Thermal Energy Recovery from Wastewater at the TU Delft Campus

in partial fulfilment of the requirements for the degree of

Bachelor of Science

in Civil Engineering

at the Delft University of Technology,

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Preface

This BSc thesis, named ‘Thermal Energy Recovery from Wastewater at the TU Delft Campus’, originally arose from my interests in water management, environmental technologies and the combination of the two. Seeing projects from a sustainable and environmental friendly perspective is gaining interest progressively. Personally, I appreciate this development and it therefore gained my interest during my bachelor program.

I would like to take this opportunity to thank both of my supervisors for their support during the process. I have gained great insight from Prof. dr. J.P. van der Hoek during the regular meetings. Additionally, my interest in the technologies and developments regarding water treatment increase during the lectures given by my second supervisor, Prof. dr. ir. L.C. Rietveld. Especially his BSc course ‘Introduction to Water Treatment’ (CTB3365), has caused my interest in water management to increase greatly.

To Whom it may concern, I hope you will enjoy reading my BSc thesis.

Omar van der Marel

Delft, October 22, 2018

Abstract

In order to reduce the emissions of CO_2 and other greenhouse gasses, sustainable development is gaining in importance in the recent years. This is also the case for TU Delft. The sustainable advancement requires renewable energy sources that do not require fossil fuels. The wastewater flow is currently not utilised as a renewable energy source at the TU Delft campus. Thermal energy is 80% of the total energy embedded in wastewater. In order to increase the amount of green energy that is produced on campus, it is useful to analyse the possibilities regarding the thermal energy recovery from wastewater.

This study aims to give substantiated recommendations towards TU Delft, about how this currently dissipated flow can be used to generate energy. The main research question this research aims to answer is: "*How can thermal energy recovery from wastewater contribute to the TU Delft campus?*"

This main research question could be answered through literature reviews and three case studies, whereafter and implementation followed. First, an understanding of energy recovery from wastewater should be gained. Based on the conclusion that thermal energy carries the most potential in a wastewater flow, different technologies on different scales were defined. This lead to a toolkit that could be used in further analyses. It was used in the three case studies that followed. This provided further insight into how the technologies on different scales on university campuses can be implemented. Locations at the TU Delft campus have then been reviewed and potential interventions have been pointed out. The results showed that small and medium scale interventions at selected locations are possible. Projects on a larger scale would not be feasible on the campus.

Further research could be conducted to extend the toolkit and make a cost-benefit analysis (CBA). Installation and maintenance costs should be evaluated in order to make the recommendations economically feasible.

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1. Introduction

1.1 Background

Waste production and recovery procedures are dynamic and inevitable subjects within environmental discussions (Sander, Jepsen, Schilling, & Tebert, 2004). Since the predominant source of energy in the current situation consists of fossil fuels, the amount of energy obtained from this source is limited (Lodhi, 2004). The energy consumption results in several forms of waste, which will then be squandered and left unused. This model is rather linear (figure 1-1).

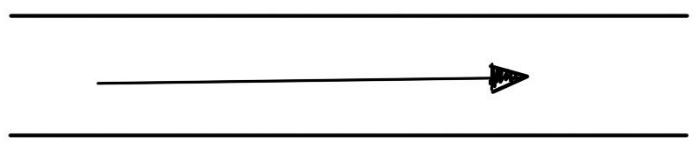

Figure 1-1: Current situation regarding wastewater flow

Therefore, a logical response would be to increase the number of renewable energy sources, to create a somewhat circular model. Wastewater has the potential to recover energy, so it can not only be used as a waste product (linear), but also as a source of energy (circular). Frijns, Hofman, & Nederlof (2013) have found that 23% of the demand for gas in Dutch households is used for the heating of water. Frijns et al. (2013) additionally found that part of this heated water gets into the wastewater, which means the wastewater carries the potential of thermal energy recovery.

Thermal energy (heat) recovery from wastewater has been proven to be successful in the past. In the eighties, a thermal energy recovery installation in Tokyo has been introduced. The installation provided energy to control the temperature in the present office buildings (Funamizu, Iida, Sakakura, & Takakuwa, 2001). Therefore, thermal energy from wastewater is proven to be successful and carries a considerable potential to change the current system into a rather circular model, rather than the linear model in the current situation (figure 1-2).

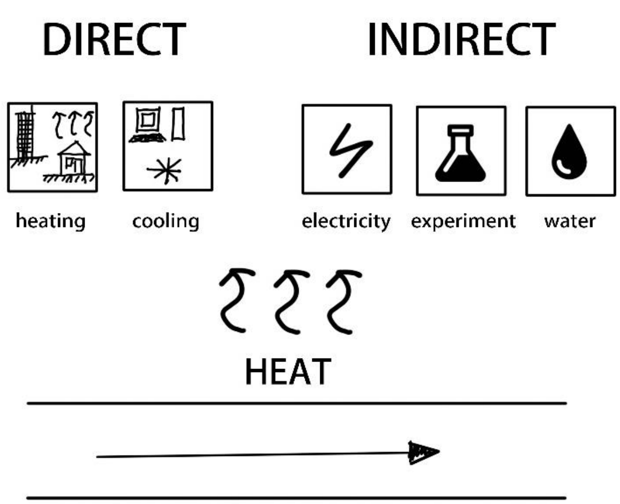

Figure 1-2: Potential use of the thermal energy recovered from wastewater

In the current situation, as far as the author is concerned, the wastewater discharge is not utilised in any way at the TU Delft Campus, so also not to add input to the adapted heat infrastructure. In this way, energy is being wasted and dissipated that could have been used as a contribution towards a more sustainable campus.

Looking at the vision of TU Delft (n.d.), heat and water use are important aspects of future strategies towards a sustainable campus. The 'TU Delft smart thermal campus grid' has been established to reduce the gas demand and C02 emissions. This is done by developing and adapting the current heat net in an effort to make this net compatible with sustainable energy sources like geothermal energy sources.

1.2 Research questions and corresponding methods

This future vision allows for sustainable interventions in multiple forms. TU Delft could therefore apply thermal energy recovery from wastewater. In order to come to substantial recommendations for TU Delft to do this, this Bachelor Thesis will aim to answer the following research question:

- *How can thermal energy recovery from wastewater contribute to the TU Delft campus?*

To formulate an answer to this main research question, an underlying understanding of the terms, thus a division into sub-research questions, is necessary. These are as follows:

- *What forms of energy can be recovered from wastewater?*

Methods used to answer this question: Review of works of literature to create a theoretical foundation on energy recovery from wastewater.

- *How can thermal energy be recovered from wastewater and what are the potentials on different scales?*

Methods used to answer this question: Review of works of literature to elaborate on the potentials of thermal energy recovery from wastewater.

- *What thermal energy recovery systems are applied at other universities?*

Methods used to answer this question: Review of works of literature and evaluation of existing projects in order to come to a substantial review of thermal energy recovery from wastewater on campuses.

- *How can the thermal energy recovery systems be applied at TU Delft?*

Methods used to answer this question: Evaluation and analysis of the TU Delft campus to potentially realise possible sustainable interventions regarding thermal energy recovery from wastewater coming from the TU Delft campus.

1.3 Structure of the thesis

In chapter two, the potentials of energy recovery from wastewater in general will be highlighted. It explains thermal energy recovery from wastewater and its potential is compared to other forms of energy recovery from wastewater. The end of the chapter will form a foundation for the conclusion that can be drawn from chapter three.

Chapter three will be explaining the different techniques for thermal energy recovery and the requirements will be studied. At the end of chapter three, a ‘toolkit’ will be provided containing the different technologies to recover thermal energy from wastewater. This ‘toolkit’ can then be used in chapter four and five for review and application respectively.

Chapter four will contain case studies from other campuses from around the world. Different techniques, from the toolkit, have been applied at different campuses. This chapter will give an indication of the potential uses of the technologies and thermal energy on university campuses.

After chapter four, chapter five will apply the technologies found in the toolkit in chapter three for TU Delft. This chapter will end with a reflection and recommendation for TU Delft, to assist in reaching the targets according to the vision of TU Delft (n.d.).

Finally, in chapter six, the possibilities for the TU Delft campus and campuses in general will be concluded and a discussion will follow, where the significance of the results of the research can be described and interpreted. Additionally, a reflection will wrap up the chapter, where a personal response to experiences, limitations and unexpected situation will be stated. This allows for critically thinking and reviewing the process.

An overview of the structure of the thesis is given in figure 1-3.

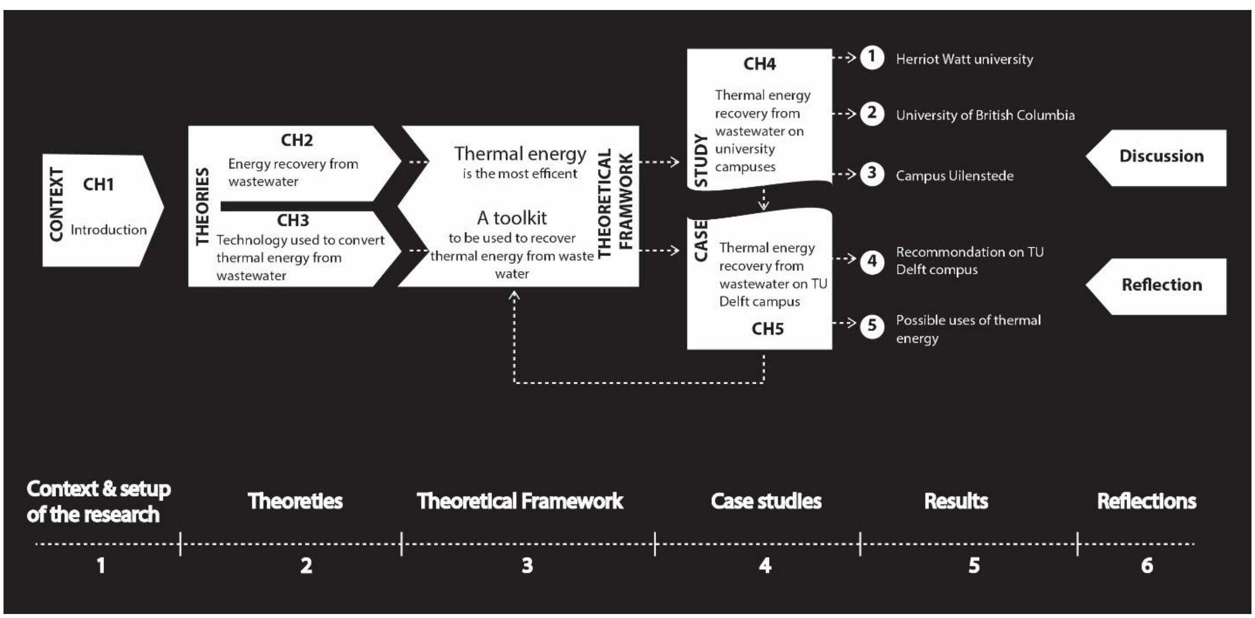

Figure 1-3: Structure of the thesis

2. Energy recovery systems from wastewater

In order to gain an understanding of the general forms of energy recovery from wastewater, an analysis will be done to highlight different potentials of a wastewater flow. In this chapter, the importance of renewable energy use will be mentioned. Additionally, the different ways to recover energy from wastewater will be examined, whereafter an explanation will follow as to why thermal energy carries the most potential.

2.1 Renewable energy

In the present day, fossil fuels are still the predominant source of energy globally (Lodhi, 2004). According to Dahl and Mcdonald (1998), the energy demand is expected to triple in the coming decades. Therefore, in order to limit the greenhouse effect, there should be an increase in the amount of produced renewable energy.

Renewable energy is an upcoming source of energy globally. According to REN21 (2016), renewable energy had an estimated share of 19,2% of the global energy consumption in 2014. Fossil fuels are still predominant and account for the source of 78,3% of the total global energy consumption. Nuclear energy had a share of 2,5%. From the 19,2% renewable energy, 8,9% consists of what is called ‘traditional biomass’. Traditional biomass is described as the energy used for cooking and heating in rural areas in the developing world. The remaining 10,3% contained renewable heat energy (4,2%), hydropower (3,9%), wind/solar/biomass/geothermal energy (1,4%) and biofuels (0,8%).

Technology regarding renewable energy sources is developing fast and is therefore gaining interest from potential investors. By reducing the production costs, doubling the durability and increasing the capacity, the efficiency of the technology is higher than ever and is expected to increase even more (Office of Energy Efficiency and Renewable Energy (U.S. Department of Energy), 2012). This results in an increase of corporations developing technology and generally more investment in it. This makes renewable energy a broad focus point and should therefore be incorporated into the current and future development.

2.2 Wastewater

In recent years, energy recovery from wastewater has been proven to be a successful way of generating sustainable energy. Despite the successes, there are still opportunities for further enhancements. In general, the three main forms of energy that can be restored are chemical, hydraulic energy, and thermal energy. As an example, in the United States, these recovering processes can produce a considerable amount of energy “is five times the energy demand estimated for treatment of domestic wastewater in the U.S.” (Tarallo, 2014, pp. 9-2). This potential should not be untouched and dissipated.

2.2.1 Chemical energy

First of all, wastewater has the potential to recover chemical energy. Chemical energy is mainly recovered at the location of the wastewater treatment plant and it is generally symbolised by the chemical oxygen demand (COD) (Tarallo, 2014). The study finds that approximately 20% of the energy stored in wastewater exists in the form of chemical energy. This would be around 46600 GWh annually.

However, other studies suggest that this could be slightly more when the right method is applied. Heidrich, Curtis, and Dolfing (2011) found that the chemical energy potential not necessarily relates to the COD concentration, but is significantly influenced by the approach of measuring the properties of the wastewater.

All in all, the chemical energy that could be recovered (with a hypothetical efficiency of 100%) is around 20% to 25% of all the energy that is stored in domestic wastewater.

2.2.2 Hydraulic energy

Additionally, hydraulic energy is a source of energy that is widely produced globally. Its share of the total energy production is around 3,9% (REN21, 2016). This is largely in produced by dams (conventional hydropower), but can also be generated in other ways. Small and micro hydropower is focused on small projects and generally generate less than 10 megawatts or even a few kilowatts for smaller villages or individual households. It has therefore been proven to be a successful way of recovering energy on different scales.

The principle is the same across the different scales. The energy that can be recovered is the kinetic energy in the water. The difficulty, however, is that a constant flow rate would be required to maintain a higher efficiency. This is usually not an obstacle for projects involving dams and reservoirs, but on a smaller scale, this can lead to complications. An example is found in Switzerland, where the design flow rate was only reached for a handful of days annually (Choulot, Denis, & Puyns, 2012).

Therefore it is important to note that not every flow is constant when this technique is applied at wastewater flows. This highly varies across scales. On the small scale, it can be visualized by a sink. Projects that could hypothetically recover energy from the wastewater flow from the sink have economic benefits. Mainly because of the size of the intervention needed, but on the other hand, the flow is highly fluctuating and depending on the frequency of consumption. Projects that would be realised on a larger scale (wastewater treatment plant) contain relatively more constant flows. Additionally, the amount of water in the influent is significantly larger, which means a larger amount of energy that can be recovered.

However, the potential of hydraulic energy is relatively low, compared to the other forms of energy that can be restored from wastewater. According to Tarallo (2014), the kinetic energy from the wastewater only accounts for less than 1% of the energy that is stored in the wastewater. Therefore it should be considered as a less significant source of energy regarding the wastewater flow.

2.2.3 Thermal energy

The idea of recovering thermal energy is around for more than a century. The heat that can be generated could be used for space or water heating. However, the older techniques would utilise traditional energy sources, (fossil fuels), to provide the energy that is necessary to execute the process. Nowadays, the new technology regarding this restoration of thermal energy makes it possible to reduce CO_2 emissions and to reduce energy costs (Johnson, Lindquist, Hart, & Homenuke, 2009).

However, there are restrictions with respect to the recovery of thermal energy from wastewater. When the heat is recovered, it needs to be distributed to consumers. Generally, there is a scarcity of distributing framework, which could lead to additional costs when installing a corresponding recovery system. Additionally, the distance between the recovery installations and the consumer should not be too large. Distances that are too large could lead to significant heat losses. Nevertheless, some cities in Europe and several buildings in the United States thermal energy recovery is a source of energy that can cover part of the energy demand and in some cases even 100% (Tarallo, 2014).

Finally, Tarallo (2014) found that approximately 80% of the energy in wastewater consists of thermal energy, which is equal to around 202512 GWh annually. This energy would serve as a source of heating to supply heat for individual housing, neighbourhoods or other systems, depending on the scale. Tarallo considered seasonal differences in temperature. This could cause less efficiency, as different temperatures require different amounts of energy to deliver an effluent having a constant temperature. There are several ways of recovering thermal energy on these different scales. These techniques will be elaborated on in chapter three.

2.3 Conclusion

Renewable energy will be one of the main focusses when it comes to the reduction of greenhouse gas emissions. The wastewater flow is currently untouched and the energy that it carries is 100% being dissipated. It is therefore important to uncover it's potential in becoming a renewable source of energy.

Three ways of energy recovery from wastewater have been considered; chemical energy, hydraulic energy, and thermal energy. Chemical energy accounts for 20% of the energy stored in wastewater, 80% is in the form of thermal energy and less than 1% of the energy embedded in wastewater consists of hydraulic energy. It can therefore be concluded that thermal energy carries the most potential. When the right techniques are used to reach a considerable efficiency, the thermal energy recovery process from wastewater can be beneficial.

3. Technology used to convert thermal energy from wastewater

The recovery of thermal energy therefore carries the most potential. To gain insight into the potential of restoring thermal energy from wastewater, the different techniques should be differentiated and evaluated. This chapter will, therefore, analyse and evaluate these different techniques in order to determine their potentials for the TU Delft campus.

Thermal energy recovery from wastewater implies the extraction of heat from the consumed water. The recovery can be performed even when the temperature of the sewage is relatively low, sometimes as low as 10 degrees Celsius, with an average temperature of 20 degrees Celcius. Industrial discharge contains water with a temperature of 30 to 40 degrees (Alekseiko, Slesarenko, & Yudakov, 2014). This means that the recovery of thermal energy from wastewater is a low-temperature heat recovery process.

This recovery is possible at on different scales in the wastewater cycle. First of all, the process of thermal energy recovery can be carried out at the start of the cycle, right after consumption. The energy (temperature) loss is relatively low and it would therefore be highly efficient to recovery the heat from the water at this location. However, the considerable drawback is that the difference in the amount of water highly depends on local consumption and the flow is therefore not constant. Second of all, thermal energy recovery can be executed at the scale of the local sewage infrastructure. As expected, the temperature will be lower, due to heat being wasted into the soil, but also due to cold rainwater entering the sewage. However, the flow will be significantly more constant. Lastly, the thermal energy recovery can be done at the level of neighbourhoods, cities or a wastewater treatment plant. The flow at the latter is the most constant flow, but a minimum in temperature is reached. Therefore, a balance should be found in order to determine the perfect location where the thermal energy should be recovered (Oesterholt & Hofman, 2014).

3.1 The small scale

Projects involving thermal energy recovery directly after consumption have been done in multiple ways. One of the designs that were successful, was the Dutch Solar System's (DSS) shower heat exchanger, which has been designed by BRIES Energietechniek. In general, there are two main principles; the shower drain system and the vertical shower system. The designs are generally bought by individuals when shaping a new bathroom.

The shower drain system is designed for showers that are located on the ground floor of a house or in apartments. The principle is relatively simple: a heat exchanger is built in the shower drain. A countercurrent exchange, with a turbulent water flow flowing through a pipeline with a diameter of around 50 mm, is used to optimise the efficiency up to 49,1%. The cold water comes from drinking water and is approximately 10 degrees Celsius. This cold water will rise in temperature using the heat from the warmer flow coming in from the other side. The wastewater that has lost temperature will be discharged into the sewage system and the clean, preheated water will be discharged back to the house for further use (Bries Energietechniek, 2013). This principle is displayed in figure 3-1.

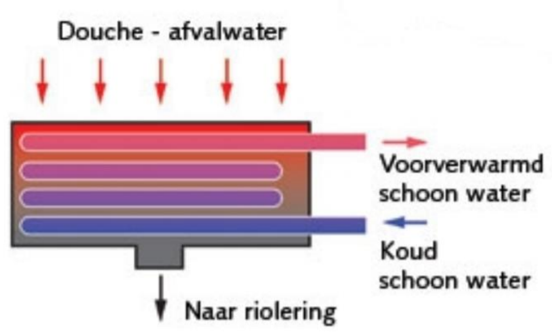

Figure 3-1: Countercurrent exchange in the shower drain (Bespaar-nu-energie, n.d.)

Generally, there are two ways to install the shower drain system. The difference is mainly the connection of the influent of the boiler. This can come from the preheated (clean) water, or the cold (clean) water. The highest efficiency is reached when the first is being used. This is due to the fact that in the first situation, the amount of wastewater is significantly larger than the amount of cold, clean water needed for heating the water. In both ways, the preheated water will be connected to the 'cold side' of the mixing valve, resulting in a lower demand of hot water from the main boiler, and thus in a lower demand of gas. To be exact, 50 m^3 of gas could be saved per year per person, which equals around 488,5 kWh per year per person. (Bries Energietechniek, 2013a). The connection with the highest potential is presented figure 3-2.

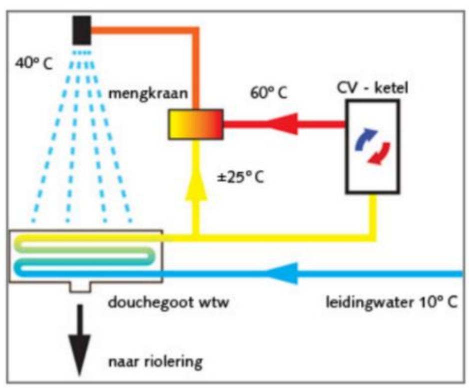

Figure 3-2: Shower drain heat exchanger connection scheme (Bries Energietechniek, 2013a)

DSS's vertical shower system, also designed by BRIES Energietechniek, is another form of thermal energy recovery directly after consumption. It is designed for showers on the first floor or higher, in single-family homes or apartments. The principle is similar to the shower drain system, but the vertical direction makes it possible to apply the system to greater heights. The wastewater coming from the shower flows down to the sewage system. In the opposite direction, the clean (cold) water is pumped in separate pipelines right next to the wastewater, where it absorbed the heat coming from the warm wastewater. Even though the difference in temperature is relatively low, the amount of thermal energy that is transferred is relatively high and can reach values up to

63,7%. Just like the horizontal heat exchanger, approximately 50 m^3 of gas can be saved per person per year, which equals around 488,5 kWh per person per year (Bries Energietechniek, 2013b). The principle is illustrated in figure 3-3.

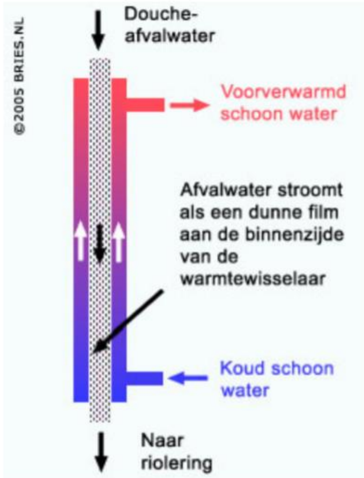

Figure 3-3: Principle of the vertical shower system (Bries Energietechniek, 2013b)

The most efficient method to install the vertical shower system is similar to the shower drain system. The preheated water from the vertical shower system is connected to the mixing valve as well as the boiler. In this way, less energy (gas) is needed for the heating of the incoming cold water. Due to possible difficulties during installation, it can be more convenient to connect the preheated water to only the mixing valve, or only the boiler. However, this will lead to a decrease in efficiency of 15% and 25% respectively (Bries Energietechniek, 2013b). The connection scheme carrying the highest potential is displayed in figure 3-4.

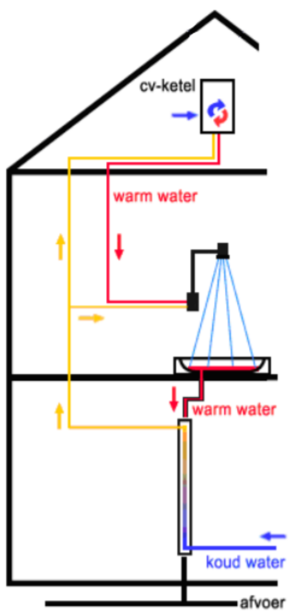

Figure 3-4: Vertical shower system connection scheme (Bries Energietechniek, 2013b)

3.2 The medium scale

Techniques involving thermal energy recovery from the wastewater cycle on the medium scale have been applied widely, all around the world. The scale of local sewage systems will be considered the medium scale. In general, thermal energy can be recovered on this medium scale on two levels; at the scale of an apartment (property) or at the scale of the local sewage pipes (local precinct). These projects have been implemented with varying degrees of success.

First of all, it is important to note that on the medium scale, heat exchangers are not the only technique being used to recover thermal energy. Heat pumps offer an addition to the process and can reach higher temperatures, up to 60 degrees Celsius. Heat pumps gather cold (clean) water and heat it with a surrounding, warmer water body (in this case the wastewater). This stage is called the evaporation stage. This heated water is then compressed by an electric compressor and this process increases the temperature dramatically, where it can be transferred elsewhere at the condenser. In this case, the heated water effluent can be used directly for radiators, or it can be connected to the main boiler, where a small amount of energy is needed to increase the temperature even more. The latter makes it possible to use the effluent of the heat pump for applications like showers. After usage, the water needs to cool, in order to be discharged. This is done in the expansion valve. Depending on the heat pump, 4 to 5 kW of thermal energy can be produced for every 1 kW that is needed during the process (The Greenage, n.d.). The principle of a water source heat pump is presented in figure 3-5.

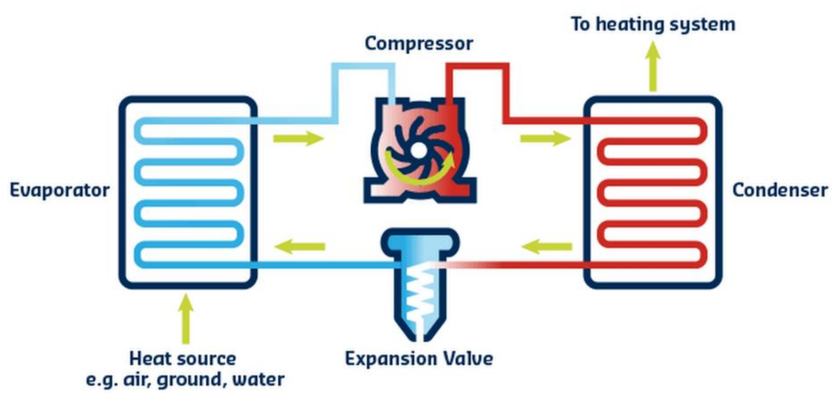

Figure 3-5: Principle of heat pump providing heat (Caplor Energy, n.d.)

A study to thermal energy recovery in a small-scale sewage system has been done by Oesterholt and Hofman (2014). They designed a recovery system where 20 to 50 households in Groningen would be supplied by heat coming from the local sewage system. This energy would be used to heat water and air conditioning. After the design, a corresponding business case had been developed. The computed business case showed that a complementary design is economically not beneficial. This is mainly due to the low gas price. The gas price would have to increase by almost 70% in order to make the design cost-effectively feasible.

However, there are projects involving thermal energy recovery that are economically feasible. A swimming pool in Sweden applied a system involving two a combination of heat exchangers and heat pumps to recover the thermal energy. After measurement, the amount of energy recovered was 4800 kWh, while only using 840 kWh for the heat pump (Nykvist, 2012).

Another successful example is found in the B1000 heat exchanger, designed by Ecodrain (Ecodrain, n.d.). The heat exchanger receives the wastewater effluent directly, due to the connection to the main sewage line and to direct connections to household applications that discharge large amounts of wastewater (showers, dishwashers etc.) The diameter of these installations depends on the amount of wastewater that will be discharged, but can vary from 3 to 12 inches (approximately 75 to 300 mm) and can be applied horizontally and vertically. With a high efficiency, the recovery rate of this system could reach up to 41%. The efficiency could potentially be even higher using the vertical installation, due to the larger contact surface of the cold water.

Finally, wastewater can be collected outside of a structure, in an isolated small reservoir, where wastewater will be stored temporarily and even cleaned slightly before being discharged on the main sewage system. An example of this is found in Eulachhof, Winterthur, (Switzerland), where a heat exchange system designed by FEKA is installed. The wastewater from 132 apartments is collected and cooled through a separate (shaft) heat exchanger. The heated effluent is then discharged to two heat pumps, which can bring the temperature up to 60 degrees Celsius, to be used for hot water in the dwellings. This system can provide a total of 140 kWh to the dwellings, which accounts for almost 15% of the total energy demand (Schinnerl, Bucar, Piller, & Unger, 2007; Heiduk, 2009). The advantage of this system is the fact that a high temperature can be reached using a low amount of energy. However, this technique requires a considerable amount of space and could therefore cause spatial difficulties. According to Van Velsen and Benz (2013), the efficiency is difficult to estimate, but the efficiency is higher than 20% and increases when the technology is used in the proper structures. For the FEKA shaft system, this would be more than 40 housing units, sports buildings or hospitals to name a few examples. Additionally, the minimum amount of wastewater that should flow in the sewage system is around 8000 to 10000 litres per day (Schinnerl et al., 2007). Finally, the heat recovery has given in a study executed by Arnell, Lundin, and Jeppsson (2017) and was found to be around 6,56 kWh/m^2.

3.3 The large scale

Thermal energy can also be recovered on a larger scale than separate houses or local sewage systems. This larger scale would cover a neighbourhood, village or even (a part of) a city. The recovery of thermal energy at the wastewater treatment plant is also possible. However, due to the scale of the research, this will not be incorporated in the literature review. Additionally, in this research, within the defined larger scale, the focus will be on thermal energy recovery in the two most common methods. The main distinction is the installation of the heat exchanging system.

First of all, the heat exchanging system can be installed together with the sewage pipe. This can not only be done in the case of installing a new sewage system, but also while renovating a current sewage infrastructure. An example is the Rabtherm system, developed by Rabtherm Energy Systems. The thermal energy will be exchanged in the pipeline system surrounding the sewage pipelines, whereafter the warm water flows to the heat pump (collector). After the water gets heated even more through the heat pump, the temperature of the water can reach a maximum of approximately 70 degrees Celsius. The principle is explained in figure 3-6. The sewage pipelines should have a minimum diameter of around 400 – 800 mm and an average discharge of more than 12 l/s. The length of the system can vary from 9 to 20 meters. Finally, the distance to the consumer shouldn't be more than approximately 200 meters, in order to avoid energy losses. Depending on these variables, the system could recover around 2 to 3 kW/h per cubic meter of wastewater (Rabtherm Energy Systems, n.d.).

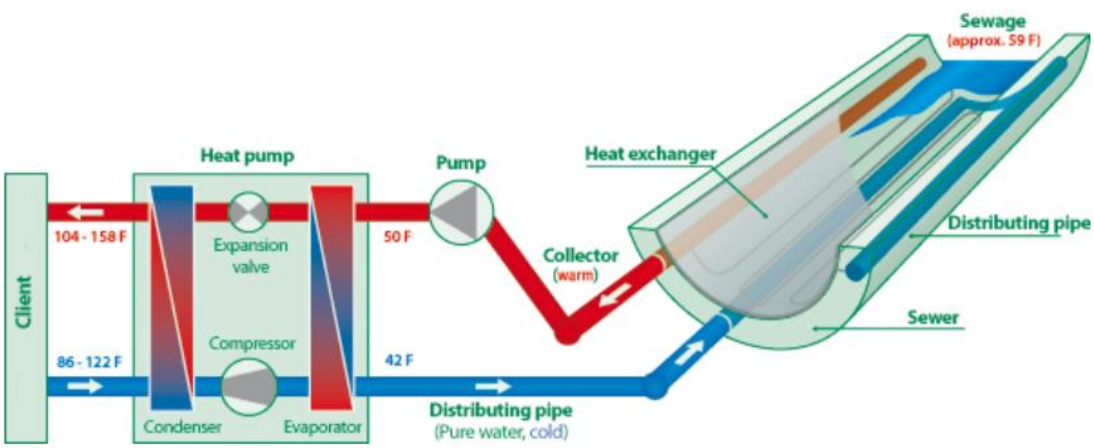

Figure 3-6: Rabtherm System (Rabtherm Energy Systems, n.d.)

Finally, another installation method is possible. This required the heat exchanger to be above ground level. In this case, part of the sewage should be filtered using a screen (to prevent clogging of the heat exchanging system) and will be pumped above ground level to the heat exchanger. An example of this is the ThermWin system that is designed by Huber Technology.

The ThermWin system consists of a shaft with a delivery pump, a heat exchanger and a heat pump. A part of the wastewater from the sewers is screened in the shaft. This is mainly to prevent clogging of the pump and the heat exchanger. The screened water is then pumped to the heat exchanger whereafter it flows to the heat pump. After the thermal energy is extracted, the cooled wastewater flows back into the shaft, where it collects the coarse materials located at the screens and continues to flow into the sewage system (Huber Technology, 2010). The ThermWin system is displayed in figure 3-7.

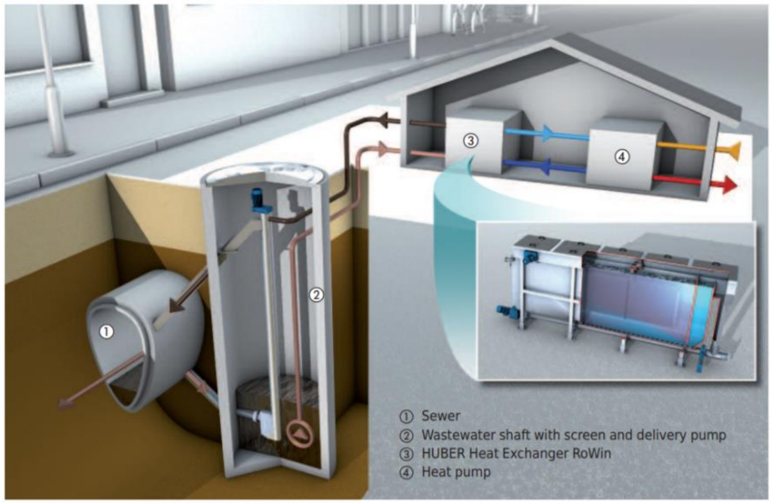

Figure 3-7 HUBER ThermWin system (Huber Technology, 2010)

The newly installed ThermWin system can operate with sewage systems of a wide range of dimensions. The minimum required continuous flow rate is approximately 5 l/s. For every kW of energy that is put into the process, up to 5 kW of thermal energy will be transported for consumption. According to Huber Technology (2015), the amount of energy that can be produced by this system is around 10 kW per litre per second. To name an example, a 28 storeys high building in Switzerland uses the ThermWin system, which takes a maximum of 50 l/s from the sewer system, which has a dry weather flow of 160 l/s. This provides 585 kW of thermal energy to the heating framework of the building, which accounts for 75% of the energy demand of the building (Huber Technology, 2010).

It is important to note that another alternative to the ThermWin system is available, which is suitable for existing sewage infrastructure; the Huber TubeWin system. However, the Tubewin system can only be installed on existing sewage pipelines with a diameter over 1000 mm (Huber Technology, 2012).

3.4 Conclusion

It is necessary to choose the fitting technique into the right situation regarding thermal energy recovery from wastewater. Therefore, it is important to differentiate the three scales on which the energy can be recovered. After a literature review on the different technologies, a toolkit can be developed in order to analyse certain cases. The toolkit serves as a summary of the technologies covered in chapter three and can be found in table 3-1. Table 3-1 displays an overview of the different techniques used to recover thermal energy from wastewater. For every technique, the scale, the amount of energy recovered, requirements (discharge and diameter of the pipelines) and the efficiency is presented. Examples that have been elaborated on, are shown in the last column of table 3-1.

	Scale	Recovered energy	Required discharge	Diameter range	Efficiency	Example
Horizontal heat exchanger	Small	~ 488,5 kWh per person per year	~ 0,2 l/s	~50 mm	~49%	Shower drain system
Vertical heat exchanger	Small/medium	~ 488,5 kWh per person per year	~ 0,2 l/s -	70 - 300 mm	~ 41%-64%	Vertical shower system; B1000
Collected wastewater heat exchanger + heat pump	Medium	6,56 kWh/m^2	> 8.000 - 10.000 l/d	-	>20%	FEKA System
Integrated heat exchange + heat pump	Large	2 - 3 kW/h $/m^3$ wastewater	> 12 l/s	400 - 800 mm	-	Rabtherm system
Separate heat exchanger + heat pump	Medium/ large	10 kW/l/s	> 5 l/s	>1000 mm	-	Huber ThermWin; Huber TubeWin

Table 3-1: Overview of technologies used for thermal energy recovery from wastewater

4. Thermal energy recovery from wastewater on university campuses

In chapter two and chapter three, thermal energy recovery from wastewater has been proven to be efficient and successful. The following chapter will review the thermal energy recovery projects from the Herriot Watt University, the University of British Columbia and the campus of Uilenstede. These projects will be evaluated on different subjects. In this way, the implementation of different techniques from the toolkit developed in the previous chapter can be analysed which give a reference point for the appliance at the TU Delft campus.

4.1 Evaluated subjects

In order to review and compare different thermal energy recovery systems from wastewater, several points should be examined. These points are: the technology that is being used on the campus to recover thermal energy from wastewater; the amount of energy that is being recovered; the amount of water that is used; the spatial dimensions of the intervention and the implementation.

The several technologies are covered in chapter three, where different technologies have been briefly elaborated on. It is important to note that not all of the systems that have been mentioned in the preceding chapter are used on the campuses. This might be due to the differences in scale, or available resources.

The amount of energy that is recovered and therefore generated is also described. This gives an indication of how efficient this system is for the campus. The number given in the table is given in the units that are available and converted where possible.

Different campuses have different discharges in wastewater flows and therefore different potentials regarding thermal energy recovery. The amount of water treated gives an indication of the potential energy recovery; the more water that can be treated, the more thermal energy that can potentially be recovered.

The space that is needed in order to apply the technology on campus, varies per system. This also varies per campus, owing to the fact that different campuses allow for different sewage infrastructure and therefore differ in potential space for practical implementations. The space that is used is defined as the area that the system in question needs to function, as well as the diameter of the pipelines.

Finally, the energy that has been generated can be utilised in different ways (SEE FIGURE 1-2). This utilisation can be divided into two: direct use and indirect use of thermal energy. The implementation of the energy is given in the last column of the table. This will illustrate how the energy can be used and could assist in suggesting certain applications for the TU Delft campus.

4.2 Case studies

The three different chosen sites have different ways of recovering thermal energy from wastewater. The possibilities may differ and this results in different possible dimensions of the recovery system. Spatial issues might cause limitation as well.

4.2.1 Scottish Borders campus

First of all, the Scottish Borders campus has been chosen. This campus is located in Galashiels, Scotland, and is home to students from the Herriot Watt University in Edinburgh and the Borders College in Galashiels. The Scottish Borders campus provided space to the first project regarding thermal energy recovery from wastewater (Dunsmore, 2016).

The technology that is used, is the SHARC system, designed by SHARC Energy Systems. The system generally works in three phases. First of all, the solid parts of the wastewater will be extracted, so that the solid parts and liquid go different ways. This is mainly to prevent the system from clogging. Then the thermal energy from the warm wastewater is transferred by a plate heat exchanger, whereafter it will be processed by the heat pumps and further transferred for consumption (Dunsmore, 2016). A plate heat exchanger is similar to a horizontal heat exchanger, but the metal plates in a plate heat exchanger provide more surface area and therefore a higher efficiency. Overall, this technique is similar to the separate heat exchanger and heat pump system; the wastewater gets put into a reservoir, whereafter the liquid part of the sewage will be processed above ground level for thermal energy recovery. The principle of the SHARC system is displayed in figure 4-1.

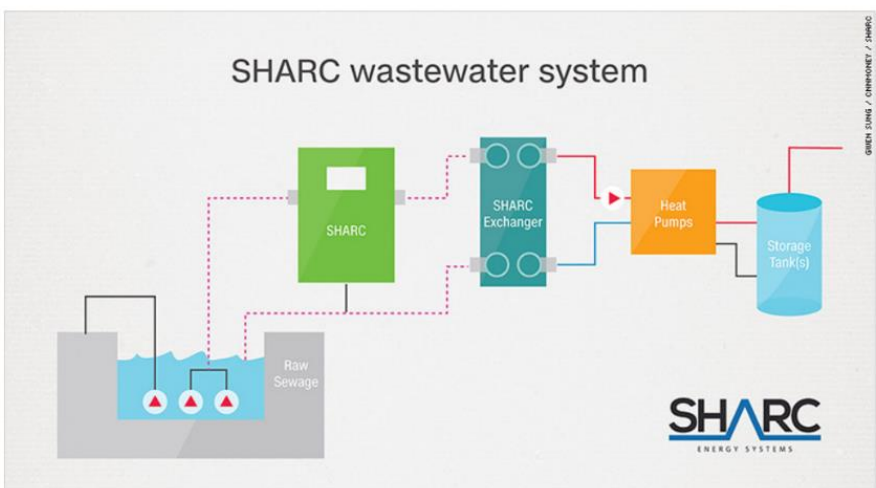

Figure 4-1: Diagram of SHARC system (Wattles, 2016)

The amount of water treated and the space the SHARC system occupies is not exactly specified, but the sewage pipelines have a diameter of 900 mm and the SHARC system is installed in the energy centre at the campus. This implies that additional space is needed in order to execute the energy recovery. The efficiency is also not exactly given, but Dunsmore (2016) stated that for every unit of energy that is required for the process to take place, almost five units of thermal energy are being produced. Furthermore, the energy that is generated, around 1,90 GWh/y, at the Scottish Borders campus is enough to cover 95% of the thermal energy demands of the campus, which houses 4500 students. This saves approximately 150 tonnes of CO_2 emissions annually (WWT (Water & Wastewater Treatment, 2016).

4.2.2 University of British Columbia

Secondly, the campus of the University of British Columbia in Vancouver, Canada uses a similar system to recover thermal energy from wastewater. It uses several units of the PIRANHA system, also designed by SHARC systems. The PIRANHA system is similar to the SHARC system, however, the PIRANHA system can be used for smaller projects and is therefore designed for individual buildings, between 50 and 200 dwelling units per system. It can provide these dwellings with around 2000 to 4000 gallons (7500 - 15000 litres) of heated, clean water per day (International Wastewater Systems, 2016).

In the case of the University of British Columbia, the SAIL Condos have been equipped with the PIRANHA system, where it supplies heat to 172 dwellings. This heat is utilised for space and floor heating. According to SHARC Energy Systems (2017), the amount of domestic wastewater that flows depends on the model that is being used and this can vary between 0.45 and 2.27 l/s. As there is no official source available that indicates the exact model, the exact amount of water that is treated can not be specified, but it should be within the given range. The recovery system restores 379,000 kWh (around 0,38 GWh) and saves approximately 100 tonnes of CO_2 emissions annually (SHARC Energy Systems & International Wastewater Systems, 2017).

4.2.3 Campus Uilenstede

Finally, at the campus of Uilenstede in Amstelveen, The Netherlands. This campus is home to approximately 3400 students from the University of Amsterdam and the VU University Amsterdam. A pilot study has been performed regarding thermal energy recovery from wastewater, on the small scale.

The project at campus Uilenstede involved the shower heat exchanger, as has been elaborated on in section 3.1. DSS's horizontal and vertical shower heat exchangers were used to recover the thermal energy from the wastewater coming from the showers in 100 student dwellings. As discussed in section 3.1, the efficiency of the vertical is significantly higher. However, due to technical difficulties, the vertical system could not be installed on the ground floor, so the horizontal system was used (Deng, Mol, & Van der Hoek, 2016).

Deng et al. (2016) found that the efficiency of both of the systems depends on multiple factors, like the flow rate, the duration of the shower, the temperature of the effluent, and the number of showers taken. To name an example, the higher the flow rate, the lower the recovery efficiency. However, the duration of the showers or differences in seasons showed no substantial influence on the efficiency. This finding resulted in a recommendation of using a water saving shower valve.

The amount of water that has been treated at the campus of Uilenstede was around 6.4 l/min, or 0.1 l/s. However, it is important to note, that this flow is not continuous and depends on the number of showers are being taken and the duration of the showers. The efficiency that was measured at the site was approximately 57%, which is slightly lower than the efficiency of (up to) 63.7% that is claimed by BRIES Energietechniek (2013b).

The study conducted by Deng et al. (2016) has additionally determined the annual savings regarding thermal energy and CO2 emissions. They have found that if every household in Amsterdam would install a shower heat exchanging system, 260.000.000 kWh could be saved per year. To estimate the energy savings per unit, with respect to the project at Uilenstede, this number can be divided by the total amount of dwellings in Amsterdam (412.000). This results in an estimate of the annual savings of approximately 0,631 MWh per unit, or 63,1 MWh for the collective 100 dwellings. The same could be done with the reduction of the CO2 emissions. This would theoretically result in an annual saving of 0.131 tons of CO2 per year, and 13.1 tons for the whole project at the campus of Uilenstede.

4.3 Conclusion

Thermal energy recovery has been a phenomenon on university campuses globally in recent years. Different university campuses allow for different recovery systems due to spatial difficulties, or different scales.

The Scottish Borders recovers enough energy (1,90 GWh/year) to cover 95% of the heating demand of the campus, which saves around 150 tons of CO2 emissions annually. This contributes to the sustainable vision of both universities sharing the campus. An addition to the existing sewerage (which has a diameter of 900 mm) has been made in order to recover this amount of energy. This made the process rather effective. However, the SHARC system, heat exchanger and heat pump had to be placed in a separate area at the campus, which requires a considerable amount of space.

At the campus of the University of British Columbia, the PIRANHA system is used to recover thermal energy from wastewater. This requires, similar to the SHARC system used at the Scottish Borders campus, space to collect and treat the wastewater. However, the PIRANHA system is, in contrast to the SHARC system, applicable to medium-scale systems, in this case an individual building. 0,38 kWh is being generated for 172 student dwellings annually, saving around 100 tons of CO2 emissions.

Finally, the campus Uilenstede has used a small-scale system in the form of a shower heat exchanger. The horizontal or vertical shower systems have been installed in 100 student dwellings, whereafter the efficiencies and potential savings could be determined. Efficiencies vary with the flow rate of the shower water, but are found to be approximately 57%. With this efficiency, around 63,1 MWh could be saved yearly on the scale of the whole project. This would correspond to a saving of around 13.1 tons of CO2 emissions for the whole project in a year.

The reviewed subjects have been summarised in table 4-1 for every case.

	Technology	Energy generated	Amount of water treated	Space needed	Implementation
Scottish Borders campus	Separate heat exchanger + heat pump: - *SHARC System*	1,90 GWh per year	-	Ø of 900 mm; an external energy center	Meets 95% of the heat demand of the campus for 4500 students; saving 150 tons of CO2 emissions per year
University of British Columbia	Collected wastewater heat exchanger + heat pump: - *PIRANHA System*	0.38 GWh per year	0,45-2,27 l/s	-	Space and floor heating for 172 apartments; saving ~100 tons of CO2 emissions per year
Campus Uilenstede	Vertical heat excchanger: - *Shower heat exchanger (DSS)*	63.1 MWh per year (100 units)	~ 0.1 l/s	Ø of 50-77 mm; shower infrastructure	Heating of shower water for 100 student dwellings; saving ~13.1 tons of CO2 emissions annually

Table 4-1: Summary of the three evaluated case studies

Table 4-1 provides a summary of chapter 4 and can give an understanding of the different systems on the different scales. An idea is created of the implementation of the system; how the thermal energy is being used. These implementations can serve as a reference point for chapter 5 and substantiate the recommendations that would follow afterwards.

5. Thermal energy recovery on the TU Delft campus

After the potentials of thermal energy recovery have been uncovered in chapters two and three and implementations on different campuses in chapter four, the next step is to analyse the area of the TU Delft, to discover the possibilities for its campus. This chapter will therefore look at the current situation on campus and will analyse the area accordingly. Efficiencies of implementations of the different techniques will be investigated, so that substantiated recommendations can be made.

5.1 The current campus

The campus in its present form has a vision on sustainability for the campus. Not only the buildings of the faculties, but also the utilisation of water, food, and waste are also topics that are being observed by TU Delft. Energy consumption is also a topic of broad and current interest at TU Delft. From solar panels to wind energy, renewable energy sources are of great importance regarding the consumption of electricity on the whole campus (TU Delft, n.d.).

To name an example, several sizable solar photovoltaic (PV) systems have been installed throughout the campus in order to provide the buildings with green energy. On a yearly basis, approximately 1 TWh is being generated. Currently, TU Delft is experimenting with this produced energy, in order to expand the possible utilisation of this solar power. Other emphases are put on the reduction of electricity in every faculty (TU Delft, n.d.).

Heating is also a subject that TU Delft (n.d.) sees as an opportunity that contributes to a sustainable campus. Currently, a project is being developed regarding geothermal energy. The well should lower both the energy demand and the CO2 emissions. However, this project is still under development and no decision has been made as of October 2018. Another project on the campus is the TU Delft central heat and power (CHP) plant, which produces enough energy to cover 30% of the heating demand. Strategies for the future involve expanding the heating infrastructure to other heating systems surrounding the campus.

In order to increase the sustainability of the campus and its buildings, other potentials could be uncovered, such as the wastewater flow. The sewage system remains untouched, regarding the recovery of energy, as of October 2018. This additional renewable energy source can contribute to the sustainable vision of TU Delft and the municipality of Delft, especially because the latter strives to become an energy neutral municipality by 2050 (Wielders & Scholten, 2017).

5.2 Evaluation of the TU Delft campus

In the previous chapters, the techniques regarding thermal energy recovery from wastewater are evaluated by different properties. A similar analysis can be done with the TU Delft campus. Analysing the properties of the current campus of the TU Delft, the toolkit from chapter three and four can be used to come to substantial recommendations for an implementation at the TU Delft campus.

A map of the pipelines located at the TU Delft campus is presented in Appendix A. The map shows the locations of the pipelines as well as the pumping stations. In communication with the project manager of Campus & Real Estate (G. Hofland, personal communication, September 20, 2018), it is relatively more convenient to apply interventions at the location of the pumping stations. This is mainly because these pumping stations are accessible from the ground level without having to make physical adaptations to the soil. In the map found in Appendix A, the diameters of the pipelines located at the campus are presented as well. Using the diameters, the scale of the potential interventions and its efficiencies can be determined.

First of all, during personal communication with the project manager of Campus & Real Estate (G. Hofland, personal communication, September 20, 2018), the main pumping station connected to a pressure pipeline (Dutch: ‘persleiding’) is located at the Mekelweg, close to the Faculty of Civil Engineering and Geosciences. This location is labelled as number 1 in Appendix A. This pumping station is named ‘Stevinweg’ and its discharge rates for an entire year (September 2017 to September 2018) are displayed in Appendix B-1. The average discharge rate that has been measured is 677 m^3. This number represents the total wet weather flow. This is the dry weather flow, plus influences from outside of the sewage system (infiltration and precipitation). Finally, this amount of water can be transformed into a unit of litres per second. Due to assumed inactivity on campus between midnight and 6:00 AM, the amount of ‘active hours’ per day is assumed to be 18. Therefore, 677 m^3 per day would correspond with a flow of approximately 10 l/s.

The diameter of this pressure pipeline is 300 mm, as can be seen in Appendix A-2. According to the toolkit presented in chapter three, this allows for medium scale projects regarding thermal energy recovery. Since the main pumping station is located underneath the Mekelpark, in front of the Faculty of Civil Engineering and Geosciences, there is enough space available above ground level for interventions. This allows for a ‘collected wastewater heat exchanger + heat pump’. This system requires new space, in addition to the sewage infrastructure. An example could be the FEKA System, where two 18 m^3 shafts were installed to collect the wastewater from the apartments in Eulachhof. Thus, this needs a considerable amount of space, however it would result in an effluent of 60 degrees Celsius and could therefore be connected to the existing heating grid at the TU Delft campus.

Another option at this location that can be considered is the ‘separate heat exchanger + heat pump’ system. Similar to the previous option, this would require available space above ground level. The Huber ThermWin system, as described in chapter three, could be applied, because this space is available on ground level. In addition, when using this system, part of the sewage can be used and therefore it is not necessary for the continuous discharge to be high.

However, there is a flaw when implementing an intervention like the ThermWin system. It would require a replacement of the current sewage infrastructure, which would be highly costly. The alternative presented by Huber is the TubeWin, which can be installed on existing sewage systems. However, as concluded in the toolkit from chapter three, this can only be done on sewage pipelines with a diameter of more than 1000 mm. Considering that no pipeline on campus meets this requirement (Appendix A-2), it can be concluded that this intervention, which is a large scale project, is not possible on any location on campus.

Another location, location 2 given in Appendix A-1, is the Feldmannweg. At Appendix A-3 the properties are given for this location. The street on the top of Appendix A-3 includes pipelines with a diameter of 600 mm. Looking at the toolkit, this meets the requirements of the 'integrated heat exchange + heat pump' system, on the large scale. An example of this would be the earlier described RabTherm system. This can be applied at the existing wastewater infrastructure and is rather easy to install. The heat pump can be installed above or below ground, which is also beneficial as at this given location, space is limited. However, the minimum required discharge is 12 l/s. Even though the discharge at this location is not given, as far as the author is concerned, it is highly unlikely that this minimum flow rate is ever achieved 'integrated heat exchange + heat pump'. Assuming that the continuous discharge is too low, it would be impossible to install an efficient large-scale heat exchanging system.

However, at this location student accommodation, under the supervision of DUWO, could potentially be a source of thermal energy from wastewater. The showers in the dwellings at the Korvezeestraat could be equipped with the horizontal and vertical heat exchanging system. The exact dimensions are not known, but it will be assumed that the shower systems installed in the apartments meet the requirements of these systems. In other words: it is assumed that the diameters of the shower drains is between 50 and 77 mm. In this way, 225 dwellings (DUWO, n.d.-a; DUWO, n.d.-b) could be installed with a heat exchanger in the shower. Using the available data regarding the efficiencies and potential recovery rates, a total of 0,631 MWh per apartment per year can be recovered. This would correspond with approximately 142 MWh annually for the whole apartment block, which corresponds with approximately 14535 m^3 of gas (De Energieconsultant, n.d.). However, with an installation cost of €490,- per unit, the initial investment can be costly. The payback time of the project would be between 7 and 13 years for single-student dwellings (Deng et al., 2016).

5.3 Conclusion

As of October 2018, TU Delft prioritises sustainable development on the campus. Projects and research that support this advancement have been established. However, the wastewater flow is unaffected and this carries a high potential concerning thermal energy recovery.

Using the toolkit defined in chapter three and four, a brief analysis can be made and several locations on the TU Delft campus can be reviewed. Three locations have been chosen and these have been evaluated on several subjects, in order to come to recommendations regarding thermal energy recovery from wastewater.

First of all, the main pumping station, which is connected to the pressure pipeline, in front of the Faculty of Civil Engineering and Geosciences is suitable for intervention. The discharge, diameter and location would allow for a thermal energy recovery system on the medium scale, the 'collected wastewater heat exchanger + heat pump'. A solution could be a system like the FEKA system, where one or two shafts would be installed at the Mekelpark, close to the pumping station. The other option, 'separate heat exchanger + heat pump' system, would not be as efficient as the 'collected wastewater heat exchanger + heat pump'. This is mainly due to the fact that a total replacement of the existing sewage infrastructure at this location is necessary. This would increase the costs considerably.

The second location that has been evaluated is the Feldmannweg. This location contains pipelines with a bigger diameter and would therefore allow for a large-scale recovery system. However, when applying the 'integrated heat exchange + heat pump' system, a rather high discharge is necessary to make the recovery process efficient (G. Hofland, personal communication, September 20, 2018).

Finally, the 225 student apartments from DUWO at the Korvezeestraat could be installed with small-scale heat exchanging systems in the showers. Assuming the flow rate is optimal in the showers and the diameter does not differ much with the diameter of the shower systems in campus Uilenstede, these properties meet the requirements of the small-scale systems. The horizontal and vertical heat exchanging systems could therefore be installed. The payback time is between 7 and 13 years, which could be considered as a long time. However, the initial costs, €490,- per unit, are not as high as installations on larger scales.

6. Conclusion and discussion

6.1 Conclusion

The demand for renewable energy sources is increasing, in order to decrease the emissions of CO_2 and other greenhouse gasses. Additionally, the current energy flow is linear, which indicates that the effluent of energy flows is being dissipated and therefore remains untouched. Thermal energy recovered from wastewater is one of these unaffected flows and could therefore potentially transform this linear energy flow into a circular model.

While TU Delft envisions sustainable development on its campus, the wastewater flow remains linear. To be able to determine whether interventions regarding the wastewater flow could assist in the sustainable development, the contribution from thermal energy recovery to the TU Delft campus has been examined.

Generally, three ways of energy recovery from wastewater can be distinguished: chemical energy recovery; hydraulic energy recovery and thermal energy recovery. 20% of the energy enclosed in wastewater can be recovered in the way of chemical energy, whereas 80% can be recovered through thermal energy. Hydraulic energy accounts for less than 1% of the energy stored in the wastewater flow. Thermal energy therefore is the segment of the wastewater flow that has the most potential. However, a sufficient and efficient approach should be considered, in order to make the process favourable.

Thermal energy recovery can be done in three different scales: the small scale, medium scale, and the large scale. The small scale involves recovery immediately after consumption, where the temperature is the highest, but the flow rate less constant. A shower drain system showed that high efficiencies can be reached on the small scale. The medium scale consists of projects at local sewage pipelines or individual buildings. Several systems have been successfully applied in different parts of the world. On the scale of neighbourhoods, villages or cities (the large scale), bigger systems have been developed. These systems on the medium and large-scale treat wastewater with a minimum temperature, hence the installation of one or more heat pumps is necessary. An overview of the technologies across the different scales (table 3-1) should give a foundation for the case studies.

Some of these techniques have been applied at several university campuses worldwide. An analysis of the Scottish Borders campus, the campus of the University of British Columbia and campus Uilenstede resulted in a reference point for possible implementations at the TU Delft campus. The efficiencies and savings provide insight on quantifications that could be made for the TU Delft campus.

To contribute to the achievement of the sustainable goals of TU Delft, thermal energy recovery can be applied at the TU Delft campus. An analysis at three potentially suitable locations has pointed out varying ranges of recommendations. The pumping station at the Mekelpark provides space for a ‘medium scale’ intervention. This could mainly be the ‘collected wastewater heat exchanger + heat pump' system, rather than the 'separate heat exchanger + heat pump' system. This is mainly due to economic benefits. The water that can be supplied to the heating grid is around 60 degrees Celsius. The amount of water can be supplied would depend on how much water will be treated. The location at the Feldmannweg would not be suitable for interventions, as the minimum required discharge rate would not be reached. The 225 DUWO dwellings could be installed with a small-scale system, which could save around 142 MWh annually, with a payback time of the initial investment of around 7 to 13 years.

These interventions regarding thermal energy recovery from wastewater can contribute to the TU Delft campus. However, the proper considerations should be made. Every system that has been mentioned has benefits, but flaws as well. Interventions can be costly and therefore form a flaw. However, most systems have a reasonable payback time and can therefore be considered as beneficial in the long term.

6.2 Discussion

This BSc thesis has examined the possibilities for implementation of thermal energy recovery systems at the TU Delft campus. The potentials of the wastewater flow have been analysed whereafter technologies to uncover this potential have been reviewed. After these have been determined, the implementation at other university campuses has been studied. All of these steps have led to the substantiated recommendations for implementations at the TU Delft campus. However, the conducted research has not touched upon every aspect related to the subjects, due to limitations.

One of the aspects that were not covered in the research is **the maintenance** of the different systems. Although data has been gathered about costs and methods to perform the maintenance, due to limitations in time, this could not be integrated into this BSc thesis. A recommendation for further research would be an analysis of the exact costs and procedures with respect to maintenance expenditures and feasibility.

Another aspect that can be covered in future research is a **more exact determination of the requirements for technologies** on the different scales. Due to a lack of data, the requirements have been determined by analysing several technologies. A larger number of technologies could provide a more substantiated 'toolkit', where a more detailed list of requirements should be determined.

Finally, a subject that was not featured in the conducted research is the exact costs. The next step in future research could be a **Cost-benefit analysis** (**CBA**). This could give an insight into the economic feasibility of the planned interventions.

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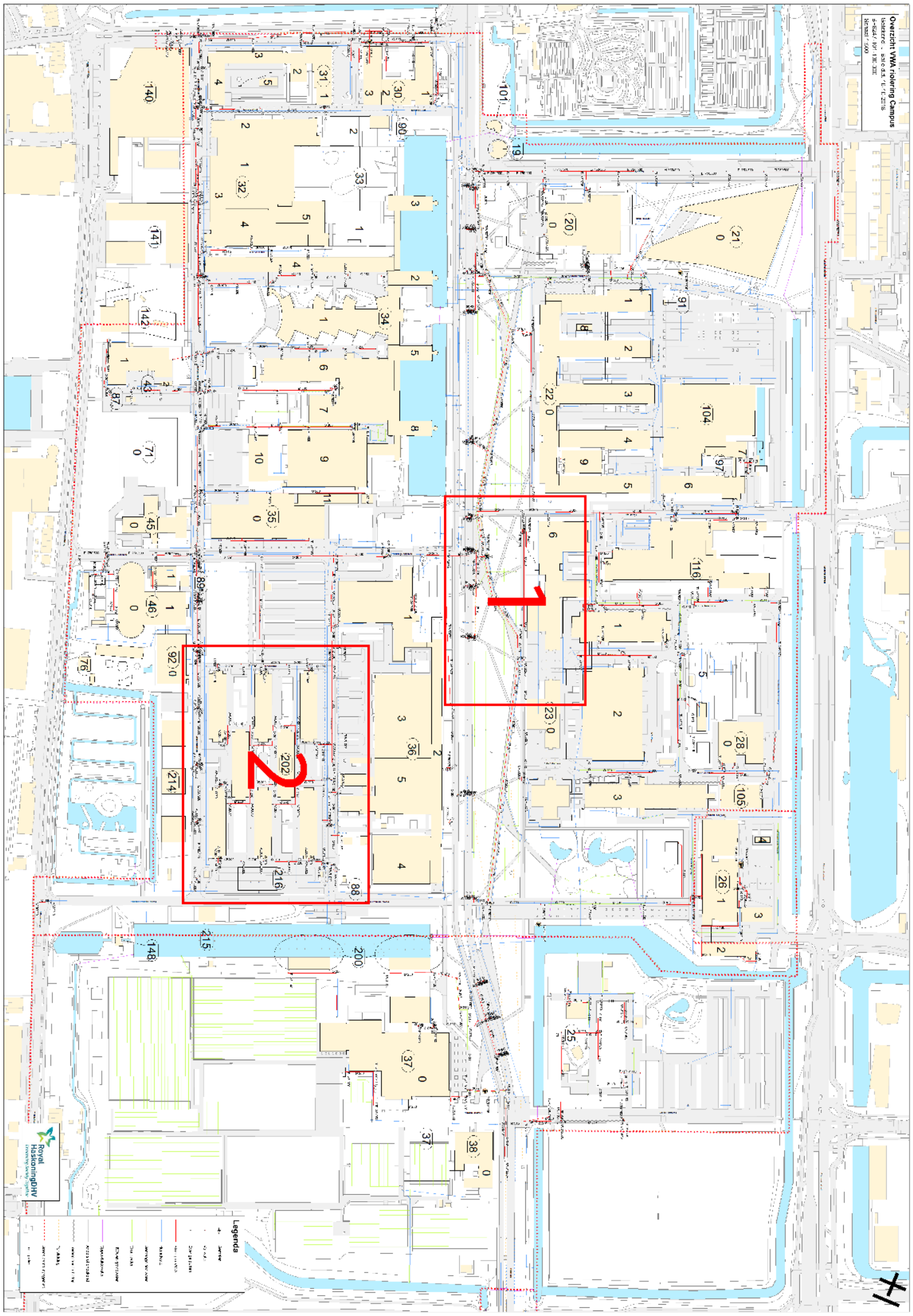
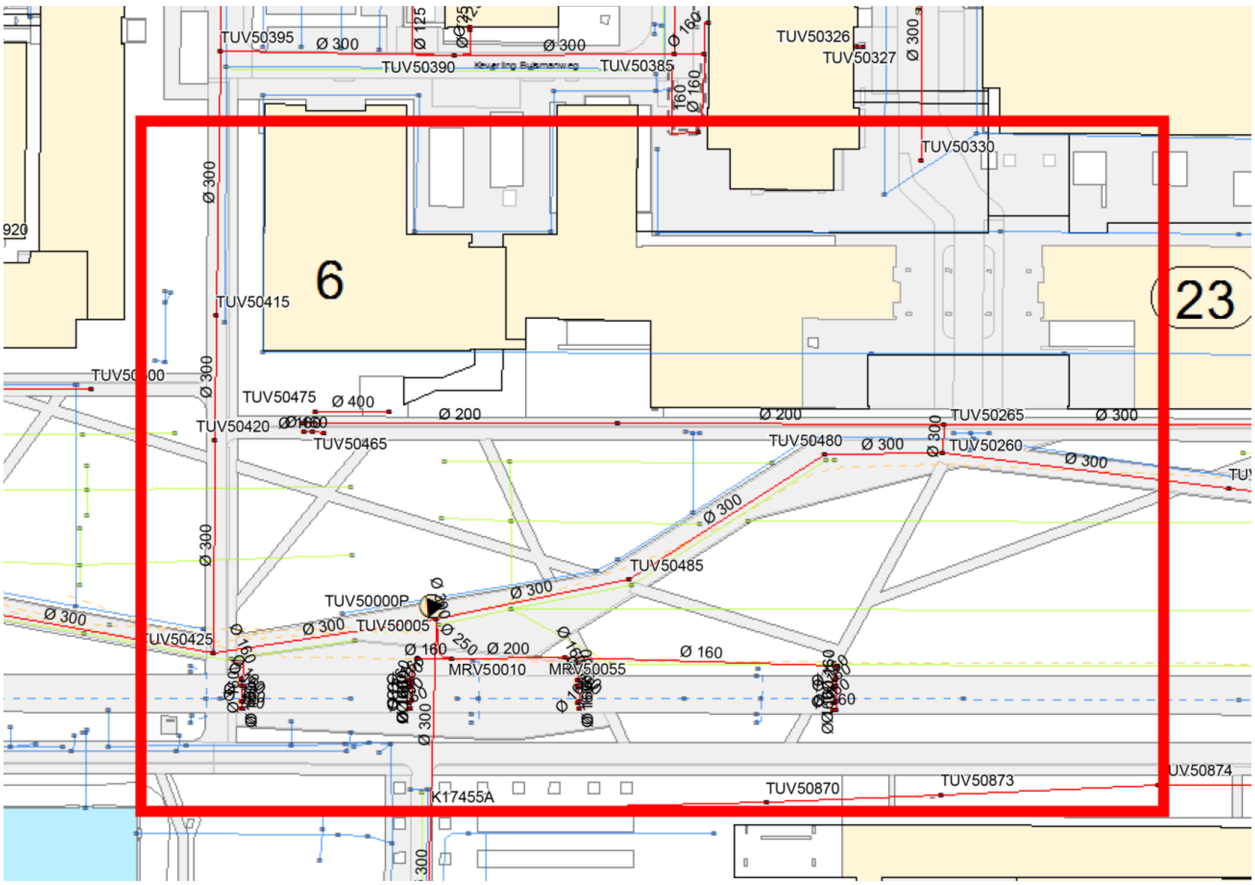
Appendices

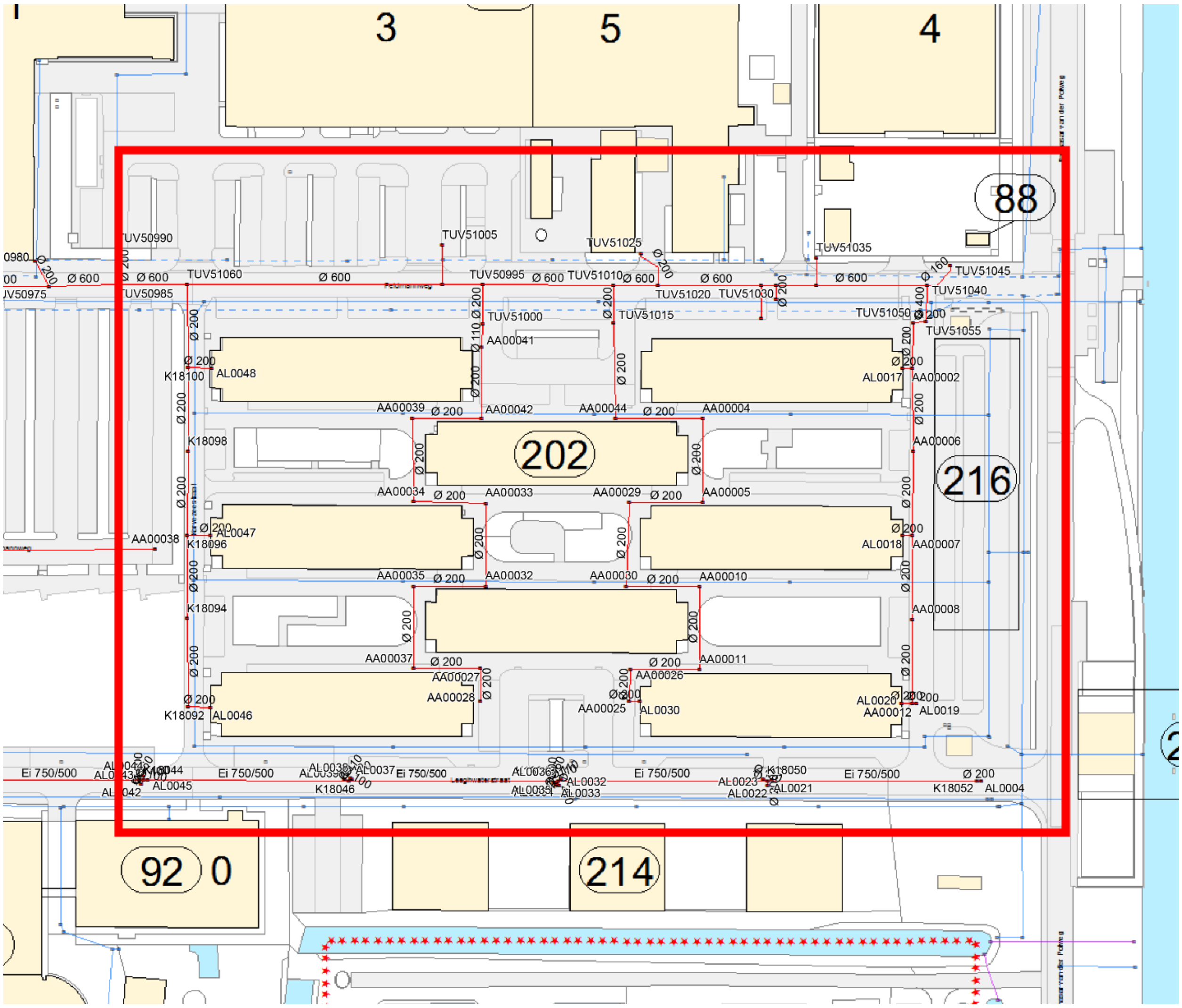
A: Evaluated locations at the TU Delft campus



Appendix A-1: Overview of locations chosen at the TU Delft campus (G. Hofland, personal communication, September 20, 2018)



Appendix A-2: Properties of location 1: Mekelpark (G. Hofland, personal communication, September 20, 2018)



Appendix A-3: Properties of location 2: Feldmannweg & student dwellings (G. Hofland, personal communication, September 20, 2018)

B: Discharge rates at the Mekelpark pumping station

FLYGT

xylem
Let's Solve Water

Periode : 25-09-2017 t/m 24-09-2018

Standaard rapportage - Eigen selectie					
	Stevinweg Looptijd P1 (uur)	Stevinweg Looptijd P2 (uur)	Stevinweg Looptijd Samenloop (uur)	Stevinweg Aant.st. P1	Stevinweg Aant.st. P2
25-09-2017	02:17	02:08	00:00	80	80
26-09-2017	03:30	03:12	00:00	104	104
27-09-2017	02:23	02:16	00:40	60	60
28-09-2017	03:51	03:29	00:00	116	115
29-09-2017	03:12	02:57	00:20	88	89
30-09-2017	01:34	01:28	00:00	57	57
01-10-2017	01:26	01:22	00:00	53	53
02-10-2017	02:12	01:52	00:00	71	71
03-10-2017	03:47	00:54	00:00	91	32
04-10-2017	03:05	01:15	00:00	78	34
05-10-2017	04:59	04:08	00:06	112	111
06-10-2017	02:59	02:44	00:00	96	97
07-10-2017	02:38	02:24	00:00	87	87
08-10-2017	03:08	02:52	00:00	104	103
09-10-2017	02:58	02:44	00:00	96	97
10-10-2017	02:17	02:11	00:00	79	79
11-10-2017	02:56	02:37	00:00	91	90
12-10-2017	02:38	02:24	00:00	88	88
13-10-2017	02:28	02:16	00:00	85	86
14-10-2017	02:08	02:01	00:00	76	76
15-10-2017	02:11	02:01	00:00	77	76
16-10-2017	02:49	02:35	00:00	91	92
17-10-2017	02:43	02:28	00:00	90	89
18-10-2017	02:37	02:27	00:00	89	90
19-10-2017	02:31	02:20	00:00	86	86
20-10-2017	03:24	03:10	00:14	97	97
21-10-2017	02:08	01:58	00:00	74	74
22-10-2017	03:15	03:01	00:00	103	102
23-10-2017	03:13	02:58	00:00	104	104
24-10-2017	03:09	02:52	00:00	102	103
25-10-2017	02:45	02:33	00:00	94	94
26-10-2017	02:47	02:32	00:00	94	93
27-10-2017	02:34	02:24	00:00	88	89
28-10-2017	02:20	02:08	00:00	81	80
29-10-2017	02:29	02:18	00:00	86	86
30-10-2017	02:44	02:35	00:13	85	86
31-10-2017	02:37	02:26	00:00	88	87
01-11-2017	02:35	02:22	00:00	86	86
02-11-2017	02:44	02:31	00:00	91	91
03-11-2017	02:43	02:29	00:00	90	90
04-11-2017	02:20	02:11	00:00	80	81
05-11-2017	02:14	02:04	00:00	77	76
06-11-2017	02:52	02:37	00:00	90	91
07-11-2017	02:31	02:22	00:00	84	84
08-11-2017	02:26	02:14	00:00	82	81
09-11-2017	02:48	02:37	00:00	89	90
10-11-2017	02:42	02:31	00:00	87	86
11-11-2017	02:01	01:54	00:00	70	71
12-11-2017	02:43	02:29	00:00	88	87
13-11-2017	03:06	02:55	00:00	100	101
14-11-2017	02:41	02:28	00:00	89	89
15-11-2017	02:10	01:59	00:00	75	74
16-11-2017	01:40	01:34	00:00	59	60
17-11-2017	01:52	01:47	00:16	57	57
18-11-2017	01:56	02:08	00:00	67	67
19-11-2017	01:56	02:03	00:00	67	66
20-11-2017	03:05	02:24	00:00	92	55
21-11-2017	03:26	00:42	00:00	116	27
22-11-2017	02:01	01:55	00:00	71	70
23-11-2017	02:59	02:31	00:10	66	67
24-11-2017	02:04	01:55	00:00	71	71
25-11-2017	01:25	01:19	00:00	52	52
26-11-2017	01:11	01:06	00:00	44	44
27-11-2017	07:56	07:48	05:41	48	48
28-11-2017	01:40	01:31	00:00	59	59
29-11-2017	01:45	01:38	00:00	63	63

30-11-2017	02:13	02:02	00:00	71	71
01-12-2017	01:17	01:12	00:00	48	47
02-12-2017	00:57	00:54	00:00	36	37
03-12-2017	01:02	00:58	00:00	39	39
04-12-2017	01:27	01:19	00:00	53	52
05-12-2017	01:20	01:16	00:00	52	50
06-12-2017	01:25	01:18	00:00	52	52
07-12-2017	02:23	02:02	00:00	63	63
08-12-2017	02:07	01:55	00:00	65	66
09-12-2017	01:17	01:10	00:00	47	47
10-12-2017	01:40	01:32	00:00	58	58
11-12-2017	01:33	01:23	00:00	56	55
12-12-2017	01:53	01:43	00:00	64	64
13-12-2017	16:03	16:17	15:28	15	16
14-12-2017	06:36	06:20	02:32	74	74
15-12-2017	01:35	01:25	00:00	56	55
16-12-2017	01:10	01:07	00:00	43	44
17-12-2017	01:29	01:16	00:00	45	44
18-12-2017	01:37	01:28	00:00	57	57
19-12-2017	01:27	01:19	00:00	53	53
20-12-2017	01:24	01:18	00:00	52	52
21-12-2017	01:28	01:21	00:00	54	54
22-12-2017	01:14	01:08	00:00	46	47
23-12-2017	00:52	00:46	00:00	33	32
24-12-2017	00:44	00:41	00:00	28	29
25-12-2017	00:41	00:36	00:00	26	25
26-12-2017	00:41	00:39	00:00	26	27
27-12-2017	01:04	00:59	00:00	40	39
28-12-2017	00:56	00:51	00:00	35	35
29-12-2017	01:43	01:31	00:00	50	50
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02-01-2018	01:11	01:07	00:00	43	44
03-01-2018	04:37	04:22	02:26	53	53
04-01-2018	01:11	01:07	00:00	43	43
05-01-2018	01:24	01:16	00:00	50	49
06-01-2018	01:02	00:56	00:00	38	38
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10-01-2018	01:44	01:33	00:00	56	55
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13-01-2018	01:14	01:07	00:00	46	45
14-01-2018	01:04	01:01	00:00	40	41
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18-01-2018	02:29	02:08	00:00	72	72
19-01-2018	01:32	01:22	00:00	53	53
20-01-2018	01:04	00:58	00:00	40	39
21-01-2018	01:08	01:02	00:00	42	42
22-01-2018	01:27	01:22	00:00	53	54
23-01-2018	01:25	01:17	00:00	52	51
24-01-2018	01:59	01:46	00:00	58	58
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08-02-2018	01:11	01:07	00:00	43	43
09-02-2018	01:08	01:03	00:00	41	41
10-02-2018	00:56	00:50	00:00	34	33

11-02-2018	01:12	01:07	00:00	43	43
12-02-2018	01:25	01:19	00:00	50	50
13-02-2018	01:25	01:20	00:00	50	51
14-02-2018	01:24	01:16	00:00	50	50
15-02-2018	01:32	01:23	00:00	55	54
16-02-2018	01:20	01:14	00:00	48	48
17-02-2018	00:59	00:56	00:00	37	38
18-02-2018	01:02	00:55	00:00	38	37
19-02-2018	01:29	01:22	00:00	52	52
20-02-2018	01:33	01:25	00:00	54	54
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03-03-2018	00:59	00:55	00:00	36	37
04-03-2018	01:10	01:02	00:00	42	41
05-03-2018	01:27	01:20	00:00	52	52
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13-03-2018	01:50	01:42	00:00	63	64
14-03-2018	01:37	01:27	00:00	56	56
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25-03-2018	00:57	00:53	00:00	35	35
26-03-2018	01:25	01:20	00:00	50	51
27-03-2018	01:32	01:24	00:00	54	53
28-03-2018	01:52	01:44	00:00	62	63
29-03-2018	01:26	01:17	00:00	50	50
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31-03-2018	01:06	00:53	00:00	36	35
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02-04-2018	00:59	00:56	00:00	36	37
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08-04-2018	01:05	01:01	00:00	39	40
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17-04-2018	01:29	01:23	00:00	52	53
18-04-2018	01:19	01:11	00:00	48	47
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24-04-2018	01:24	01:16	00:00	49	48

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26-04-2018	01:16	01:10	00:00	46	46
27-04-2018	00:47	00:44	00:00	29	30
28-04-2018	00:52	00:45	00:00	32	31
29-04-2018	01:45	01:17	00:16	39	40
30-04-2018	10:55	10:28	07:49	47	46
01-05-2018	02:08	01:53	00:00	64	64
02-05-2018	01:20	01:13	00:00	47	47
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20-05-2018	00:57	00:53	00:00	35	35
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28-06-2018	01:17	01:13	00:00	48	48
29-06-2018	01:08	01:07	00:00	43	44
30-06-2018	00:50	00:46	00:00	32	32
01-07-2018	00:50	00:47	00:00	32	32
02-07-2018	01:32	01:25	00:00	52	52
03-07-2018	01:17	01:11	00:00	47	47
04-07-2018	00:11	00:08	00:00	7	6
05-07-2018	01:08	01:03	00:00	41	41
06-07-2018	01:11	01:08	00:00	44	45

07-07-2018	00:50	00:47	00:00	32	32
08-07-2018	00:49	00:44	00:00	31	30
09-07-2018	01:15	01:10	00:00	45	46
10-07-2018	01:10	01:04	00:00	42	42
11-07-2018	01:15	01:11	00:14	35	35
12-07-2018	01:07	01:27	00:00	39	39
13-07-2018	00:59	01:16	00:00	35	34
14-07-2018	00:46	01:03	00:00	28	28
15-07-2018	00:45	01:07	00:00	27	28
16-07-2018	00:58	01:25	00:00	35	34
17-07-2018	00:56	01:24	00:00	34	35
18-07-2018	00:55	01:14	00:00	33	33
19-07-2018	00:57	01:18	00:00	34	34
20-07-2018	00:52	01:11	00:00	32	31
21-07-2018	00:40	00:53	00:00	25	25
22-07-2018	00:41	00:55	00:00	25	26
23-07-2018	00:54	01:13	00:00	33	32
24-07-2018	00:50	01:13	00:00	31	32
25-07-2018	00:53	01:14	00:00	34	33
26-07-2018	00:53	01:11	00:00	32	33
27-07-2018	00:50	01:10	00:00	31	31
28-07-2018	00:47	01:02	00:00	29	28
29-07-2018	00:40	00:54	00:00	25	25
30-07-2018	00:55	01:10	00:00	33	33
31-07-2018	01:04	01:20	00:00	38	39
01-08-2018	00:54	01:05	00:00	33	32
02-08-2018	00:53	01:14	00:00	33	34
03-08-2018	00:53	01:09	00:00	32	32
04-08-2018	00:44	00:57	00:00	27	27
05-08-2018	00:44	00:57	00:00	27	27
06-08-2018	00:53	01:11	00:00	33	32
07-08-2018	00:52	01:15	00:00	32	33
08-08-2018	01:11	01:14	00:00	40	48
09-08-2018	01:19	01:13	00:00	43	43
10-08-2018	01:10	01:05	00:00	38	39
11-08-2018	01:09	01:03	00:00	38	38
12-08-2018	00:45	00:42	00:00	27	27
13-08-2018	01:12	01:06	00:00	41	41
14-08-2018	01:06	01:01	00:00	39	39
15-08-2018	01:04	00:59	00:00	38	38
16-08-2018	01:05	01:06	00:00	39	39
17-08-2018	01:02	00:59	00:00	38	38
18-08-2018	00:50	00:47	00:00	31	31
19-08-2018	00:55	00:52	00:00	34	34
20-08-2018	01:12	01:06	00:00	43	43
21-08-2018	01:16	01:11	00:00	44	46
22-08-2018	01:16	01:10	00:00	45	45
23-08-2018	01:21	01:15	00:00	48	48
24-08-2018	01:50	01:47	00:37	43	43
25-08-2018	01:41	01:33	00:00	55	54
26-08-2018	00:50	00:47	00:00	30	31
27-08-2018	01:14	01:06	00:00	43	42
28-08-2018	01:14	01:07	00:00	44	44
29-08-2018	01:20	01:14	00:00	47	48
30-08-2018	01:16	01:08	00:00	45	44
31-08-2018	01:08	01:03	00:00	41	41
01-09-2018	00:50	00:47	00:00	31	32
02-09-2018	00:52	00:47	00:00	32	32
03-09-2018	01:21	01:14	00:00	49	48
04-09-2018	01:28	01:23	00:00	52	53
05-09-2018	03:29	02:59	01:17	57	57
06-09-2018	01:59	01:45	00:00	60	60
07-09-2018	02:35	02:16	00:49	55	54
08-09-2018	00:59	00:55	00:00	36	36
09-09-2018	01:01	00:56	00:00	37	37
10-09-2018	01:28	01:23	00:03	53	53
11-09-2018	01:38	01:30	00:00	57	57
12-09-2018	02:10	01:56	00:00	69	68
13-09-2018	02:07	01:55	00:00	65	65
14-09-2018	01:22	01:16	00:00	49	49
15-09-2018	00:58	00:53	00:00	36	36
16-09-2018	00:59	00:55	00:00	36	37
17-09-2018	01:28	01:20	00:00	53	52

18-09-2018	01:25	01:20	00:00	51	52
19-09-2018	01:25	01:17	00:00	52	51
20-09-2018	01:24	01:19	00:00	51	52
21-09-2018	01:19	01:14	00:00	49	49
22-09-2018	01:11	01:04	00:00	43	42
23-09-2018	01:23	01:16	00:00	49	49
24-09-2018	01:31	01:25	00:00	55	56
Totaal	**619:42**	**576:28**	**62:10**	**18801**	**18579**
Gemiddeld	**01:42**	**01:35**	**00:10**	**52**	**51**
Minimum	**00:11**	**00:08**	**00:00**	**7**	**6**
Maximum	**16:03**	**16:17**	**15:28**	**116**	**115**

	Stevinweg Aant.st. Samenloop	Stevinweg Verpompt volume (m3)	Stevinweg Capaciteit P1 (l/s)	Stevinweg Capaciteit P2 (l/s)
25-09-2017	0	976	55.98	57.2
26-09-2017	0	1596	55.12	58.37
27-09-2017	2	1055	56.97	62.18
28-09-2017	0	1763	59.63	64.57
29-09-2017	1	1384	61.45	63.6
30-09-2017	0	630	54.93	57.1
01-10-2017	0	572	53.93	56.85
02-10-2017	0	841	53.68	57.28
03-10-2017	0	853	54.93	56.57
04-10-2017	0	692	53.55	57.8
05-10-2017	1	2130	57.93	67.47
06-10-2017	0	1335	58.9	61.43
07-10-2017	0	1138	56.27	59.72
08-10-2017	0	1397	61.03	64.68
09-10-2017	0	1292	57.42	60.43
10-10-2017	0	979	58.93	62.1
11-10-2017	0	1278	54.05	57.53
12-10-2017	0	1128	57.55	60.75
13-10-2017	0	1062	57.03	59.23
14-10-2017	0	909	57.15	60.7
15-10-2017	0	908	56.47	59.45
16-10-2017	0	1217	56.1	59.18
17-10-2017	0	1150	55.37	59.75
18-10-2017	0	1134	56.18	60.4
19-10-2017	0	1084	56.3	59.57
20-10-2017	1	1489	55.8	59.58
21-10-2017	0	885	55.02	58.15
22-10-2017	0	1446	62.75	66.98
23-10-2017	0	1429	56.88	62.72
24-10-2017	0	1400	57.8	62.67
25-10-2017	0	1217	58.07	61.78
26-10-2017	0	1212	57.6	60.02
27-10-2017	0	1118	57.27	60.25
28-10-2017	0	977	56.22	60.05
29-10-2017	0	1046	57.72	60.22
30-10-2017	2	1161	55.13	59.75
31-10-2017	0	1114	55.3	58.5
01-11-2017	0	1091	54.07	59.77
02-11-2017	0	1178	54.33	59.28
03-11-2017	0	1164	57.03	60.13
04-11-2017	0	988	55.78	58.8
05-11-2017	0	920	53.7	58.22
06-11-2017	0	1215	55.38	58.07
07-11-2017	0	1065	54.93	57.78
08-11-2017	0	1020	54.25	57.67
09-11-2017	0	1209	53.97	57.53
10-11-2017	0	1152	55.47	59.13
11-11-2017	0	821	55.22	58.02
12-11-2017	0	1168	54.8	57.98
13-11-2017	0	1374	62.53	65.6
14-11-2017	0	1150	54.08	58.52
15-11-2017	0	902	55.48	58.47
16-11-2017	0	679	50.92	55.53
17-11-2017	1	779	53.1	56.82
18-11-2017	0	797	54.92	49.8
19-11-2017	0	777	54.15	50.42
20-11-2017	0	1126	53.67	50.92
21-11-2017	0	883	51.55	58.57
22-11-2017	0	832	53.85	56.68
23-11-2017	1	1197	53.97	57.08

24-11-2017	0	860	58.23	60.97
25-11-2017	0	564	53.98	57.4
26-11-2017	0	461	51.82	56.18
27-11-2017	1	3575	51.08	54.62
28-11-2017	0	664	51.67	55.98
29-11-2017	0	724	65.92	68.45
30-11-2017	0	961	52.75	56.62
01-12-2017	0	515	52.02	56.52
02-12-2017	0	370	52.55	55.25
03-12-2017	0	398	51.15	55.48
04-12-2017	0	580	52.58	55.33
05-12-2017	0	545	52.83	55.1
06-12-2017	0	569	51.85	57.57
07-12-2017	0	989	52.35	56.73
08-12-2017	0	899	52.03	56.78
09-12-2017	0	529	53.08	56.88
10-12-2017	0	690	53.7	55.97
11-12-2017	0	614	52.82	57.03
12-12-2017	0	794	53.18	56.82
13-12-2017	1	6571	53.27	56.85
14-12-2017	2	2831	55.28	60.02
15-12-2017	0	619	51.02	55.95
16-12-2017	0	453	52.23	54.83
17-12-2017	0	557	52.02	56.1
18-12-2017	0	653	50.97	57.25
19-12-2017	0	578	51.43	57.43
20-12-2017	0	570	52.13	56.57
21-12-2017	0	595	51.97	57.83
22-12-2017	0	490	51.32	59.13
23-12-2017	0	324	52.78	56.3
24-12-2017	0	281	52.42	55.83
25-12-2017	0	248	51.75	55.67
26-12-2017	0	258	51.13	54.95
27-12-2017	0	403	52.12	55.83
28-12-2017	0	352	51.27	55.75
29-12-2017	0	698	51.63	54.77
30-12-2017	0	544	50.2	55.18
31-12-2017	0	898	54.02	58.68
01-01-2018	0	476	58	63.03
02-01-2018	0	451	49.68	54.45
03-01-2018	1	1936	58.6	63.3
04-01-2018	0	448	50.8	53.75
05-01-2018	0	543	51.87	55.87
06-01-2018	0	390	50.77	56.53
07-01-2018	0	404	51.28	55.02
08-01-2018	0	588	50.82	55.63
09-01-2018	0	580	51.62	55
10-01-2018	0	684	50.88	55.72
11-01-2018	0	586	52.3	56.03
12-01-2018	0	555	51.67	55.87
13-01-2018	0	479	53.07	57.3
14-01-2018	0	423	51.77	56.97
15-01-2018	3	1860	52.37	56.4
16-01-2018	0	972	52.17	56.48
17-01-2018	0	601	50.07	55.15
18-01-2018	0	1024	67.17	73.8
19-01-2018	0	616	52.28	56.4
20-01-2018	0	408	52.03	57.62
21-01-2018	0	438	51.92	55.38
22-01-2018	0	586	52.37	56.95
23-01-2018	0	563	52.08	57.07
24-01-2018	0	825	50.65	57.97
25-01-2018	0	578	52.67	56.57
26-01-2018	0	531	52.38	56.68
27-01-2018	0	404	52.23	55.82
28-01-2018	0	410	51.3	54.67
29-01-2018	0	584	51.38	55.32
30-01-2018	0	559	51.5	55.05
31-01-2018	0	628	52.73	55.85
01-02-2018	0	638	50.3	56.27
02-02-2018	0	641	51.82	55.17
03-02-2018	0	583	50.67	55.13
04-02-2018	0	325	50.17	52.02

05-02-2018	0	429	49.08	53.65
06-02-2018	0	437	49.12	54.4
07-02-2018	0	484	49.67	53.58
08-02-2018	0	454	49.85	54.1
09-02-2018	0	425	49.07	53.5
10-02-2018	0	336	49.65	54.1
11-02-2018	0	446	51.77	55.45
12-02-2018	0	540	49.07	52.53
13-02-2018	0	549	48.67	54.12
14-02-2018	0	542	49.85	54.38
15-02-2018	0	594	53.1	55.95
16-02-2018	0	515	49.08	53.78
17-02-2018	0	383	51.35	54.7
18-02-2018	0	381	49.95	55.38
19-02-2018	0	580	49.4	54.98
20-02-2018	0	612	50.52	55.3
21-02-2018	0	785	50.5	55.05
22-02-2018	0	603	50.73	54.68
23-02-2018	0	526	51.15	55.27
24-02-2018	0	366	51	54.62
25-02-2018	0	361	49.67	54.02
26-02-2018	0	527	50.52	55.43
27-02-2018	0	568	50.37	55.22
28-02-2018	0	546	50.92	55.08
01-03-2018	0	567	50.82	55.83
02-03-2018	0	501	50.67	55.37
03-03-2018	0	370	49.75	54.62
04-03-2018	0	437	51.8	53.87
05-03-2018	0	570	51.35	54.73
06-03-2018	0	569	50.55	54.87
07-03-2018	0	587	50.57	54.82
08-03-2018	2	1949	51.2	54.78
09-03-2018	0	600	49.43	53.12
10-03-2018	0	506	50.77	56.42
11-03-2018	0	534	50.05	53.75
12-03-2018	0	632	50.65	53.7
13-03-2018	0	732	51.8	55.95
14-03-2018	0	620	50.33	55.45
15-03-2018	0	673	50.97	55.87
16-03-2018	0	588	51.85	53.25
17-03-2018	0	396	48.62	54.93
18-03-2018	0	400	49.23	54.73
19-03-2018	0	582	48.67	55.32
20-03-2018	0	577	49.95	54.37
21-03-2018	0	570	50.37	54.58
22-03-2018	0	650	50.3	54.68
23-03-2018	0	524	50.73	55.33
24-03-2018	0	371	50.1	55.03
25-03-2018	0	357	50.77	55.07
26-03-2018	0	557	50.32	54.6
27-03-2018	0	596	50.93	54.1
28-03-2018	0	767	51.03	54.2
29-03-2018	0	547	50.67	54.67
30-03-2018	0	427	49.43	55.18
31-03-2018	0	359	51.2	53.8
01-04-2018	0	489	60.45	66.85
02-04-2018	0	373	48.5	53.47
03-04-2018	1	1306	50.12	53.47
04-04-2018	0	1661	55.78	62.95
05-04-2018	0	572	50.23	53.77
06-04-2018	0	553	49.82	52.88
07-04-2018	0	404	50.23	54.32
08-04-2018	0	407	50.63	54.55
09-04-2018	0	582	50.47	53.82
10-04-2018	0	620	50.92	54.27
11-04-2018	1	2071	59.6	63.77
12-04-2018	0	667	50.77	55.07
13-04-2018	0	593	49.87	55.23
14-04-2018	0	368	51.15	55.43
15-04-2018	0	388	51.22	54.83
16-04-2018	0	609	50.73	54.43
17-04-2018	0	605	51.62	55.85
18-04-2018	0	511	52.13	54.98

19-04-2018	1	1470	49.78	56.12
20-04-2018	0	495	47.7	52.6
21-04-2018	0	330	48.43	52.05
22-04-2018	0	340	48.68	52.37
23-04-2018	0	534	49.13	52.93
24-04-2018	0	530	48.8	54.17
25-04-2018	0	481	49.17	54.27
26-04-2018	0	486	50.72	54.83
27-04-2018	0	294	50.32	54.67
28-04-2018	0	314	50.2	54.9
29-04-2018	1	623	49.72	54.62
30-04-2018	4	4714	58.4	63.13
01-05-2018	0	821	57.52	63.35
02-05-2018	0	511	50.1	53.72
03-05-2018	0	492	50.08	53.97
04-05-2018	0	496	48.45	54.32
05-05-2018	0	317	49.62	40.78
06-05-2018	0	317	48.95	40.8
07-05-2018	0	547	48.95	40.68
08-05-2018	0	558	50.57	52.63
09-05-2018	0	514	48.35	54.2
10-05-2018	0	379	51.42	54.32
11-05-2018	0	341	50.65	53.75
12-05-2018	0	324	50.42	54.35
13-05-2018	0	339	50.13	54.08
14-05-2018	0	537	50.78	53.78
15-05-2018	0	528	50.7	54.38
16-05-2018	0	524	51.03	54.83
17-05-2018	0	525	49.87	53.75
18-05-2018	0	480	49.82	54.5
19-05-2018	0	359	47.93	55.93
20-05-2018	0	353	50.02	55.22
21-05-2018	0	371	50.6	54.95
22-05-2018	0	644	48.78	55.63
23-05-2018	0	527	49.48	53.82
24-05-2018	0	542	50.77	53.62
25-05-2018	0	511	50.62	54.88
26-05-2018	0	405	50.95	54.12
27-05-2018	0	387	50.68	55.78
28-05-2018	0	559	51.3	52.92
29-05-2018	1	1942	48.97	55.53
30-05-2018	0	825	49.92	52.3
31-05-2018	1	3383	49.48	54.3
01-06-2018	0	561	48.65	51.13
02-06-2018	1	945	53.25	58.1
03-06-2018	0	365	49.5	52.82
04-06-2018	0	518	49.37	53.33
05-06-2018	0	506	50	53.28
06-06-2018	0	512	50.22	55.68
07-06-2018	0	579	51.4	53.85
08-06-2018	0	482	51.4	56.27
09-06-2018	0	342	52.23	55.97
10-06-2018	0	351	51.77	56.17
11-06-2018	0	525	51.57	55.62
12-06-2018	0	545	52.73	55.88
13-06-2018	0	524	52.53	55.97
14-06-2018	0	528	51.72	55.17
15-06-2018	0	490	51.93	55.05
16-06-2018	0	340	52.53	55.63
17-06-2018	0	331	52.07	55.57
18-06-2018	0	528	52.45	55.92
19-06-2018	0	494	50.43	54.73
20-06-2018	0	489	51.1	54.53
21-06-2018	0	498	51.33	55.38
22-06-2018	0	453	52.07	55.3
23-06-2018	0	325	51.75	55.97
24-06-2018	0	320	50.75	56.23
25-06-2018	0	531	50.57	56.02
26-06-2018	0	503	52.53	55.8
27-06-2018	0	491	51.95	55.93
28-06-2018	0	521	52.87	56.33
29-06-2018	0	461	51.83	56.33
30-06-2018	0	321	52.13	54.95

01-07-2018	0	319	52.52	55
02-07-2018	0	628	51.3	55.95
03-07-2018	0	507	51.45	55.13
04-07-2018	0	64	52.43	56.1
05-07-2018	0	458	57.92	62.27
06-07-2018	0	476	51.2	54.93
07-07-2018	0	318	52.23	56
08-07-2018	0	304	50.15	54.98
09-07-2018	0	494	51.47	55.5
10-07-2018	0	443	50.38	55.23
11-07-2018	1	455	51.12	55.08
12-07-2018	0	422	48.92	45.23
13-07-2018	0	356	48.87	37.75
14-07-2018	0	280	48.45	37.93
15-07-2018	0	274	47.5	35.3
16-07-2018	0	358	48.23	35.18
17-07-2018	0	359	49.78	35.95
18-07-2018	0	337	50.48	36.92
19-07-2018	0	354	49.13	37.32
20-07-2018	0	320	50.02	36.23
21-07-2018	0	243	50.73	36.93
22-07-2018	0	248	49.13	38.32
23-07-2018	0	332	49.8	37.72
24-07-2018	0	323	49.93	37.15
25-07-2018	0	336	50.28	37.57
26-07-2018	0	335	50.13	40.92
27-07-2018	0	313	50.73	38.02
28-07-2018	0	289	48.7	38.05
29-07-2018	0	244	50.32	35.83
30-07-2018	0	335	50.68	38.18
31-07-2018	0	419	51.68	43.68
01-08-2018	0	330	49.92	42.5
02-08-2018	0	343	49.4	39.3
03-08-2018	0	325	49.63	39.92
04-08-2018	0	267	49.65	39.48
05-08-2018	0	261	48.97	38.45
06-08-2018	0	334	49.43	37.93
07-08-2018	0	331	49.67	38.38
08-08-2018	0	400	52.83	40.23
09-08-2018	0	474	47.42	48.63
10-08-2018	0	412	46.65	52.18
11-08-2018	0	419	53.33	58.25
12-08-2018	0	263	47.47	51.1
13-08-2018	0	444	48.32	53.17
14-08-2018	0	398	49.08	53.32
15-08-2018	0	393	49.33	52.45
16-08-2018	0	402	49.8	50.83
17-08-2018	0	388	49.8	53.4
18-08-2018	0	307	50.55	52.6
19-08-2018	0	343	51.38	52.8
20-08-2018	0	454	51.32	54.5
21-08-2018	0	473	50.68	53.65
22-08-2018	0	476	50.15	52.6
23-08-2018	0	518	50.63	54.9
24-08-2018	1	701	50.93	54.18
25-08-2018	0	658	56.22	58.22
26-08-2018	0	300	49.58	52.22
27-08-2018	0	447	48.63	51.67
28-08-2018	0	468	50.05	53.92
29-08-2018	0	517	50.48	53.83
30-08-2018	0	470	50.48	54.58
31-08-2018	0	431	50.85	52.93
01-09-2018	0	314	51.13	54.45
02-09-2018	0	319	50.22	53.9
03-09-2018	0	527	50.38	53.43
04-09-2018	0	577	50.98	55.3
05-09-2018	2	1364	50.57	54.63
06-09-2018	0	770	50.2	51.77
07-09-2018	1	947	49.9	55.17
08-09-2018	0	366	49.67	53.25
09-09-2018	0	375	48.92	54.55
10-09-2018	1	590	49.72	54.5
11-09-2018	0	657	50.88	55.2

12-09-2018	0	891	49.92	55.52
13-09-2018	0	876	50.52	54.48
14-09-2018	0	532	49.55	54
15-09-2018	0	365	50.63	53.8
16-09-2018	0	371	51.17	54.85
17-09-2018	0	581	51.25	54.67
18-09-2018	0	563	51.4	56.05
19-09-2018	0	562	51.62	55.77
20-09-2018	0	563	51.88	56.2
21-09-2018	0	529	52.22	57.47
22-09-2018	0	462	51.53	55.25
23-09-2018	0	546	49.87	55.9
24-09-2018	0	608	49.73	55.78
Totaal	**36**	**247201**	**18935.42**	**19919.53**
Gemiddeld	**0**	**677**	**51.88**	**54.57**
Minimum	**0**	**64**	**46.65**	**35.18**
Maximum	**4**	**6571**	**67.17**	**73.8**

Appendix B-1: Discharge rates at the Mekelpark pumping station (G. Hofland, personal communication, September 20, 2018)