. It was a relatively easy job: the fencing slats slid right into the existing concrete fencing base poles. He then needed to cut the existing downspout off to connect to the new hollow fencing system to finish installation. In autumn, the heaviest downpour of the year hit Enschede. The SRB emptied itself beforehand with an electrical valve and automatically buffered half the water that fell on their roof during the downpour, a registered 1800 litres. Petra and Jos weren't alone in purchasing this system, a lot of neighbours of Petra and Jos purchased the SRB this year. The neighbourhood was surprised to notice the streets weren't flooded this time. In the days after, Petra and Jos' system slowly releases 1600 litres of water back to the sewerage system, leaving 300 litres of water for Jos and Petra to water the plants.

*Figure 19: iPACT analysis of the Smart Rainwater Buffer*

## 5 Specification

In chapter 4 – Ideation one concept of an intended system has been chosen by the client. In this chapter, this concept is further analysed and elaborated upon by proposing a setup with functional design, including system specifications. Then two iterations of a lo-fi prototype will be discussed, transcending into two high-fi prototypes later.

### 5.1 Proposed setup

An outline of the proposed setup is given below in a bottom-up approach. Choices for individual elements and their dimensions are discussed in this section. Client interviews pointed out that the proposed solution has to be functional, require low maintenance and be cost-effective.

The standard measurement for a concrete fencing slat base pole in the Netherlands is 10x10 centimetres [36]. The standard measurement of a fencing slat is 180 cm x 180 cm [37]. Figure 20 shows the dimensions of the proposed fencing element. An inner diameter of 14 centimetres was chosen. Consecutive fencing elements connect to each other with a 3.2 cm pipe on the bottom side. The maximum buffering capacity per element consists of 450 litres per fencing slat element. The material used will be plastic. Material thickness and strength of material has to be further researched. An inner diameter of 14 centimetres is determined to ensure high buffering capacity whilst not taking lots of space.

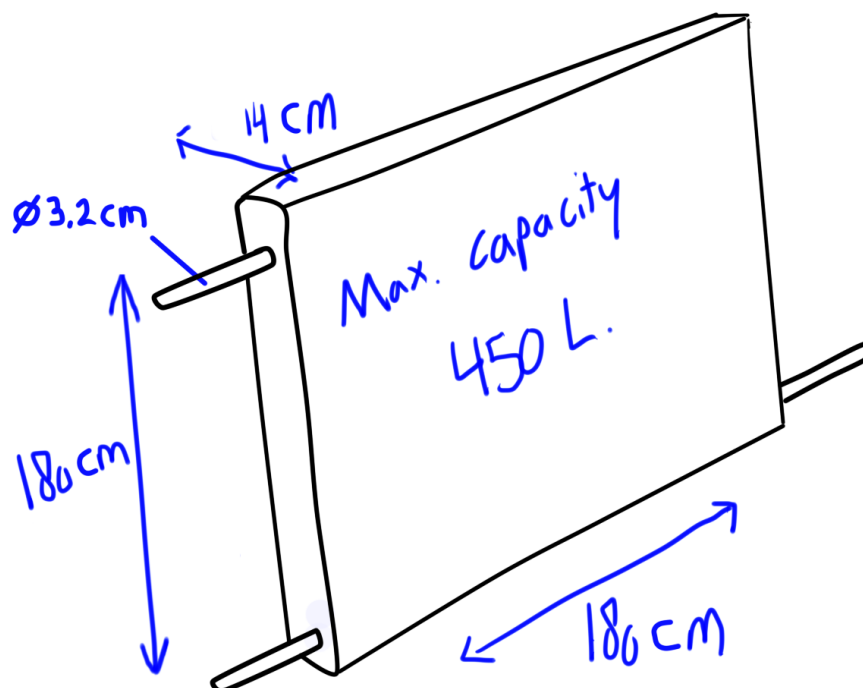


Figure 20: Dimensions of a single fencing element

There are two ways to link the elements in this system together, displayed in figure 21. In a cascaded setup, rain will flow to the next buffering element as the previous element fills up. An advantage of this setup opposed to the second setup is easier installation, as the latter elements in the chain will hardly be used. In a parallel setup, the elements are connected

openly at the bottom side, allowing water to flow through. Water levels will be even. An advantage of parallel over cascaded is the fact that only one valve is required, whereas every cascaded element needs to have an own valve, in order to let water out.

The client decided the system would need to be engineered in a parallel-type fashion because cascading would require too much maintenance and the system would be more error-prone in a cascaded setup in case of congestion. Moreover, the costs of a cascaded system would be significantly higher because of the requirement of a separate valve for every element. A cascaded system does not allow for water to flow back into the sewerage system. The suggestion was made by the client not to use any valves but to use narrow-diameter pipes that have a low throughput, which will dump the water back into the sewerage system over time. This suggestion was made to keep the system reliable. This is not considered viable because control of water flow out of the system is lost without a valve.

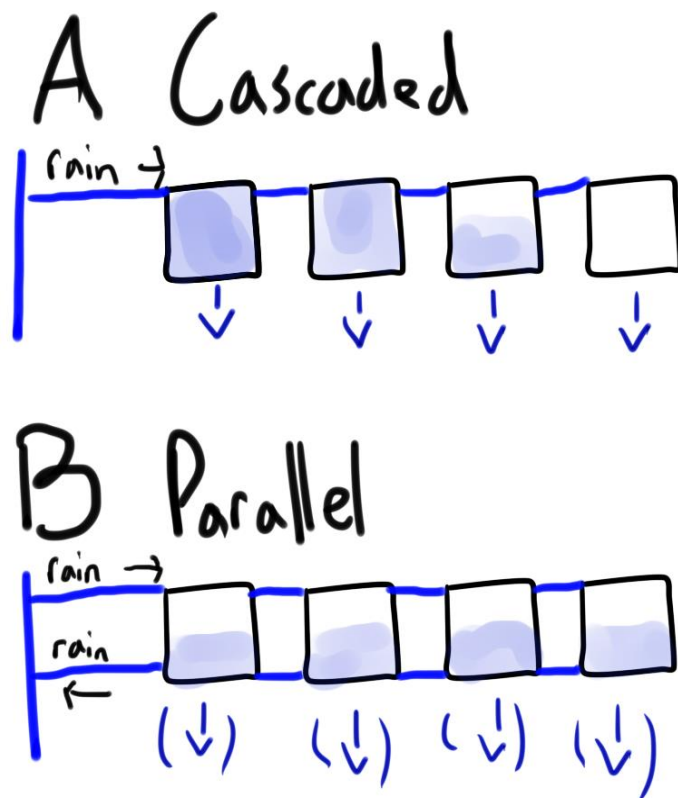


Figure 21: Cascaded versus Parallel fencing setup

It was determined through the use of satellite images that the typical garden size is 40 sq. meters for the houses in the targeted problem area that are in possession of a garden. A simple setup in a typical garden is shown in figure 22 to illustrate a typical maximum capacity. Assuming the fences in the length of the garden are shared with a neighbour, the capacity is at least 2700 litres. This simple example is illustrated without the use of any other modular elements such as rain barrels, hollow flower pots or other types of hollow garden furniture which add to maximum capacity.

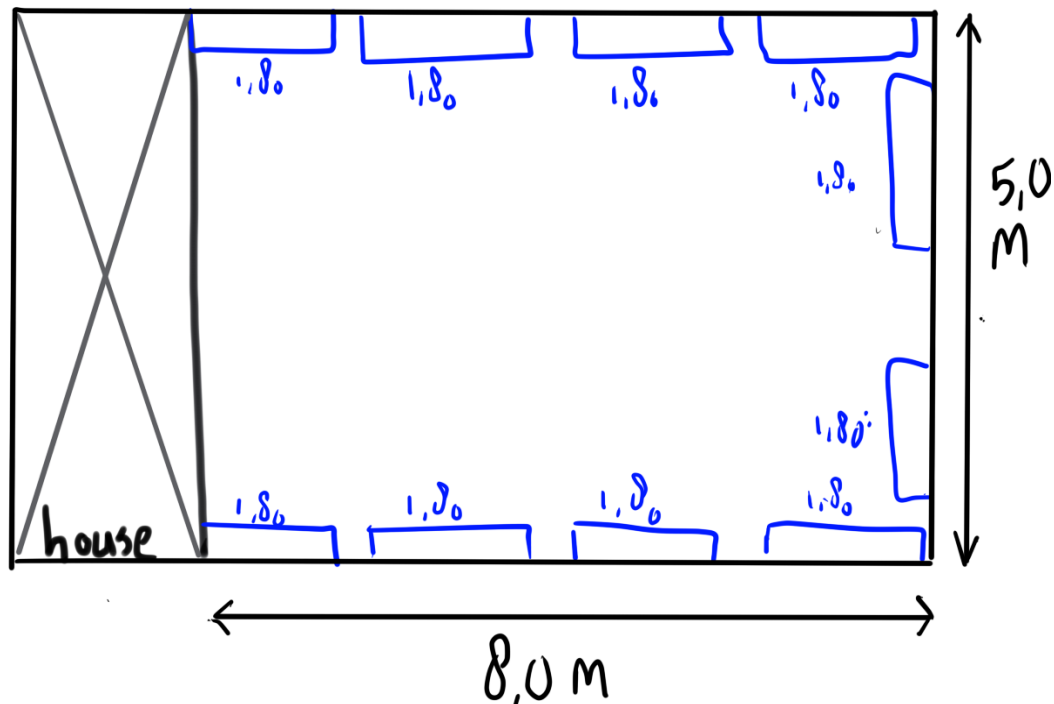


Figure 22: Typical setup in a 40 square metre backyard

An estimation has been made that determined there's roughly 3500 parcels in this area. Using satellite pictures in google maps, an estimation has been made for the average surface area of the roofs of the houses in the aforementioned problem area. Using these satellite images 50 different roofs of resident houses in the area Oldenzaalsestraat have been measured, and average out to roughly  $70 \text{ m}^2$  per roof per house with a backyard.

Interviews with the client showed there's a surface runoff of  $7000 \text{ m}^3$  of water in this problem area during the heaviest downpour of last year. In order to buffer all this water, 28,5 litres of water per  $\text{m}^2$  of roof surface would have to be buffered. If all houses in this area would need to buffer all this water, the average house with a roof of  $70 \text{ m}^2$  should buffer  $2 \text{ m}^3$  or 2000 litres of water during occurrence of extreme downpour. This is made given the assumption that rain falls straight down, without the influence of wind.

Predictions from the municipality of Enschede show that in a situation with an occurrence of  $T = 100$ , once in the hundred years, there's a downpour of 40mm in Enschede in 75 minutes time. The total amount of water that will fall on the roofs in this problem area in this period of 75 minutes is  $(70 \cdot 3500) \cdot 0,04 = 9.800 \text{ m}^3$  of water. Per average roof of  $70 \text{ m}^2$  this is 2800 litres of water.

In conclusion, it can be said the throughput of the valves need to be able to handle at least 2800 litres per 75 minutes, or 2240 litres per hour.

#### Throughput

It is important to choose a valve width which can handle the necessary flow at peak times. Choosing the valve with too narrow can result in a too low throughput or clogging of the tubing. Choosing it too wide causes higher costs. As calculated earlier on, the average roof needs to be able to handle a throughput of at least 2240 litres per hour.

Throughput Kv [38] is defined as:  $Kv = \sqrt{\frac{Q(l \text{ per minute})}{F_{gl} \times F_{sg}}}$

With Q as the wanted volumetric throughput measured in l/min, Fgl as the throughput factor for water and Fsg as the relative density. The desired minimum throughput is 33,33 litres per minute, which relates to a minimum diameter of at least 13mm. A diameter of 13mm will be able to handle a throughput of 3000 litres per hour at a pressure of 1 bar. Because at this width the leads could easily clog with dirt, a minimum width of 30mm is desired. Choosing this width will ensure the leads won't get clogged easily.

### Filtering

To minimize the chance of clogging and to reduce maintenance intervals, filtering of the rainwater is a necessity. A coarse filter is placed on the existing downspout to filter out larger dirt such as leaves. Secondly, a fine filter of 500 micrometres is proposed to filter out the smaller dirt [39].

## 5.2 Functional Architecture

In order to get a clear understanding of the intended functioning of the system, two decomposition layers have been made. Figure 23 shows the functional architecture of this system as a 'black box'. The forecast data and system setup data are inputs, as well as end-user and administrator overrides, and the system outputs effectuation in the form of valve actuation, posting of performance data and error messages.

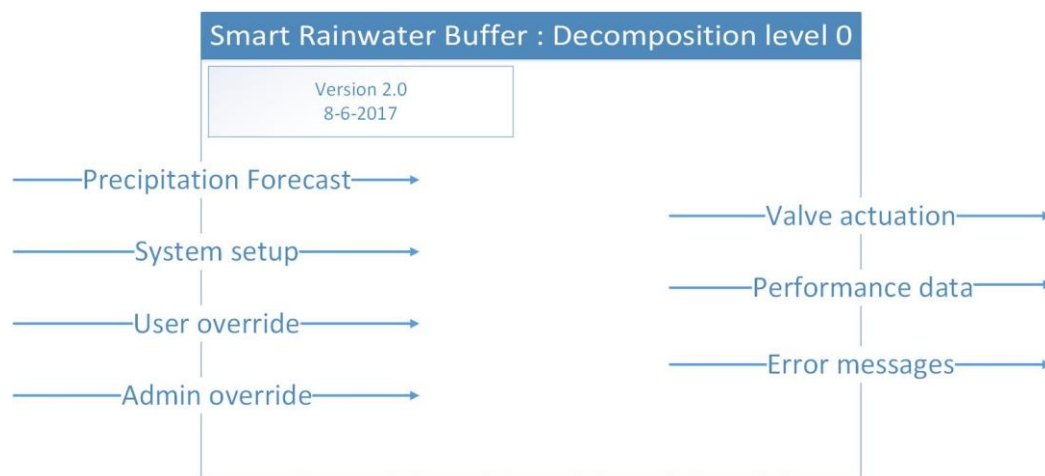


Figure 23: Decomposition level 0 of the functional architecture of the Smart Rainwater Buffer

Figure 24 zooms one level deeper on the functional architecture of the system, opening up the black box.

Starting on the left-hand side: Precipitation data is pulled by the rainForecastReceiver function. This function calculates how many litres of rainwater are expected in the buffer in the next two hours. Next, this processed precipitation data is sent to the bufferLogic function.

The bufferLogic handles four inputs: processed precipitation data, system setup data, monitoring data and possibly system override data. Next, the bufferLogic makes a decision on how the system should act based on the received inputs. This decision is then sent to a

controlling function called bufferController. The bufferController then effectuates this decision.

System performance data is sent from the bufferLogic to the user and officialities. The users and officialities can override the bufferLogic decision making in order to force immediate effectuation the bufferController, opening the valves. Users can also configure their system and send system setup data to the bufferLogic.

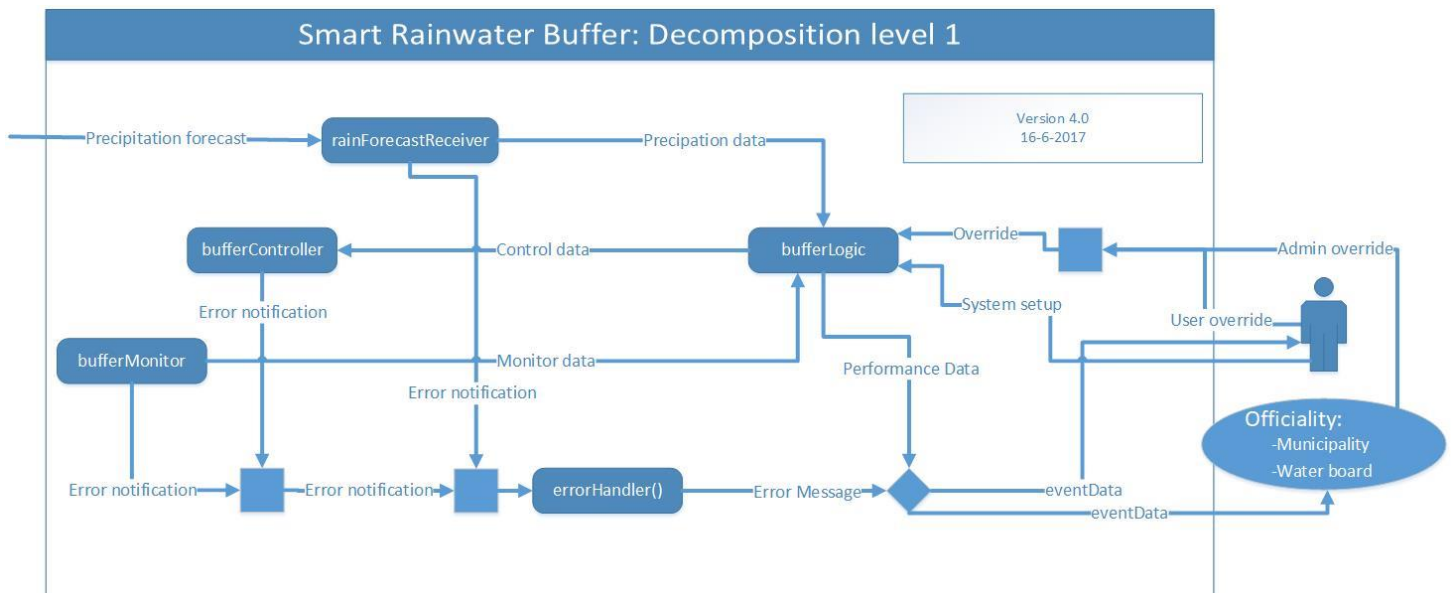


Figure 24: Decomposition level 1 of the functional architecture of the Smart Rainwater Buffer

### 5.3 Specifying the prototypes

Through iterative prototyping, additional system requirements were obtained. This section starts by describes specification, a short evaluation and additional system requirements for each prototype. Then, a second iteration of the functional and non-functional requirements of the intended system can be specified.

#### Prototype 1: Lo-fi

This initial prototype focuses on the requirement of measuring the input and releasing the buffered water in a controlled way. In order to realize this controlled feedback loop. A buffer to retain the water is required. Secondly, a sensor is required to measure the water level. Thirdly, a controllable valve should be placed as low as possible in the buffer. Lastly, a controller to regulate the system. In order to get a good understanding of the functionality and problems that arise, it is suggested to use a large buffer.

An Additional requirement that resulted from the presentation of this prototype to the client and supervisor:

FR 1 – Monitoring data displayed by the system should be presented in a meaningful way for the end-user

### Prototype 2: Lo-fi

Prototype 2 is a continuation of prototype 1. An overview of the result of prototype 1 can be seen in chapter 6 – Realization. Added functionality to the system include fetching local rain predictions based on a T+120 minutes model. The number of litres of rain expected in the buffer are calculated based on the location of the SRB prototype and roof surface. Raw SRB performance data is output on a terminal window.

Additional requirements that resulted from the presentation of this prototype:

- FR 1 – The system should calculate the optimal time for discharging rainwater
- FR 2 – The system must monitor buffered water temperature
- FR 3 – The system must display legionella warnings to the user
- FR 4 – The system should display system performance data which includes water level and water temperature
- FR 5 – The system should be able to discharge rainwater in the garden as well as back into the sewerage system
- FR 6 – The system should display the water level in percentages
- FR 7 – System error notifications should be displayed to the user through the interface
- FR 8 – The system should have a physical button that allows discharging of buffered water

### Prototype 3: Hi-fi

In this third iteration, a dashboard was implemented to display system performance data to the end-user in a more meaningful way. Water level in the buffer is displayed visually in percentages. To realize this, a webserver is required.

Additional requirements that resulted from the presentation of this prototype:

- FR 1 – The system must use wireless connectivity to fetch data and broadcast a web interface
- FR 2 – The system should automatically discharge water in the buffer after extended periods of high water temperature

### Prototype 4: Hi-fi

No new functionality was added in this last prototype. The prototype has been improved upon to increase robustness and reliability. Moreover, the system must function wirelessly.

This prototype was presented twice. First to the client, the dike warden of the Water board Vechtstromen and secondly to the supervisor and critical observer of this project. Feedback from these two presentations are discussed in Chapter 7 – Evaluation.

## 5.4 Requirements, second iteration

Preliminary system requirements have been described in chapter 4 – Ideation. Additional requirements emerged during the development of these four prototypes, and have been added to the list. Requirements categorized using the MoSCoW method [34], as described in chapter 3 – Methods and Techniques.

### 5.4.1 Non-functional requirements

#### **Should have**

- NFR1 The system should be modular
- NFR2 The system should be scalable
- NFR3 The system should require low maintenance
- NFR4 Monitoring data displayed by the system should be presented in a meaningful way to the end-user
- NFR5 The system should use wireless connectivity to fetch data and broadcast a web interface
- NFR6 The system should display performance data using a webserver
- NFR7 The system should display the water level in percentages

#### **Could have**

- NFR8 The system could be robust
- NFR9 The system could be economically efficient
- NFR10 The system could buffer rainwater without leaking
- NFR11 The system could be able to control water flow rate
- NFR12 The system could have additional manually operated taps
- NFR13 System error notifications could be displayed to the user through the interface

#### **Won't have**

- NFR14 The system won't have a built-in infiltration solution
- NFR15 The system won't make use of the LoRa network [34] to communicate

### 5.4.2 Functional requirements

#### **Must have**

- FR1 The system must be able to buffer rain water
- FR2 The system must be able to empty buffered water autonomously
- FR3 The system must be automatically regulated
- FR4 The system must be weather proof (ip54+)
- FR5 The system must drain buffered rainwater without the possibility of damaging land or property
- FR6 The system must monitor buffered water temperature
- FR7 The system must display legionella warnings to the user
- FR8 The system must have a physical button that allows discharging of buffered water
- FR9 The system must automatically discharge water in the buffer after extended periods of high water temperature

FR10 The system must display system performance data which includes water level and water temperature

**Should have**

FR11 The system should be able to handle a throughput of a least 2000 litres per hour

FR12 The system should be adjustable from a distance

FR13 The system should use make use of a network in order to receive weather updates and to be regulated externally

FR14 The system should filter dirt and rubbish from the water before buffering

FR15 The system should be able to discharge rainwater in the garden as well as back into the sewerage system

FR16 The system should calculate the optimal time for discharging rainwater

FR17 The system should warn the user when maintenance is required

## 6 Realization

This section starts with a decomposition of system components, including materials used. Next, a description of the development of each prototype is given, with a small evaluation after the realization of every prototype.

### 6.1 Decomposition of system components

A decomposition step was taken to analyse necessary system components.

After researching different existing valve types, three different two-way valve types are considered. Butterfly valves are the industry standard in large fluid control applications, but are better suited for use in tubes with a large diameter. Another option is a magnetic solenoid valve, these valves are cost-efficient albeit sensitive to dirt or other kinds of pollution. It is not feasible to completely filter out all dirt in the system, therefore this valve might perform worse over time. A third option is the use of ball valves, these seem more suited as these are applicable to narrow pipes. Ball valves become costly as the diameter increases, but a small diameter of half an inch allows for a high enough flow rate at 1 bar. A ball valve is more insensitive to dirt pollution, a ball valve will be used in the product.

The choice of controller is a Raspberry pi, as these are powerful, cost-efficient and have an on-board general-purpose input/output (GPIO) interface. An Arduino is not considered because this lo-fi prototype is to merge into a hi-fi prototype which includes running a webserver in a later stage. Author's experience teaches that Arduino microcontrollers often run into problems when hosting webserver concurrently with other continuous tasks. The programming language of choice is Python because of wide availability of libraries and ease of use in combination with GPIO-based applications.

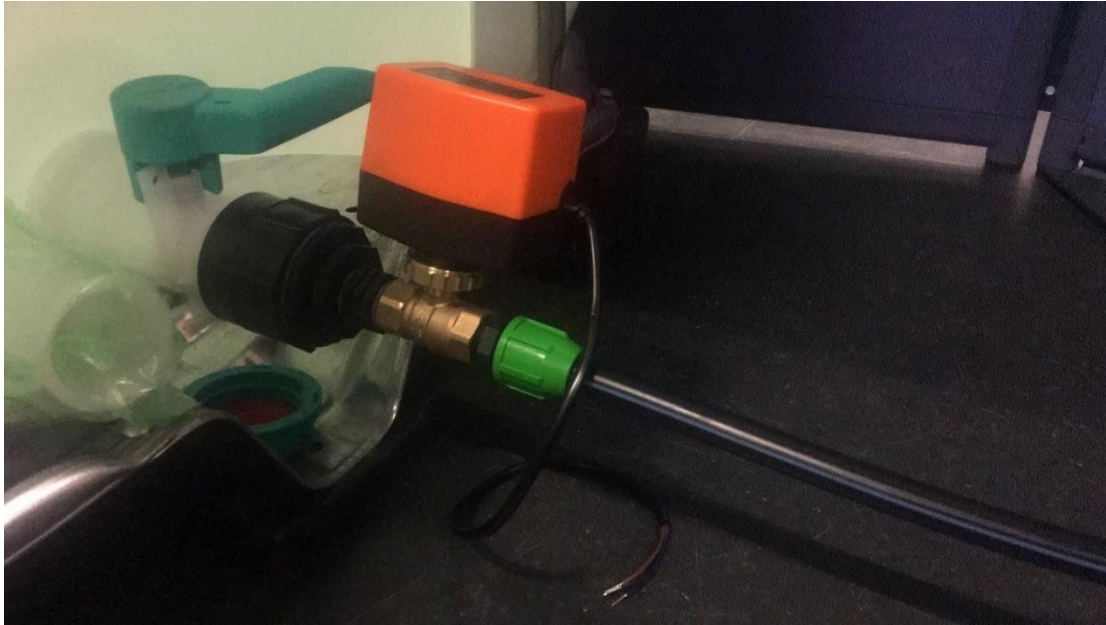
The proposed sensor for measuring the water level is a waterproof ultrasonic sensor. Other options include measuring the liquid levels through capacitive sensing or a float sensor, but the choice was made for an ultrasonic sensor because this should be more reliable; less sensitive to errors as a result of accumulation of dirt and algae to it compared to a float sensor, and less unpredictable and error-prone than a capacitive liquid sensor.

### 6.2 Development of lo-fi prototype 1

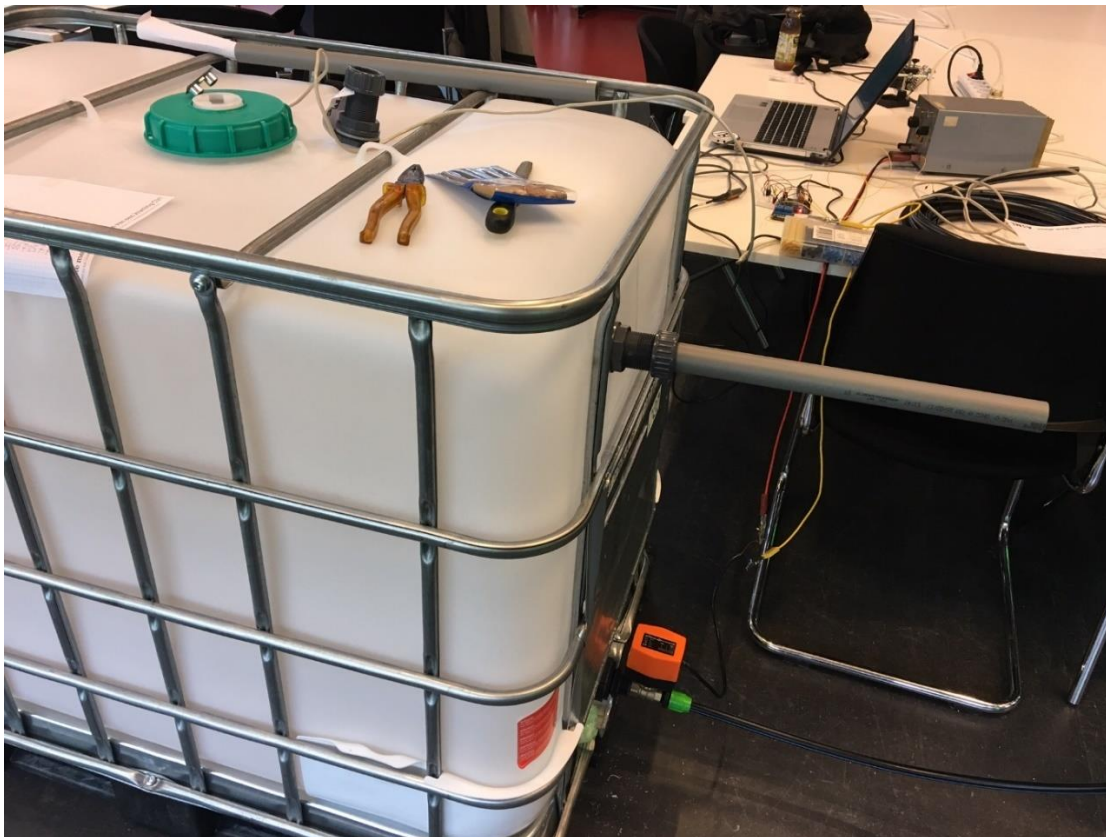
The focus for development of this prototype was on the hardware setup. Figure 19 shows a picture of the building process. The Ø 32mm PVC tube on the top hand side was placed as high up as possible, slightly next to the middle of the buffer – an Intermediate Bulk Container (IBC). An IBC was chosen because of the large buffering capacity and low cost. This was done to ensure a water tight seal with the rubber of the connections to the high-density polyethylene. The electrical ball valve, displayed in figure 18, was attached to the Ø 2" tap using a combination of a brass ½" to ¾" converter and three polypropylene connectors up to 2".

The water-proof ultrasonic distance sensor type JSN-SR04T 2.0 was unfortunately not interfaceable with a raspberry pi. It could be a problem with voltage conversion adding a delay in the time-sensitive signal of the ultrasonic sensor. A different type ultrasonic distance sensor (HC-SR04) was chosen. It has been installed in the IBC screw cap and fixed with nuts

and bolts. This ultrasonic distance sensor sends a 5v signal on the output (echo), so a voltage divider with resistor values of 1k and 2k Ohm was used to lower the voltage coming into the raspberry pi to roughly 3.3. volt, not to damage the raspberry pi. The buffer was connected to the existing 75mm downspout with a simple rain filler. By means of experiment, it was estimated that less than 20% of the water going through the downspout got harvested by the system.



*Figure 25: Fitting the valve*



*Figure 26: Smart Rain Water Buffer – Work in progress...*

This prototype has been presented to the client and the supervisor of this project. This first prototype was successful, as it was able to measure current water level and control the water level within a proof-of-concept setting on the campus of the University of Twente. Feedback was given by the client and supervisor to represent the output data of the system in a more meaningful way, and to average out readings to increase accuracy.

### 6.3 Development of lo-fi prototype 2

The system uses a rain barrel filler to fill the buffer. Rainwater harvested by this filler flows through a pipe, perpendicular to the downspout, into the buffer. If the buffer is full, water flows from the buffer to the downspout back into the sewerage system. The problem of low water harvesting power of the system was addressed in this prototype. Improvements on accuracy and stability of ultrasonic sensor readings were made by averaging 3 measurements. The original downspout was 5mm smaller than the connector of the rain barrel filler. The  $\varnothing$  75mm downspout had to be converted to  $\varnothing$  80mm in order to fit the rain barrel filler. However, because of this 5mm gap at the conversion, water flowing down created a vortex towards the middle. This vortex led to water falling through the middle instead of the side of the rain pipe. In turn, this led to rainwater not being captured by the rain barrel filler. Figure 27 shows the solution: a converter (1) with a slanted inside, bridging a diameter of 75mm to a connection piece of 80mm (2). Furthermore, the system was made leak-proof.

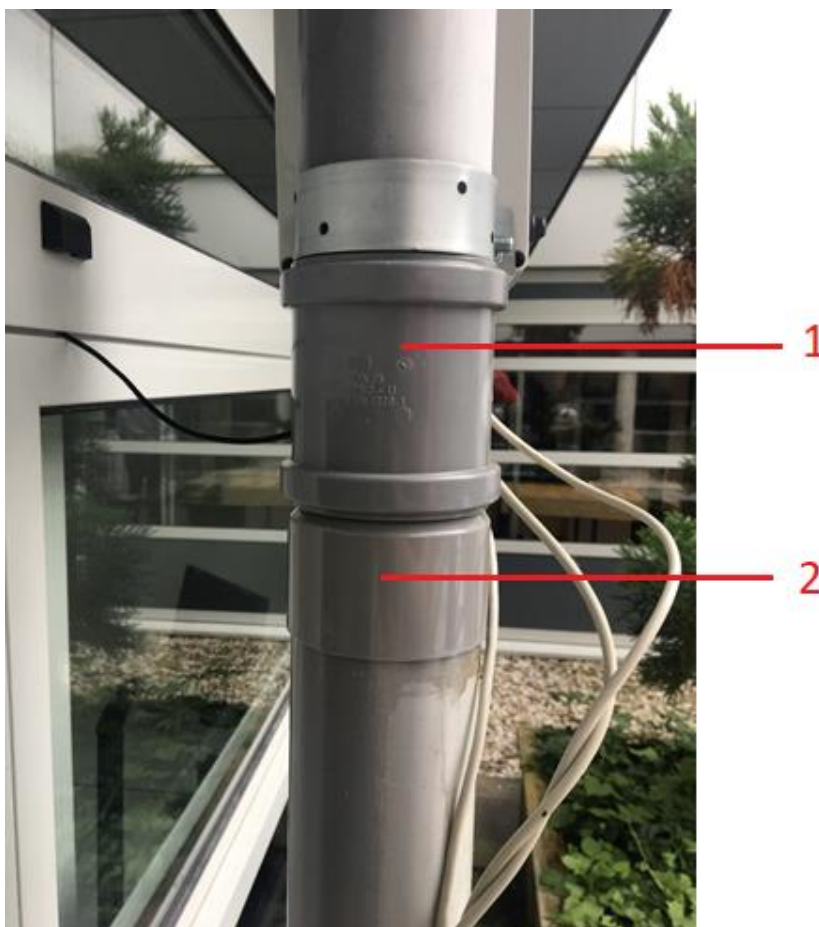


Figure 27: Converting the downspout from 75mm to 80mm

As described in 5 – Specification, this prototype needed to fetch the local rain precipitation forecast data. This was realized using python to read out Buienradars' GPSGadget app [40], which displays the precipitation forecast data for the T+120 minutes for the set GPS coordinates expressed in an integer value between 0 and 256. In order to assess the accuracy of this data, a program was written in python to log the data. During times of logging, it was not uncommon to read out precipitation forecast values over 200, as high as '226'. Using the following formula provided by Buienradar [41], the expected rainfall in mm per hour can be calculated. In this example, 226 is used for 'value':

Precipitation Intensity =  $10^{((\text{value}-109)/32)}$  = 4532 mm/hour.

At low rain intensities, the prediction model is fairly accurate. However, it was found that at high values, the inaccuracy raises dramatically. The example above displays this inaccuracy. For this system to function properly, it is key to have readings as accurate as possible. A solution to this problem is proposed in chapter 9 – Future work.

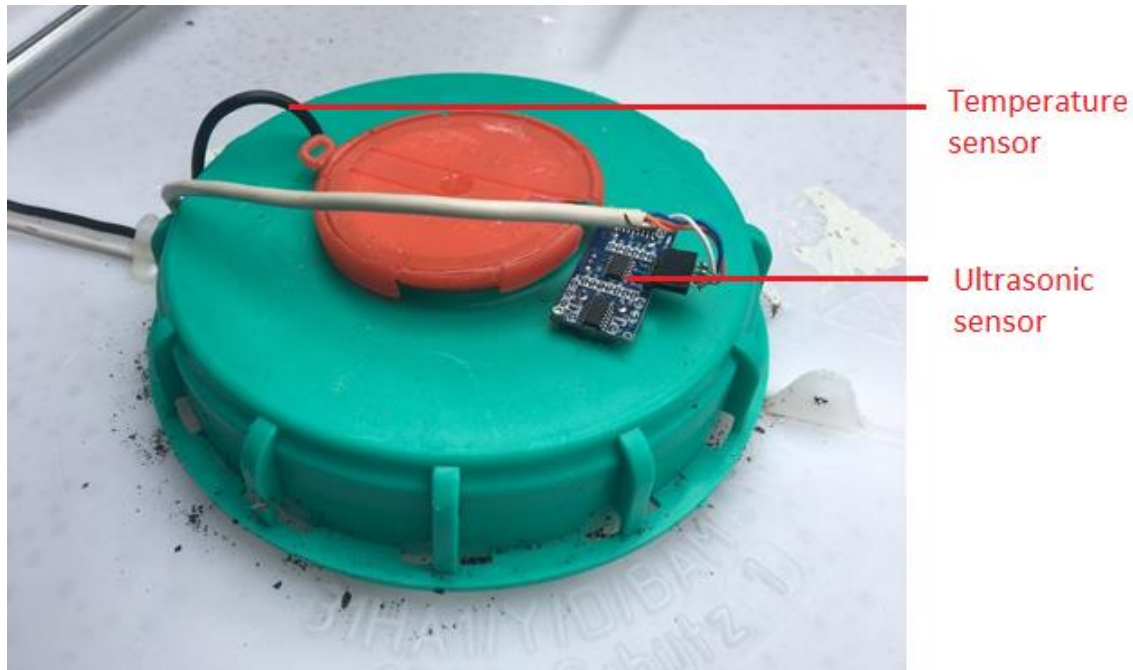
Expected rain is now displayed to the user in a more meaningful way by showing the calculated expected litres in the buffer in the next two hours, and by displaying the leftover water in the buffer expressed in litres. This is displayed later on this chapter, in figure 30.

This version was presented to the client, Regional Water Board Vechtstromen and the supervisor. During this presentation, the suggestion was made by stakeholder Regional Water Board Vechtstromen to think of other ways to discharge a surplus in rainwater. They proposed to automatically discharge rainwater in the garden in winter instead of the sewerage system because of the low groundwater level during winter. Another point of attention was the possibility of the development of legionella if the temperature of the buffered water is too high for extended periods. The system should host a webserver locally in order to function completely autonomously

#### 6.4 Development of hi-fi prototype 3

To realize displaying performance data to the end-user, implementation of a webserver was required. This has been realized using the python-based Flask microframework [42]. Real-time link between running python code is then realized using the Jinja2 template engine [43] to send back and forth data from html to running python code. Prototype 2 is then merged into this framework on a separate thread to keep the system running both tasks concurrently. The system also has a waterproof physical override button, so the user can now tap water out of the system to water the plants or wash the car. Furthermore, a waterproof temperature sensor was added to monitor water temperature.

A water-proof temperature sensor was added. The fit is shown in figure 28. The black wire of the temperature sensor is placed opposite from the ultrasonic distance sensor to avoid interference.



*Figure 28: Different sensors attached to the IBC*

Subsequently, a clamp had to be developed for the electronics enclosure. This building process is illustrated in figure 22. Additionally, a water-proof button was added on the side of the electronics enclosure for the end-user to discharge water from the system to their garden.

The system code of the lo-fi prototype was then integrated step-by-step. In order for the webserver to run concurrently with measurement of sensors, these functions are run on a separate thread. Additionally, code was added to monitor the water temperature periodically. The python code for this system can be found in Appendix E.

Figure 30 displays a simple web interface that's hosted on the webserver. This interface is meant for the end-user and displays performance indicators such as water level, water temperature, error messages. The user is able to configure the system through this interface by setting parameters such as their roof surface area.



Figure 29: Designing a clamp, fitting physical buttons and cable glands for the electronics enclosure

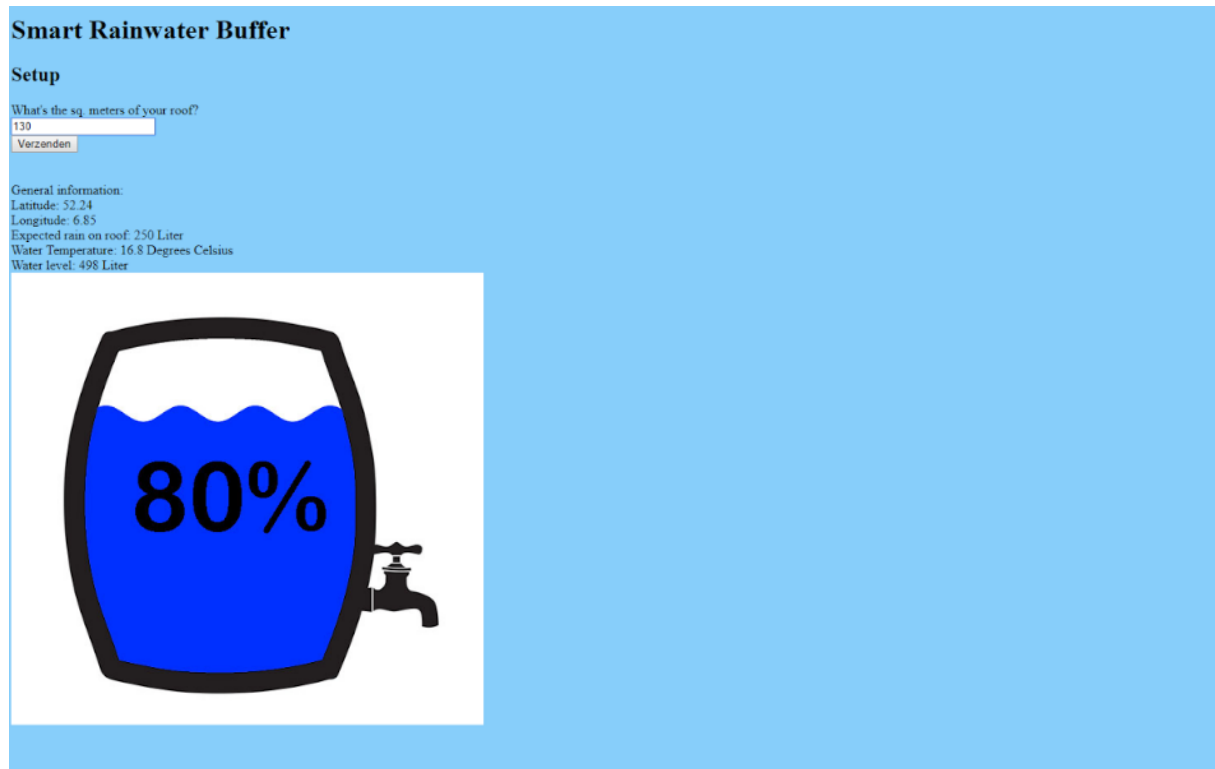


Figure 30: Simple web interface on the Smart Rainwater Buffer

### 6.5 Development of hi-fi prototype 4

In the last prototype, it was key to make the system more compact. During demonstrations, the system had a variety of cables running out to connect to a monitor, keyboard, mouse, power source, sensors, ethernet cable. The electronics of the system have been fit in the enclosure, displayed in figure 31. Instead of over ethernet, the system now uses wireless connectivity. All electronics have been enclosed in a waterproof IP-67 casing. The only external wires required are two power cables. The system uses cronjobs to automatically start on system boot. The power source is now to a smaller USB-type power supply instead of a bulky laboratory power supply. Appendix D shows a list of the used materials and their costs in the last hi-fi prototype.



Figure 31: All electronics fitted in a single enclosure

## 7 Evaluation and Discussion

The evaluation of the product consists of two phases. First, all requirements have been tested in a demonstration setting to assess the system. Secondly, documented feedback on the final prototype by stakeholders was elicited.

### 7.1 Functional and non-functional requirements evaluation

System functionality has been assessed during a demonstration by addressing each component of the functional and non-functional requirements individually. Figure 32 and 33 show the results of this evaluation session.

| Functional Requirements |                                                                                |            |                                                                           |
|-------------------------|--------------------------------------------------------------------------------|------------|---------------------------------------------------------------------------|
| ID                      | Function                                                                       | Compliant? | Comments                                                                  |
| FR1                     | Does the system buffer rainwater?                                              | Yes        |                                                                           |
| FR2                     | Does the system empty buffered water autonomously?                             | Yes        |                                                                           |
| FR3                     | Is the system automatically regulated?                                         | Yes        |                                                                           |
| FR4                     | Is the system weather proof? (IP54+)                                           | Yes*       | Ultrasonic dist. sensor is not water-proof, different sensor is suggested |
| FR5                     | Does the system discharge water without the possibility of damaging property?  | Yes        | Water flows back into the sewerage system                                 |
| FR6                     | Does the system monitor water temperature?                                     | Yes        |                                                                           |
| FR7                     | Does the system have a physical button that allows discharging buffered water? | Yes        |                                                                           |
| FR8                     | Can the system handle a throughput of at least 2000 litres per hour?           | Yes        |                                                                           |
| FR9                     | Is the system adjustable from a distance?                                      | No         | Roof surface can be configured but does not affect system                 |
| FR10                    | Does the system make use of a network to receive weather updates?              | Yes        |                                                                           |
| FR11                    | Does the system calculate the optimal time for discharging rainwater?          | Yes        | Empties two hours prior to a downpour                                     |
| FR12                    | Does the system filter dirt and rubbish?                                       | Yes        | Only a coarse filter is applied                                           |
| FR13                    | Does the system warn when maintenance is required?                             | No         |                                                                           |
| FR14                    | Does water get discharged after periods of high temperature?                   | No         | The temperature is only measured                                          |
| FR15                    | Can the system discharge water into the garden as well as the sewerage system? | No         |                                                                           |
| FR16                    | Is this system able to control water flow rate?                                | No         |                                                                           |
| FR17                    | Is it possible to operate the system manually?                                 | Yes        | Tactile push button on the side                                           |
| FR18                    | Are system error notifications displayed through the web interface?            | No         |                                                                           |

Figure 32: Assessment of functional requirements of the SRB

| Non-functional Requirements |                                                   |            |                                                      |
|-----------------------------|---------------------------------------------------|------------|------------------------------------------------------|
| ID                          | Function                                          | Compliant? | Comments                                             |
| NFR1                        | Is the system modular?                            | Yes        |                                                      |
| NFR2                        | Is the system scalable?                           | Yes        | Can connect to any buffer                            |
| NFR3                        | Is the system economically efficient?             | -          | No research performed; costs of prototype under €500 |
| NFR4                        | Does the system require low maintenance?          | No         | Not tested yet for extended periods                  |
| NFR5                        | Is monitoring data displayed in a meaningful way? | Yes        | Visual aid shows the water level                     |
| NFR6                        | Is the system robust?                             | No         | Not tested yet for extended periods                  |
| NFR7                        | Does the system buffer rainwater without leaking? | Yes        |                                                      |

*Figure 33: Assessment of functional requirements of the SRB*

## 7.2 Feedback on prototype

This final prototype has been presented to the municipality Enschede, the chairman of the Water Board, the supervisor and critical observer.

### Informational poster

As a tool to explain this system to stakeholders from different backgrounds, an informational poster was designed. This poster can be found in Appendix F. This poster explains the functioning of the system through the use of a MADE loop [44]: Monitoring, Analysis, Decision and Effectuation. An explanation of the system was given to the stakeholders by combining a cognitive walkthrough scenario and the MADE loop presented in this poster.

### Interviews

The critical observer of this project questioned why this system is designed to make use of a rain barrel filler instead of two pipes that lead 100% of the water through the pipes in the buffer. In a test session, it was estimated roughly two-thirds of the rainwater to be harvested by the system. The most important reason for designing the system with a rain barrel filler is safety. If the system happens to clog with the proposed alternative, the existing downspout will fill up with water until it reaches the roof. This could cause water damage when the system is implemented in a context with a flat roof, like on the University of Twente. Moreover, designing the system to run 100% of the rainwater through the buffer will make it clog more frequently, requiring more maintenance.

The chairman of Water Board Vechtstromen pointed to the fact the sewerage system needs to be able to vent air. This is a non-issue the way the system is currently designed, because the downspout is always 'open' through the middle. With the proposed setup by the critical observer in the last paragraph this would be a problem however, which could be resolved by using a bleeder valve. This puts an extra requirement on the end-user to perform maintenance to this valve, to avoid problems with the sewerage system venting when a bleeder valve clogs.

The client asked to elaborate on the design choice of this valve opposed to a cheaper alternative. As mentioned in chapter 5 – Specification, cheaper valves such as magnetic solenoid valves work less reliable when exposed to liquids polluted with dirt. One of the systems requirements is not to leak water, therefore a reliable valve was required.

What happens when the garden is not perfectly straight, and the buffering elements in the back of the garden are situated lower than the one next to the downspout? This comment was made by a representative of the municipality of Enschede. A water pump placed at the lower part with a second pipe on the bottom side back to the sewer would need to be added to solve this problem, or a second valve at the end which slowly releases to infiltrate in the soil.

The client warned for health hazards during the presentation of prototype 3: when rainwater is exposed to warm weather ( $>23^{\circ}\text{C}$ ) for prolonged periods, the legionella bacteria could develop [45]. Legionella has a health risk if contaminated or evaporated water is inhaled or taken in by humans. The bacteria could spread when watering the plants with buffered water. To counter this, a temperature sensor has been added. The buffer should empty itself after prolonged water temperatures of over 23 degrees.

Vechtstromen also enquired about possibilities regarding infiltrating water automatically in the soil instead of discharging buffered water back into the sewerage system. During winter, the groundwater level is low. Though not added in the current setup, this feature could be added by adding a second 2-way valve, or replacing the existing 2-way valve with a 4-way 270-degree valve.

Vechtstromen enquired about the costs of this product. Roughly 500 euros was spent on this prototype, although remaking this prototype would cost around 300 euros. The municipality and Water Board expressed interest in continuing this project in the form of a pilot study of 20-50 Smart Rainwater Buffer test setups placed in Enschede in the targeted problem area.

## 8 Conclusion

In this chapter, an answer will be given to the main research question. The goal of this project was to develop an intelligent solution for large volume rainwater buffering during heavy rainfall that reduces the strain on the existing sewerage system in the city of Enschede.

Through an iterative process of generating ideas, specifying, realizing and evaluating, also known as the Creative Technology Design Process, a system has been proposed to the client whilst carefully accounting for all stakeholders in this project. Multiple functional prototypes have been presented to the client, the municipality of Enschede. The result is an intelligent weather-aware buffering system that empties itself before heavy rainfall. This system is placed in the garden of house owners and, by connecting to the downspout, utilizes roof surface to harvest rainwater.

As a proof-of-concept, the system works. In the future, a different type of ultrasonic distance sensor should be used. Type HC-SR04 is very sensitive to small disruptions, and functions unreliably. Fetched weather data has showed exponential inaccuracy as values for precipitation forecast data go up. To combat the problem of low ground water levels in Enschede in winter, the system could be redesigned to automatically discharge rainwater in the soil. Long-term testing is required to assess system performance and stability over periods of time. This is recommended prior to starting a pilot study.

The main research question is: *“How to develop a rainwater buffering system that reduces the strain on the sewerage system of Enschede and is distributed over the premises of its inhabitants?”*

This research question has been answered by offering a resilient, solution to be placed on premises of the homeowners in Enschede. The problem, defined by the client, was an estimated 7.000 m<sup>3</sup> of water in a targeted area in Enschede. When applied to 50% of the 3.500 households in this targeted problem area, the proposed solution could buffer 100% of the water running in the streets. The municipality and Water Board Vechtstromen have expressed an interest in continuing this project in the form of a pilot study, with Smart Rainwater Buffer systems placed on the premises of inhabitants. In conclusion, it can be said the outcome of this project has been successful.

## 9 Recommendations

Garden elements with a neighbour could be shared. Elements with double the width could be placed to retain the same buffering capacity. Both backyards could be controlled by the same system in order to decrease costs and maintenance.

It is recommended to design a low-pass filter on incoming precipitation data to counter inaccuracy in precipitation predictions. Radar based predictions are the most accurate type of predictions, and can only be made for  $T+120$  minutes. However, the client requested the buffer to be empty 120 minutes prior to heavy downpour. One option to solve this problem is to have the system only keep a fraction of rainwater in an equilibrium situation.

A second option in order to make more accurate predictions, is a network of distributed Smart Rainwater Buffers equipped with a rain meter. This could be used to create a model for local precipitation data. For example, if a rain cloud is moving southwards, distributed systems placed to the north of the current system could measure rainfall and pass this data in a real-time model to help predict more accurately. This data could then be requested by the current system, to gain more accurate predictions concerning expected rainfall at the current location.

A display could be added to the electronics enclosure of the system, showing critical system information to the user.

To decrease the dependency on availability of wireless networks, it is worth researching possibilities of using the Long Range Low Power (LoRa) [35] network over Wi-Fi. Different LoRa interfaces are available for the Raspberry Pi.

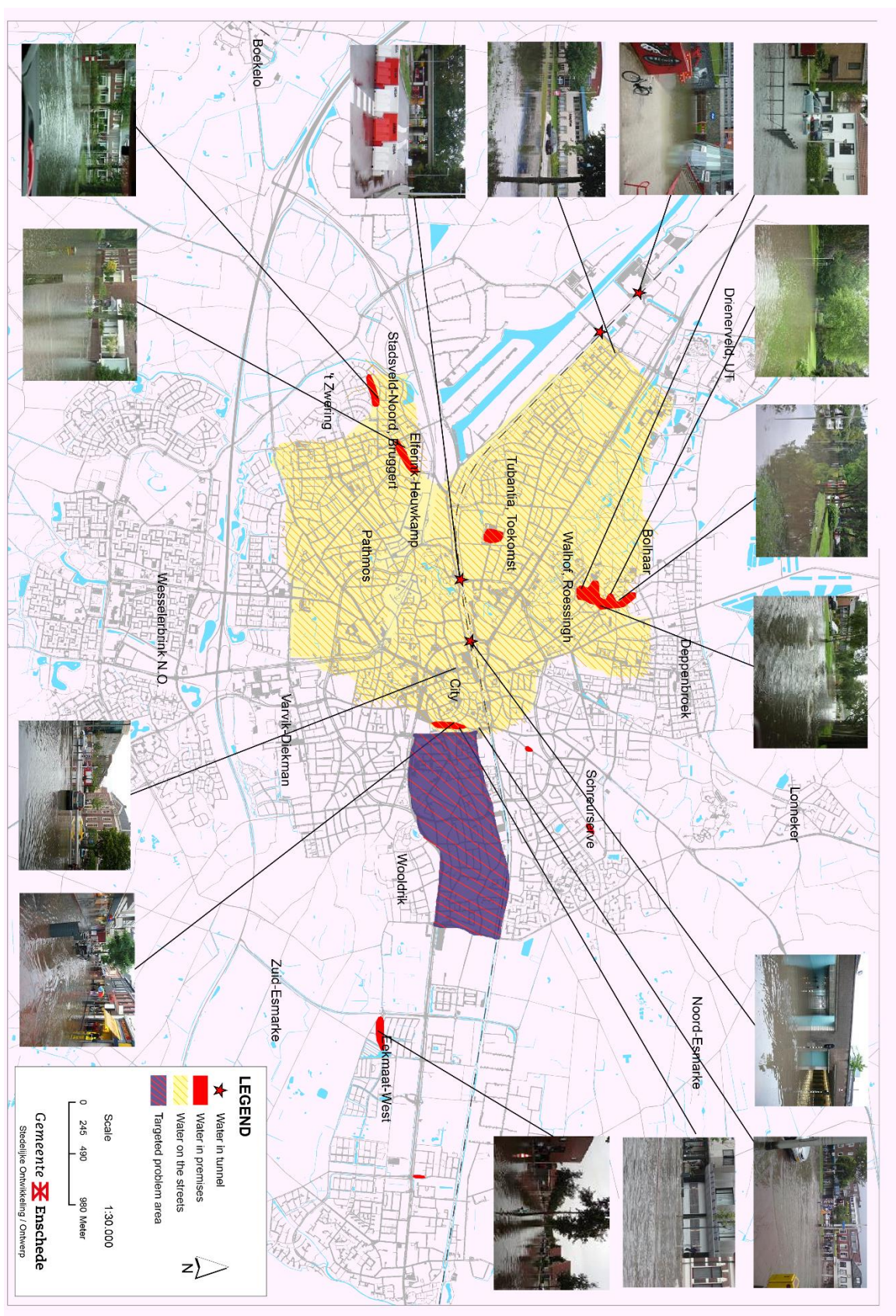
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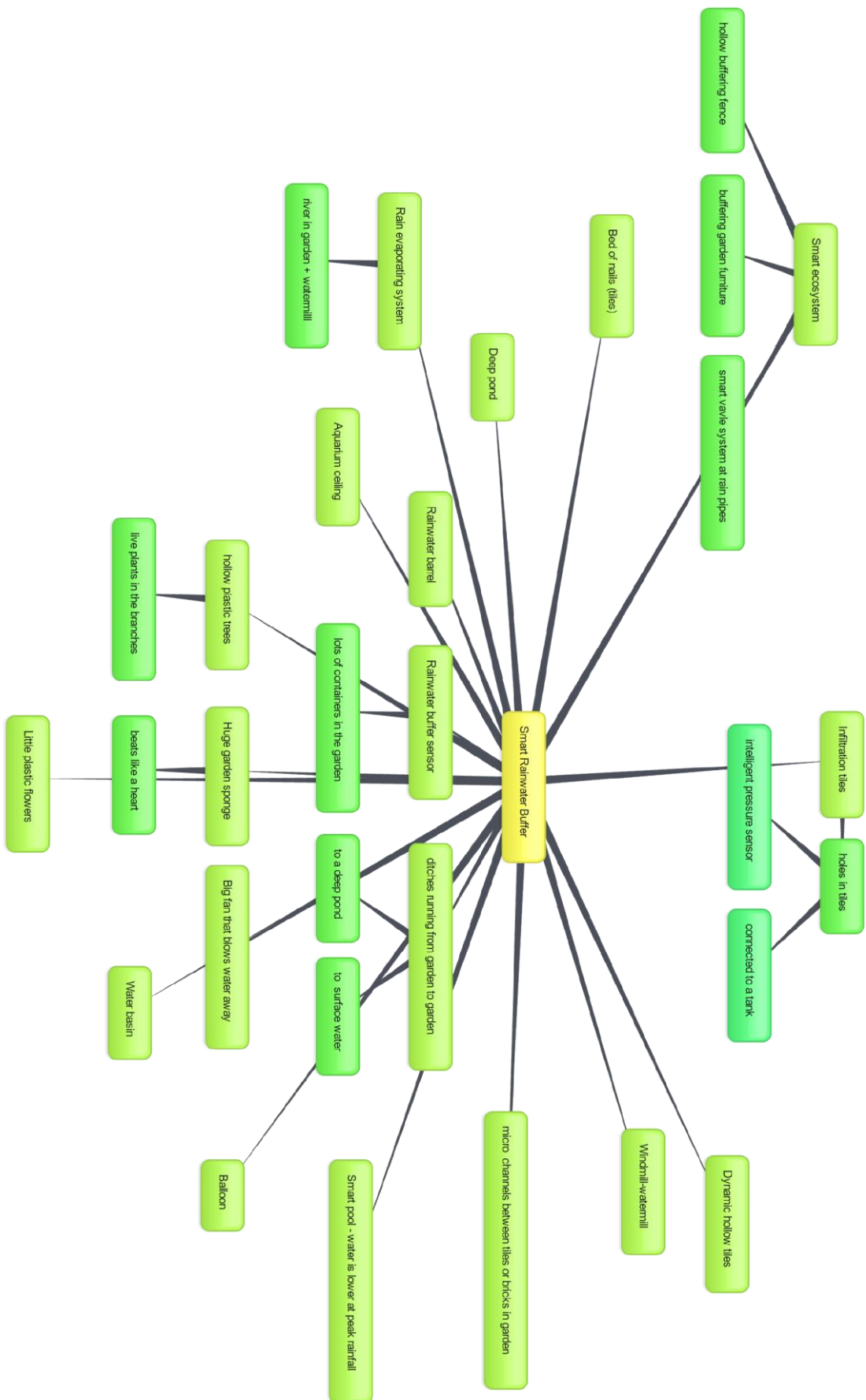
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## 11 Appendices

## Appendix A – Map displaying locations extreme runoff



## Appendix B – Results brainstorm session



## Appendix C – Baseline and satellite stakeholders

| Baseline Stakeholders                                            | Group                                            | Influence | Interest |
|------------------------------------------------------------------|--------------------------------------------------|-----------|----------|
| <b>Citizens of Enschede</b>                                      | Users – Developers                               | High      | High     |
| <b>Businesses and Industries</b>                                 | Users                                            | Average   | Average  |
| <b>Boaz Vetter</b>                                               | Developer                                        | -         | -        |
| <b>Richard Bults</b>                                             | Developer                                        | -         | -        |
| <b>Municipality Enschede</b>                                     | Developers -<br>Legislators - Decision<br>Makers | Average   | High     |
| <b>Ina van Dijk<br/>Budgetting<br/>Municipality<br/>Enschede</b> | Decision maker                                   | High      | High     |
| <b>University of Twente</b>                                      | Legislators                                      | Low       | Low      |
| <b>Brenda Horstra<br/>Tuinbranche<br/>Nederland</b>              | Developer                                        | Low       | Average  |
| <b>Regional water<br/>authorities<br/>Vechtstromen</b>           | Legislators                                      | Average   | Average  |

Table 1: Stakeholder analysis – Baseline stakeholders

| Satellite Stakeholders     | Influence | Interest |
|----------------------------|-----------|----------|
| <b>Insurance companies</b> | Average   | Average  |
| <b>Engineering offices</b> | Low       | Average  |

Table 2: Stakeholder analysis – Satellite Stakeholders

## Appendix D – Material list

| Date         | Product                | Qty | Price   | Description                                                | Source                        |
|--------------|------------------------|-----|---------|------------------------------------------------------------|-------------------------------|
| 11-05        | Ball valve             | 1   | 75,27   | Valve and motor                                            | Magneetventielshop.nl         |
| 17-05        | Hose                   | 1   | 18,73   | Tylen hose and coupler                                     | Gamma                         |
| 17-05        | IBC connectors         | -   | 51,92   | Connectors for IBC, clamping nut                           | Wildkamp Enschede             |
| 17-05        | JSN-SR04T              | 1   | 23,90   | Ultrasonic distance sensor                                 | Hobbyelectronica.nl           |
| 17-05        | Vulsysteem plus        | 1   | 41,90   | Rain barrel filling machine                                | Kunststofregenton.nl          |
| 18-05        | IBC Container          | 2   | 120     | Two industry-sized rain barrels                            | Farmer                        |
| 18-05        | Rain pipe              | 1   | 6,90    | Rain pipe 80mm                                             | Gamma                         |
| 07-06        | Buck convertor         | 1   | 8,92    | Buck converter + 20x20cm cgrid NSR male-female 1 pin wires | Scintilla stores              |
| 12-06        | 70-80mm tube converter | 1   | 12,77   | Rubber fitting 70-80mm converter                           | Gamma                         |
| 13-06        | SD Card                | 1   | 9,00    | SD card 16 GB SHDC                                         | IAPC                          |
| 15-06        | IP67 enclosing         | 1   | 32,86   | IP casing for electronics                                  | Farnell                       |
| 15-06        | Raspberry pi           | 1   | 35      | Raspberry pi 3 model b                                     | Farnell                       |
| 19-06        | Relay unit             | 1   | 2,17    | 2-channel relay unit                                       | Scintilla stores              |
| 19-06        | Cable                  | 1   | 18,63   | Electrical cable, nuts, bolts, cable glands                | Gamma                         |
| 19-06        | Waterproof push button | 1   | 21,50   | Push button and RCA connectors                             | Rick donkers auto electronics |
| <b>Total</b> | -                      | -   | €479,47 | -                                                          | -                             |

## Appendix E – Smart Rainwater Buffer python code

```
'''
Smart Rainwater Buffer
Written by Boaz Vetter at the University of Twente
06-2017

version history
v0.6 - Flask (python) web server integration
v0.5 - Better graphical feedback interface
v0.4 - Makes use of ultrasonic (HC-SR-04) and 5v relay unit
v0.3 - More coherent: continuously checks the buffer capacity and
weather data, and acts accordingly
v0.2 - calculates liters of rain expected in the buffer based on your
long/lat and roof surface
v0.1 - fetches local rain predictions based on the 2 hour prediction
model of GPSgadget/Buienradar
'''

from __future__ import division #make division work with floats
from __future__ import print_function
from flask import Flask, request, render_template, url_for
from random import randint
import threading
import atexit
import time
import requests
from requests.adapters import HTTPAdapter
import RPi.GPIO as GPIO

#Setup

#Setup
GPIO.setwarnings(False) # Turn on later, just leave off for demos
roofSurface = 77.5 #Applicable roof surface in SQ. meters
lat = "52.24" #Set latide and longitude
lon = "6.86" #UTwente ZI 1028: lat=52.24&lon=6.86
bufferEmptied = False #Start with a full buffer
relay = 22 #Relay is on pin GPIO 22

GPIO.setmode(GPIO.BCM) # Use BOARD pin numbering
GPIO.setup(relay, GPIO.OUT) # Setup GPIO pin 22 to OUT for controlling
the relay unit
GPIO_TRIGGER = 23 # Uses GPIO 23 and 24 for ultrasonic distance
measurement
GPIO_ECHO = 24
# Set pins as output and input
GPIO.setup(GPIO_TRIGGER,GPIO.OUT) # Trigger
GPIO.setup(GPIO_ECHO,GPIO.IN) # Echo
# Set trigger to False (Low)
GPIO.output(GPIO_TRIGGER, False)
# Allow module to settle
time.sleep(0.5)
# Initialising speed of sound in cm/s at room temp
temperature = 20
speedSound = 33100 + (0.6*temperature)
```

```

app = Flask(__name__) #Set flask app.py
test="Type here"

#FLASKS PAGES
@app.route('/login', methods=['GET', 'POST'])
def login():
    if request.method == 'POST':
        global test
    else:
        print('login called, nothing received')
        return test()

@app.route('/srb/')
def hello(name=None):
    global test, lat, lon, roofSurface, expectedMMonRoof
    return render_template('index.html',
        water_level=get_water_level(),
        latitude=lat,
        longitude=lon,
        roof_surface = roofSurface,
        forecast = expectedMMonRoof
    )

def get_water_level():
    return randint(0, 100)

def getData():
    global precipitationMM
    global precipitationTime
    s = requests.Session()
    try:
        s.mount('https://gpsgadget.buienradar.nl/data/raintext/?lat='+lat+'&lon='+lon, HTTPAdapter(max_retries=3)) #retry 3 times
        r = requests.get('https://gpsgadget.buienradar.nl/data/raintext/?lat='+lat+'&lon='+lon, timeout = 10) #local weather prediction, timeout = 10
        because TCP packet retransmission window is 3 sec each
        g = str(r.text) # deal with unicode
        h = g.replace('|', ' ') # separate data
        precipitationList = h.split() # split and convert to list
        precipitationMM, precipitationTime = precipitationList[::2], precipitationList[1::2] #divide odd and even into two lists:
        precipitation and time
        precipitationMM = list(map(int, precipitationMM)) #convert string to int
    except requests.exceptions.RequestException as e: #Catch http errors
        print('connection error - going into except clause and printing error code below, also setting precipitationMM and precipitationTime to arbitrary values')
        precipitationMM = [0, 1]
        precipitationTime = [2, 3]
        print(e)

def debug():
    global precipitationMM
    global precipitationTime

```

```

    print('Millimeters: ', end='')
    print(precipitationMM)
    print('Time: ', end='')
    print(precipitationTime)

def expectedRainfall(): #Calculate expected rainfall on roof in the
next two hours
    global precipitationMM
    global expectedMMonRoof
    sum = 0
    for num in precipitationMM:
        if num > 0:
            mmperHourperMeter = 10**((num-109)/32) #mm per hour per m2
source:buienradar.nl
            mmperTimeUnit = mmperHourperMeter/12 #liters per m2 per 5
min
                sum+= mmperTimeUnit
            expectedMMonRoof = sum * roofSurface #How many liters are expected?
            print('Expected rainfall in the next two hours at location ',
end='')
            print('lat '+lat+', lon '+lon, end='')
            print(' on a ', end='')
            print(roofSurface, end='')
            print(' Sq. meter roof: ', end='')
            print(expectedMMonRoof, end='')
            print(' Liter')

def measure():
    # This function measures a distance
    GPIO.output(GPIO_TRIGGER, True)
    # Wait 10us
    time.sleep(0.00001)
    GPIO.output(GPIO_TRIGGER, False)
    start = time.time()

    while GPIO.input(GPIO_ECHO)==0:
        start = time.time()

    while GPIO.input(GPIO_ECHO)==1:
        stop = time.time()

    elapsed = stop-start
    distance = (elapsed * speedSound)/2

    return distance

def measure_average():
    # This function takes 3 measurements and
    # returns the average.

    distance1=measure()
    time.sleep(0.1)
    distance2=measure()
    time.sleep(0.1)
    distance3=measure()
    distance = distance1 + distance2 + distance3
    distance = distance / 3
    return distance

```

```

def rainHandler():
    #global precipitationMM #Use global and uncomment 'expectedMMonroof
= 250' below for real-time results
    expectedMMonRoof = 400
    print('Going into rain handler, expected liters on
roof(expectedmmonroof) = ')
    print(expectedMMonRoof)
    if (expectedMMonRoof>200): #Empty buffer if more than 200 liters of
water is expected in the next two hours
        print('Heavy rainfall expected, calling emptyBuffer()!')
        emptyBuffer()

def emptyBuffer():
    global bufferEmptied
    if bufferEmptied == False:
        print ('Emptying buffer...')
        GPIO.output(relay, False) ## Turn on relay unit
        distance = measure_average() #initial measurement
        print("Initial distance : ", end='')
        print (distance)
        print (' cm')

        while (distance < 27.00): #Assuming 70 cm means an empty barrel
            distance = measure_average()
            liter = (7.3 * 11.6 * (8.2-(distance/10)))
            liter = int(round(liter))
            print("Liter in buffer: ", end='')
            #print ("{0:.2f}".format(liter, end='')) # round to two
decimals
            print (liter, end='')
            print (' L')
            time.sleep(1)
            GPIO.output(relay, True) #Close the valve
            print ('Done')
            bufferEmptied = True

def checkBufferfull():
    global bufferEmptied
    print ('Going into checkbufferfull, checking if buffer is full')
    print ('Does it still go to here?')
    distance = measure_average() #initial measurement
    if (distance < 25.00): #Assuming 20 cm means a full barrel
        print('Buffer full! Setting bufferemptied to 0')
        bufferEmptied = False

'''
def interrupt(): #use for more proper interrupts
    global t
    t.cancel()
'''
def worker():
    try:
        while True:
            time.sleep(5) # settle web server
            print('Calling getData..')
            getData()

```

```

        print('Calling debug..')
        debug()
        print('Calling expectedRainfall')
        expectedRainfall()
        print('Calling checkBufferfull')
        checkBufferfull()
        print('Calling rainHandler')
        rainHandler()
        time.sleep(5)

    except KeyboardInterrupt:
        # User pressed CTRL-C
        # Reset GPIO settings
        print ('Keyboard interrupt detected - exiting program')
    except:
        print ('Other error or exception occurred - exiting program')

    finally:
        GPIO.cleanup() # Ensures a clean exit

t = threading.Thread(target=worker)
t.daemon = True

#atexit.register(interrupt) #Use this for proper interrupts

t.start()

```

# Smart Rainwater Buffer

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## Doel

Tijdens extreme stortbuien wordt het huidige rioleringsstelsel overbelast, wat overstromingen tot gevolg heeft. Dit systeem is ontworpen om in noodsituaties de stress op het bestaande rioleringsstelsel te verminderen en zo overstromingen tegen te gaan. Dit ontwerp toont een modulair systeem dat water buffert wat op het dak is gevallen. Het hoofdelement bestaat uit een holle schutting. In plaats van een standaard houten schutting kan een kunststof schutting geplaatst worden. Een element kan ruwweg 450 liter water opslaan. Meerdere elementen kunnen aan elkaar gekoppeld worden om zo één groot buffer te creëren. Zo kunt u denken aan een vijver, tuinmeubulair, holle plantenbakken of zelfs holle bomen. De intelligentie van dit systeem zit in een slimme klep, bij de regenpijp. Op basis van neerslagvoorspellingen reageert het systeem snel en dynamisch door het buffer te legen vóór een extreme stortbui om overstromingen tegen te gaan.

## MADE Model

Dit model stamt uit de tak ziektebeheer van de gezondheidszorg[1], en bestaat uit cyclisch netwerk van vier processen:

### Monitoring (M)

Het proces van het maken van observaties van het probleem en de context, resulterend in een collectie van categorische, numerieke data.

### Analyse (A)

Omslaat het proces van het transformeren van de abstracte gemonitorde data in informatie die meer betekenisvol is voor mens en systeem.

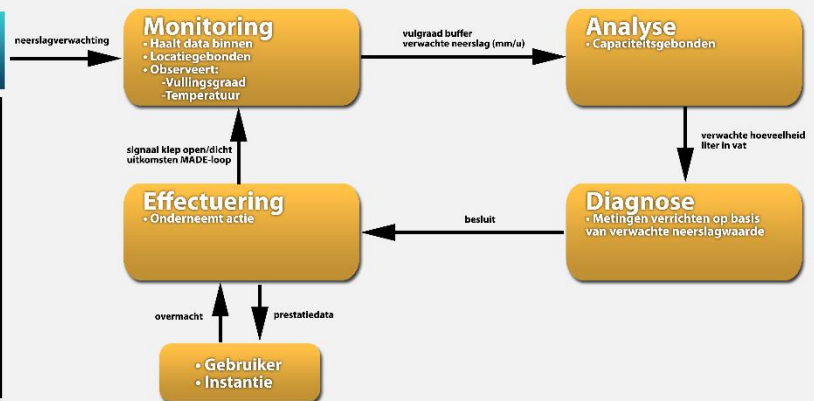
### Diagnose of Besluitvorming (D)

Keuzes worden gemaakt gebaseerd op alle mogelijke alternatieven, het juiste plan wordt uitgevoerd gebaseerd op de Analyse.

### Effectuering (E)

In de Effectuering wordt de besluitvorming uitgevoerd, met de intentie om de staat van het probleem te veranderen.

[1] A conceptual Framework for the Functional Design of Telemedicine Systems, Sults et al.



## Functionele Architectuur

