Technische Universiteit Delft

Optimal Rehabilitation of Urban Drainage Systems

Application of single-objective optimisation for the implementation of Green-Blue-Grey Infrastructures in changing climate

Azzahra Safira Suryanto

TU Delft

Master of Science Thesis

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Optimal Rehabilitation of Urban Drainage Systems

Application of single-objective optimisation for the implementation of Green-Blue-Grey Infrastructures in changing climate

By

Azzahra Safira Suryanto

in partial fulfilment of the requirements for the degree of

Master of Science
in Water Management

at the Delft University of Technology,
to be defended publicly on Thursday, October 29, 2021 at 11:00 AM.

Student number	: 5008360	
Thesis committee	: Prof. Dr. Zoran Kapelan,	TU Delft, Chair and Main Supervisor
	Dr. Ir. Jeroen Langeveld,	TU Delft, Co-Supervisor
	Dr. Ir. Edo Abraham,	TU Delft, Independent Committee Member

TU Delft

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Preface

This thesis is dedicated to my future self. In case you ever doubt yourself, remember this moment.

I still remember talking with a classmate from my Bachelor study that I would like to study on the subject revolves around the drainage systems and going to the Netherlands. Four years later, I graduated with a final project that focuses on designing a wastewater treatment plant, and wastewater treatment has been my new interest and the reason for studying at TU Delft, at least that is what I wrote in my motivation letter. Months later, after somehow passing Zoran's Urban Drainage course and Jeroen's Urban Drainage Monitoring and Modelling course, I found myself working on the things that I used to wonder about, the drainage systems. With my minimum knowledge of urban drainage, modelling, and optimisation, I decided to approach Zoran and ask about a thesis project that I might be able to do. So, now, here I am.

Writing this section and completing this research marks the end of another phase in my life. The phase that I have spent from home for the last 1.5 years. A precious phase in my life where I meet a lot of wonderful people that keep reminding me that I am capable, that it is okay to ask when you do not know, that I have a voice, that we are all learning something from each other, and that I am more than I thought I was. Therefore, I would like to express my utmost gratitude to my thesis committee, Prof. Dr. Zoran Kapelan, Dr. Ir. Jeroen Langeveld, and Dr. Ir. Edo Abraham. Zoran and Jeroen are the reason why I can pursue my long-lost interest in the field of drainage systems, and Edo is the main reason why I can even do the optimisation, which I never understood before. Thank you very much for all the time you spare to answer my confusing questions and for all of the constructive feedback, critical questions, motivations and compliments that I received from all of you while working on this research.

Next, I want to thank my non-official daily supervisor, Job van der Werf, who makes coding and getting critics sounds fun. Thank you for all the cheers and time you take to answer my questions. If I can dedicate my python script, then I would like to dedicate it to you!

I would also love to thank my biggest pride and support systems, all the way from Indonesia and the ones that I found here, my friends. Shout out to the main reason I survived TU Delft and living abroad: Citra, Bisma, Nanda, Fauza, Kak Agung, *LDRGroep,* and all of my PPI Delft friends whom I could not mention one by one. My Water Management and Environmental Engineering classmates with whom I formed an unlikely bond: Ron Bruijns, Zixi Meng, Siyuan Wang, Diego, Sadhna, Sophie, and a lot more! And, of course, my everlasting friends in Indonesia since and for forever. The ten strongest girls I have ever known, *Ceper*; seven devilish angels, *Chingu*; and five bundles of laughter, *Kelompok 4 KU 2061-13 AEI.* Thank you for making every day a happy day to live. You are all my utmost joy.

Last but not least, this preface will not be complete without a very special mention to my funny and beloved family, the only reason I can experience and enjoy every second of my life here in Europe. Thank you for your endless support and for always believing in me.

Delft, 20 October 2021

Azzahra Safira Suryanto

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Abstract

Urban Drainage Systems (UDS) are one of the most vital yet, complex infrastructures that support people's livelihood in urban areas. However, due to their mainly underground infrastructure and complexity, the planning and management of UDS are usually associated with high investment, which stakeholders sometimes overlook. As long-lived infrastructures, UDS's limited capability is being put under constantly increasing pressures due to the changes in the capacity needed. Amongst the pressures, the global effects of climate change on rainfall extremes is the most important. As climate change affects the rainfall extremes and the overall hourly and daily rainfall events, urban flooding issues are becoming more of a threat and costly to manage. Urban flooding is generally not desired in any situation, and thus, several rehabilitation efforts have been made to address this issue with minimum cost and optimal performance in flood reduction by increasing the resiliency of UDS in order to minimise the duration and magnitude of urban flooding. Therefore, it requires an optimisation method to find the optimum solution that can correlate the investment cost and the performance of the implemented measures.

Rehabilitation of UDS can be done in several ways, including implementing Green-Blue-Grey Infrastructures (G-B-G measures). The combination of Green-Blue-Grey measures (G-B-G measures) can increase the resiliency of the UDS to withstand even higher intensity rainfall by reducing both the peak flow and enlarging the capacity of the UDS system. Therefore, this thesis aims to develop a method to find the optimal way to rehabilitate or adapt an existing UDS to reduce the risk of flooding under the climate change rainfall scenarios with the minimum intervention cost. In doing so, the problem size needs to be reduced to ease the computational load and reduce computational time.

The method developed coupled a hydrodynamic model using Storm Water Management Model (SWMM) and Genetic Algorithm (GA) to find the optimal solution to rehabilitate UDS under changing climate. The effect of climate change was incorporated by simulating the solutions using composite design storms that represent the increase in hourly and daily rainfall extremes for 2030, 2050, and 2085. The objective function of this optimisation problem becomes the minimisation of the total cost to implement the measures for the rehabilitation of UDS, under the constraint that no flooding can happen anywhere on the system when tested against the climate change rainfall scenarios. Therefore, the decision variables of this optimisation will be the size and location for each implemented measure, while the penalty cost is associated with the cost of each m^3 of flooding based on the simulation.

Based on the analysis of the case study, the most appropriate G-B measures to be implemented is Rain Barrels (RB), Infiltration Trenches (IT), and Pervious Pavements (PP). Meanwhile, for grey measures, it is best to consider pipe replacement, upgrading the current pumps' capacity, and increasing the CSOs' weirs. The optimisation was done twice, using the developed formal method and manual trial-and-error. The results of the formal optimisation using the metaheuristic approaches have been confirmed to outperform the result from manual optimisation using the traditional trial-and-error method. The final objective function value of the formal optimal solutions is € 7.01 million for scenario 2030 and 2050 and € 7.08 million for scenario 2085. The optimal solutions proved that a combination of both grey and G-B measures produced the lowest cost to reduce flooding. Although the solutions can be adapted over time from 2030 until 2085, the results show that adaptive solutions might not be needed when the solution for 2085 is better implemented from the year 2030. This is because some implemented measures from the optimal solution 2030 need to be either downgraded or upgraded to comply with scenario 2085, making the implementation of these in 2030 redundant. Overall, it can be projected that in the future, the combination of G-B-G measures can produce an economically optimal solution to be implemented in order to achieve zero floodings in the case study location.

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Chapter 1

Introduction

1.1 Rehabilitation of Urban Drainage Systems (UDS) in changing climate

Urban drainage systems (UDS) are one of the most vital infrastructures that support daily life, especially in urban areas [1]. It comprises a large and complex network associated with the high investment needed for its planning and/or modification [2]; thus, it rarely becomes the priority of stakeholders [1]. Over time, UDS' limited capability is constantly being put under increasing pressure due to more extreme rainfall events associated with climate change [3, 4, 5, 6] and the rapid growth of the urban population [7, 8]. This increasing pressure results in extensive and expensive damage from urban flooding and sewer overflows to the surface water. In addition to the sources of the extra loads to UDS, most of the drainage networks already existed from several years ago and are more prone to system failure due to ageing and structural problems. Therefore, adjusting the current UDS becomes essential to avoid the expensive consequences of increasing external pressure from changing climate on the drainage systems [9].

As climate change affects the rainfall extremes, urban flooding issues are becoming more of a threat and costly to manage due to its effect on the area with a higher concentration of population and a high number of essential assets [10]. Royal Netherlands Meteorological Institute, KNMI, stated that the annual precipitation in the Netherlands increased by around 26% between 1910 and 2013 [11]. Therefore, the initial design storm used to design each UDS becomes irrelevant due to the changes in rainfall extremes from both hourly and daily rainfall. For this thesis, the terms of urban flooding used will be the same as urban pluvial flooding. Urban flooding, or urban pluvial flooding, can be defined as flooding caused by local heavy precipitation [11] that exceeds the drainage system's capacity and soil infiltration [12]; thus, causing the sewer to become surcharged and water ponding on the surface. Although its effect can range from light to extreme damage, overall, urban floodings will have a direct monetary impact and indirect, long-term, livelihood impacts (*e.g.* healths, productivity) [10]. Van Riel (2011) [13] analysed five categories of flooding impacts: material, economic, health, emergency assistance, and discomfort impacts. In the Netherlands, the damage from urban pluvial flooding per event is relatively small compared to coastal or fluvial flooding because of the low floodwater depth (~20 cm). However, the cumulative effect of urban pluvial flooding could be significant due to its frequent occurrence [13]. To cope with these problems, the adaptation of the current drainage systems through rehabilitation is needed.

Many approaches to rehabilitate UDS have been studied and proposed to tackle urban flooding issues. The most common methods to rehabilitate UDS are installation of storm tanks or reservoirs, increasing pipe storage capacity (*i.e.* pipe substitution) [6, 1, 14, 5, 15], implementation of Green-Blue-Grey (G-B-G) measures/ infrastructures (also known as Sustainable Urban Drainage Systems (SUDS), Best Management Practices (BMP), Low Impact Developments (LID), or Water Sensitive Urban Design (WSUD)) [16, 17, 18], expanding the current drainage systems to increase its capacity or construction of separate sewer system (commonly done to more modern and relatively new areas). Nevertheless, implementing these methods is challenging enough as there will always be a certain degree of trade-off between each aspect in rehabilitating UDS [19]. Therefore, it requires an optimisation method to find the optimum solution that can correlate the investment cost and the performance of the implemented measures.

1.2 Problem statement

Urban drainage systems are designed with a specific design storm in which no flooding should take place. Nevertheless, due to the change in rainfall intensity caused by climate change, urban flooding might happen even with its design storm. This issue is generally not desired in any situation, and thus, several rehabilitation efforts have been made to address urban flooding. Rehabilitation of UDS to make the system more resilient to urban flooding can be done in several ways, among which is the usage of grey measures such as pipe substitution to act as a storage basin and increase the overall capacity of the UDS. However, when the aspect of sustainability comes into the picture, implementation of Green-Blue (G-B) measures can result in a better performance of UDS. The combination of Green-Blue-Grey measures (G-B-G measures) can increase the resiliency of the UDS to withstand even higher intensity rainfall by reducing both the peak flow and enlarging the capacity of the UDS system. Conceptually, G-B measures and pipe replacement can be implemented on all sub-catchments and conduits. However, taking that measure is almost impossible due to financial and space constraints, which is common in the UDS field. Therefore, the implemented measures should be affordable.

On the other hand, it needs to perform well to achieve the desired outcome of the rehabilitation, or in this case, it needs to reduce the risk of urban flooding. Efficiently choose the right location and size to implement the green-blue-grey measures can minimise the cost needed to implement the measures associated with flood reduction. Achieving this requires the optimal solution of a metaheuristic optimisation approach. Thus, the problem in this thesis can be described as the rehabilitation of UDS to reduce urban flooding under its design storm with climate change scenarios using a single-objective optimisation for the implementation of G-B-G measures.

1.3 Research questions

This thesis deals with the rehabilitation of UDS. It aims to find the optimal location and size for implementing the Green-Blue-Grey (G-B-G) measures to reduce the risk of flooding under the climate change rainfall scenarios to make the system more resilient with the minimum intervention cost. Based on this objective, the main research question can be formulated as follows:

What is the optimal way to rehabilitate or adapt an existing urban drainage system (UDS) to a changing climate with respect to managing the risk of urban flooding?

To help in answering the main research question, several sub-questions arise:

1. How can the above UDS rehabilitation problem be formulated as an optimisation problem?
2. What are the appropriate climate change rainfall scenarios to be used to solve the above urban drainage rehabilitation problem?
3. What is the definition of ‘flooding’ used to evaluate the performance of the alternative solutions during the optimisation?
4. What interventions should be considered (Green-Blue or Grey), and how could these be characterised for optimisation when considering the respective locations and sizes? How can these be discretised best to reduce the optimisation search space?

5. What is an appropriate method to simulate and evaluate the alternative solutions during optimisation?
6. What is/are the most appropriate green-blue (G-B) and grey measure(s) to be implemented in the analysed case study? How can the optimisation results be used to project suitable G-B-G measures to be implemented in the future?

1.4 Thesis structure

In order to answer the research questions of this thesis, this report is structured in this manner. Chapter 2 addressed the studies in the field of the optimisation problem to design or rehabilitate urban drainage systems. In this chapter, the gaps in knowledge around the rehabilitation of urban drainage systems are highlighted as a basis to develop the method used in this thesis. Chapter 3 then addresses the mentioned gaps in knowledge and describes the method used in this thesis to find the optimal solution for the rehabilitation of urban drainage systems in changing climate. Hereafter, Chapter 4 elaborates on the case study used to test the developed method, which is located in Riethoven, The Netherlands. This chapter also describes the case study characteristics, land-use analysis, performance of the current urban drainage systems, and deciding some of the case-specific parameters used in the optimisation method. Chapter 5 provides the results from the optimisation, compares the results from different scenarios and the method, and discusses the possible implementation of the optimal solution in the case study area. Finally, Chapter 6 concludes the overall thesis by answering the research questions and recommending what can be done to improve the study and future research.

Chapter 2

Literature review

Rather than using traditional engineering approaches with manual trial-and-error to find the optimal solution to rehabilitate UDS, approaches using a hydrodynamic model linked with an optimisation tool are considered more reliable [20]. Usage of computational intelligence as an optimisation tool, such as genetic algorithm (GA) and its modification (*e.g.* PGA, NSGA-II, ε-NSGAII), particle swarm optimisation (PSO), and simulated annealing (SA), has grown more popular nowadays due to its capability to address more complex problems like UDS. On the other hand, the earlier deterministic optimisation methods, such as dynamic programming (DP) and linear programming (LP), are rarely used since it has difficulty in handling more complex systems [21]. Some studies on the optimisation of UDS rehabilitation using metaheuristics are reviewed below.

The literature reviewed are studies related to the usage of metaheuristics approaches to find the optimal solution in the planning and modification of UDS. Since the discussion on the usage of metaheuristics in the field of UDS is still ongoing, most studies interlink with each other. One method can be tested in several case studies with different objectives, or one objective can be approached with different methods, bounded with various constraints, objective functions, and decision variables.

A literature review was conducted to summarise some literature that used optimisation algorithms coupled with hydrodynamic models to optimise rehabilitation and UDS planning (see Appendix A-Comparison of Literatures). For each study, the problem can be differentiated into three main problems: urban flooding, CSO, and UDS design problem (*e.g.* layout, design under uncertainties). The following classification is what the literature wants to aim or the objective, whether it is the selection of location/ layout, size/ area, type of intervention, or other aspects (*e.g.* quantity such as pumping capacity, real-time control (RTC)). The third classification is each study's objective functions, generally categorised into cost, quantity (*e.g.*, number of flooding nodes, the volume of ST, peak flow), and performance-based objective function (*e.g.* resiliency index). Among the literature, most studies addressed urban flooding as the main problem that drives the need to rehabilitate UDS, associated with the intervention cost to rehabilitate the UDS or the damage cost caused by urban flooding.

Installation of in-line underground storm tank or storm detention tank and pipe substitution to reduce the peak load and retain sediments [22] in the drainage system seems like a popular solution for the dense urban area with less land availability. It can overcome the space constraints needed by aboveground measures (*e.g.* detention pond [8]) and expansion of UDS [23]. In addition, grey measures such as storm tanks can be considered a robust solution to counter more severe rainfall events than Green-Blue (G-B) measures. Research into the optimisation of storm tank design has been done a lot with different methods. However, it mainly revolves around minimising the total cost by optimising the number of installed tanks, locations, volume, and its effect on the whole drainage network (*e.g.* how the alteration of upstream affect the downstream areas) [24]. The research development of storm tank design optimisation to tackle urban flooding is well documented in the literature. In terms of storm tank installation, dated back to 1985, Bennett and Mays [25] introduced the Dynamic Programming (DP) algorithm to determine the optimal location and size of detention basins and downstream outlet structures while minimising the total cost. Many studies have been done in this area since the research of Bennett and Mays (1985) [23] with different combinations of algorithms and model different objective functions to find the optimal solution to rehabilitate UDS using storm tanks.

Delelegn et al. (2011) [2] coupled the 1D2D models (SWMM and BreZo) to determine the optimal size of implemented storm tank that can minimise the total investment cost and the total damage cost from flooding using NSGAII. The usage of the 2D model is to assess the flood damage from surcharge sewers which is considered as the mass exchange at point sources. Oxley and Mays (2014) [24] studied another approach with a similar objective with Bennett and Mays research in 1985 [25] using simulated annealing (SA) algorithm coupled with U.S. Army Corps of Engineer's Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS), with the constraints that are based on the difference between pre-development and post-development flow. The research was done using MS Excel to store data for each optimisation result. However, the usage of different platforms to store the data, run the optimisation, and simulate the model makes the method less practical despite producing a detailed simulation and hydrologic routing in the sub-catchments.

Cimorelli et al. (2015) [26] studied the optimisation approach to determine the location and size of storm tank with a similar objective with Bennett and Mays (1985) [25] and Oxley and Mays (2014) [24], with a different algorithm, which is GA coupled with Hydrologic-Hydraulics Semi-Distributed Model (HHSDM-2). However, in this study, rather than using a standard unit of storm tank, they applied a pipe-like detention tank consisting of several parallel augmented pipes to increase the drainage system's capacity. Although auxiliary pipes as storage do not need pumping to convey the water towards the downstream pipes – thus, reducing the cost associated with pumping, there is no guarantee that the maintenance of the parallel pipes itself will not pose a maintenance problem in the future. The same measures using axillary pipes were studied by Yazdi (2018) [27] using the Non-dominated Sorting Differential Evolution (NSDE) algorithm using two different models for rainfall-runoff (HEC-HMS) and flood routing (SWMM). In this study, the auxiliary pipes are only implemented in the bottleneck area, such as under a bridge/ culverts. In this case, the usage of axillary pipes will indeed bring more benefits to reduce the possibility of blockages during rainfall events that can lead to flooding, which is the study's primary objective.

Implementation of storm tanks to reduce the peak flow during rainfall events has already proven to be one of the robust systems that currently exist. Some researchers even published several papers to study different approaches to find the optimal solution to design storm tanks. Li et al. (2015) [5] used a modified version of PSO called Non-dominated Sorting PSO (NPSO) linked with U.S. EPA's SWMM to minimise both the cost of detention tank and the number of flooding nodes, which was later assessed again by Duan et al. (2016) [4] to include complex constraints of the design criteria and uncertainty analysis using Monte-Carlo simulation. From both studies, it can be concluded that the study with uncertainty analysis can give a complete picture of the trade-off for MOO rather than using only a deterministic approach.

As robust as storm tanks might sound to overcome increasing loads of UDS, it has its disadvantages. These underground structures are mainly used in newly-developed areas, in which land availability becomes a major concern. It means that they are not suitable for retrofitting the existing UDS [28]. In addition, its overall benefit can be almost the same, or even second to the hybrid combination of green-blue-grey (G-B-G) measures [23, 16, 7]. As the world starting to recognise the importance of a sustainable approach to combat the ever-changing environments, SuDS or Green-Blue measures (G-B measures) offers sustainability to address this complex environmental challenge (*i.e.* climate change, urbanisation) revolving around urban drainage; which the traditional grey measures might not achieve [16]. On the other hand, it is hard to fully replace the grey measures with G-B measures due to their inability to cope with high-intensity rainfall. G-B measures can reduce the size of grey measures needed (*e.g.* reduce the diameter of the pipe needed) and offer several benefits in terms of adaptability and sustainability. However, it means that the overall drainage systems would be more vulnerable to extreme rainfall events that are more severe than its original design storms [17].

Alves et al. (2016) [23] developed a methodology to evaluate the effect of green-grey infrastructures on CSO discharge reduction using Non-dominated Sorting Genetic Algorithm (NSGA-II), an algorithm to solve Multi-Objective Optimisation (MOO) problem developed by Deb et al. (2002) [29], coupled with US EPA's hydrodynamic model Storm Water Management Model (SWMM) which also enables the user to assess different Low Impact Development (LID) measures. The research aims to find the balance between minimising the implementation cost of the infrastructures and minimising the discharge through the CSO. Although the implementation of Green-Blue infrastructures can bring co-benefits such as energy-saving and reducing peak runoff, the study shows that the highest peak flow reduction can be achieved when using a combination of Grey and Green-Blue measures. In 2020, Alves et al. [16] conducted another study to explore the trade-off between the cost and benefit of implementing Green-Blue-Grey measures to rehabilitate UDS concerning urban flooding damage reduction using a combination of SWMM and NSGA-II. A pre-selection of the implemented measures was done using a multi-criteria analysis involving local stakeholders on which co-benefit they preferred, which later be associated with the suitable measure. The result also shows the combination of G-B measures, such as rainwater barrels (RB), pervious pavements (PP), open detention basin (ODB), with stormwater pipes addition (grey measure), resulting in recommended solutions for flood damage reduction and total benefit maximisation. Usage of aerial images can provide much ease when the available areas become the deciding factor to implement a measure. For this study, the decision variables used are the areas of each measure for every sub-catchments. They did a land-use analysis using aerial images and defining the minimum and maximum values for each variable. To look more at the combination of G-B-G measures, Bakhshipour et al. (2019) studied the relation between the different degrees of centralisation to the hydraulic performance in terms of resiliency and sustainability of the UDS. Using SWMM coupled with a simple GA algorithm, they concluded that in their case study, decentralised UDS with grey measures and G-B measures shows that it can reduce the peak flow, both the amount and the timing of it – thus, giving the highest sustainability with the price of reducing the resiliency of the UDS to counter extreme rainfall [17].

With the implementation of G-B measures, the location and area of coverage play a significant role in its performance. Giacomoni et al. (2017) studied the effect of different placement of G-B measures in the catchment scale using SWMM coupled with NSGA-II. They used green roofs and pervious pavements and concluded that installing the measures in downstream catchments is more efficient in reducing peak flow and runoff volume alteration. Meanwhile, implementing the measures in upstream catchments gives a better reduction in hydrologic footprint residence (HFR) alteration – which they described as a metric that represents the dynamic of the flooded area and residence time of the flood throughout downstream areas [7]. Thus, the locating and sizing of implemented measures to rehabilitate UDS are important factors in deciding its overall effectiveness. Since each sub-catchment/node/conduit needs to be evaluated for each decision variable and scenario, it requires a high computation capacity. Computational time is indeed a challenge in an optimisation problem. Although a large search space can keep the diversity in the solutions and can give more options to the decision-maker, it comes with the price of the increasing burden on the computational time and the efficiency of the optimisation due to the possibility that the optimisation might be stuck in a lot of local minima or maxima.

Ngamalieu-Nengoue et al. [6] proposed a single-objective optimisation using PGA to reduce the search space of the optimisation function. The study resulting in a better result shown by reducing the search space by pre-selecting the location for each UDS rehabilitation measure; in this case, storm tank and pipe substitution. Reducing the computational time can also be done either by using a more advanced PC, using parallel computation using several PCs [23, 4], or by pre-selecting the location of measures based on the real-life condition as well. To reduce the search space for the location of the storm tanks, Baek et al. (2015) [21] pre-select the possible location of the storm tank based on ground elevation and network characteristics, while Alves et al. (2016) performed the optimisation using parallel computing [23]. Manually pre-select the location of the implemented measure can be done when the catchment area and the network are relatively small, and when there is enough information. Overall, manually pre-select possible locations can be implemented quite well since it is pretty robust under several conditions, and simple to understand.

Based on the literature reviewed, the key findings are as follows:

- The usage of G-B measures or SuDS is becoming more important since the introduction of the sustainability aspect in the rehabilitation of urban drainage infrastructures. Although G-B measures alone are not resilient enough to encounter extreme rainfalls, their combination with grey measures (G-B-G measures) seems to be able to provide improved resiliency and sustainability to the UDS. However, it is still not known what the best combination of the two approaches should be.
- UDS comprises a complex network with catchments, conduits, junctions, and other components. Therefore, to rehabilitate UDS, many decision variables need to be considered to find the optimal solution(s). The traditional trial-and-error method is very unlikely to be able to find the optimal solution, and in doing so [16], it will take a huge amount of time. Hence, the usage of an optimisation based approach should be investigated, especially in the context of determining the best combination of grey and green-blue (G-B) measures.
- Although several studies include climate change in their uncertainty analysis, not many studies incorporate this aspect in their design storm selection. Climate change will bring changes to rainfall events, that when overlooked, can result in damage due to the incapability of UDS to handle it. Application of climate change scenarios to the design storm can make the rehabilitated UDS more resilient to these changes hence it is important to select these scenarios carefully.
- Metaheuristics optimisation possessed another challenge of elevated computational time that can hinder the process of finding the optimal global solutions. Thus, reducing search space to reduce the computational time of the optimisation problem of UDS becomes important. This remains as a challenge in optimisation based UDS rehabilitation.

Therefore, this thesis aims to find the optimal set of solutions in rehabilitating UDS by using the combination of G-B-G measures using a metaheuristic approach under the effect of climate change scenarios. The methodology developed uses the optimisation algorithm, Genetic Algorithm (GA), coupled with a hydrodynamic model, SWMM. The solutions need to be able to minimise the intervention cost associated with zero floodings. In addition, the method will also include a reduction of the search space of the problem to reduce the computational burden.

Chapter 3

Methodology for optimal rehabilitation of urban drainage systems

Urban drainage systems (UDS) rehabilitation for this thesis implemented the combination of Grey and Green-Blue (G-B) measures. This combination aims to reduce flood risk until no flooding depth above the ground level is recorded using all climate change rainfall scenarios. Furthermore, this thesis has developed and applied a methodology that coupled hydrodynamic model SWMM version 5.1 [6] and Genetic Algorithm (GA) as an optimisation algorithm to find the optimal solution to rehabilitate UDS under changing climate. Using hydrodynamic models such as SWMM to evaluate UDS performance under different design options has been done in many studies [5, 14, 30, 9, 6, 1].

The prediction ability of a model enables the researcher or decision-maker to assess the effectiveness of several solutions and select the optimal solution to rehabilitate UDS. However, Maier *et al.* (2019) [20] argue that despite this ability, finding the most optimal solution that can satisfy all requirements can be difficult due to the complex nature of environmental problems such as UDS. In addition to it, there are many components of the problem with varying alternatives as well. Thus, the authors concluded that by linking simulation models with evolutionary algorithm (EA) and other metaheuristics such as Genetic Algorithm, the most optimal solution for large, complex, discrete, and non-linear problems could be found.

This chapter will cover the developed optimisation algorithm to rehabilitate UDS, including the optimisation framework (Chapter 3.1), optimisation method (Chapter 3.2), design storm selection (Chapter 3.3), and selection of measures (Chapter 3.4).

3.1 Optimisation framework

The optimisation framework used in this thesis can be seen in Figure 3-1. Jupyter Notebook with Python will link the hydrodynamic model and the optimisation algorithm using the Genetic Algorithm (GA). Furthermore, to enable Python to access the SWMM 5.1 data model, PySWMM [31], a Python package will be used, along with SWMMToolbox [32].

The optimisation core will use the GA as an optimisation algorithm coupled with SWMM as a hydrodynamic model. The overall optimation process using GA will be controlled by crossover probability, mutation probability, population size [6], and generations for the stopping criterion [33]. First, each population will be evaluated using PySWMM through Python based on the objective function defined. The value of the objective function for each individual within-population will then be ranked and become the base to select the new population. This cycle is called generation and will keep repeating until the stopping criteria are met. With a population-based algorithm, the population size plays a significant role in determining the convergence of the solution. The solution will quickly converge with a low population, and the global optimum solution might be hard to find [33]. However, with a high population, the computational load will become high. Therefore, these parameters also become crucial for the computation burden and time (see Chapter 3.2.1).

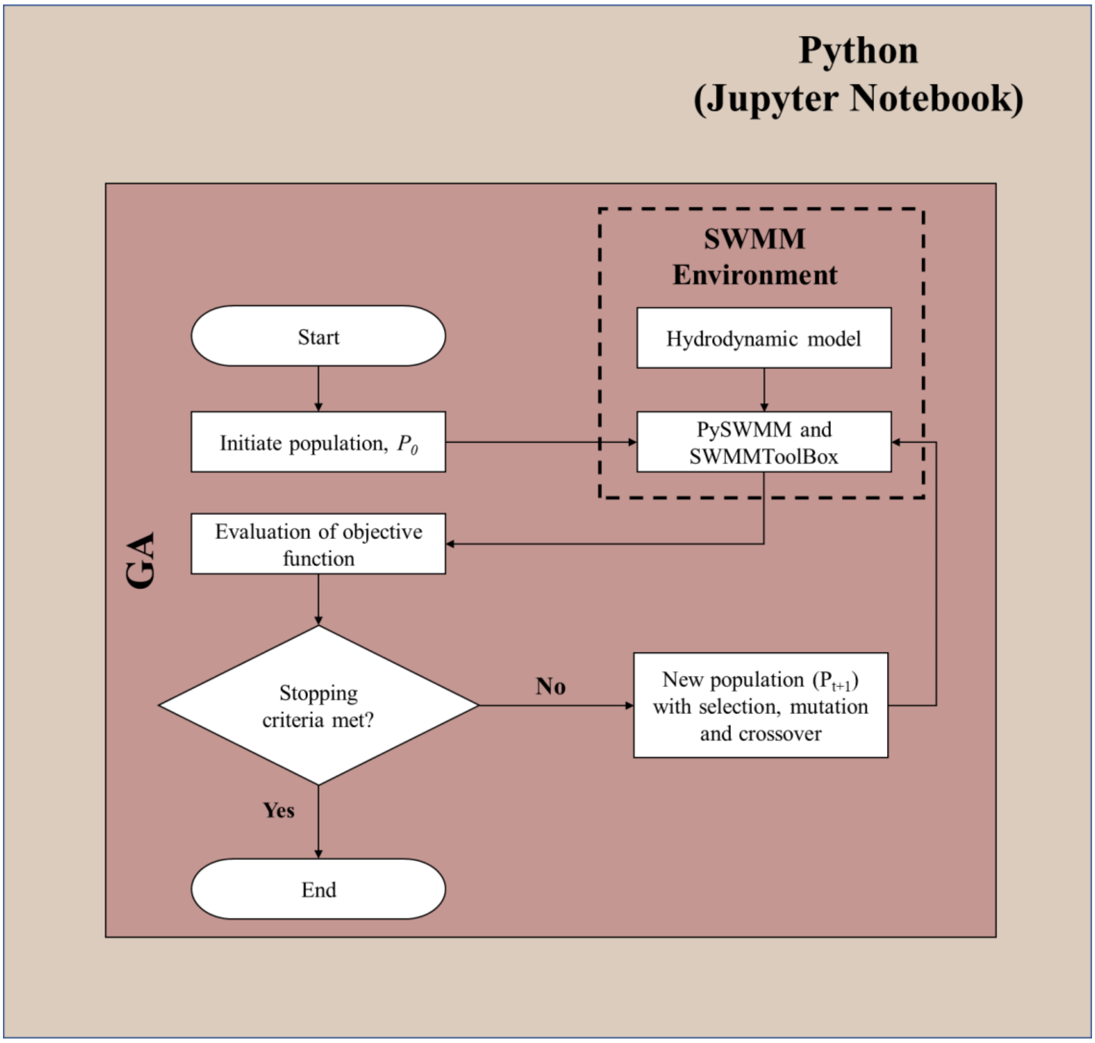


Figure 3-1 Metaheuristic optimisation framework using Genetic Algorithm (GA) coupled with Storm Water Management Model (SWMM) in Python

3.1.1 Objective function

The optimisation problem will be expressed in terms of the intervention cost. Therefore, the optimisation objective can be defined as the minimisation of the cost needed to implement the measures to reduce the risk of flooding. The measures include both grey and G-B measures. While exploring the objective function, it is decided that storm tank addition will not be considered for this thesis regardless of its widespread use in reducing flood risk. Since the application of storm tanks installation might not be a good solution when retrofitting existing UDS [28], the grey measures considered in this thesis are pipe substitution and pump replacement.

Alves et al. (2016) described that the cost of each alternative solution could be calculated using the estimated unitary cost associated with the coverage area of each measure or diameter in case of pipe addition. Thus, the objective function (*i.e.* fitness function of the optimisation) can be described as:

$$F = Min\left[\sum_{j=i}^{NSC}\sum_{i=1}^{M_{GB}}\left(C_i * S_{ij}\right) + \sum_{k=1}^{NP}\left(C_p(D) * L_k\right) + \sum_{l=1}^{NPu}\left(C_{pump}(Capacity)\right)\right] \quad (3\text{-}1)$$

Equation (3-1) comprises of three-part, the first is related to the cost of implementing G-B measures, and the latter is related to pipe and pump replacement cost, respectively. M_{GB} is the number of G-B measures applied for the whole catchment, *NSC* is the number of sub-catchments on the case study location, C_i is the cost per unit of measure i, and S_{ij} is the size (area) of measure i in sub-catchment j. For the 2nd term, *NP* is the number of pipes, C_p is the cost per length of pipe associated with diameter, and L_k is the length of pipe *k*. Meanwhile, for the 3rd term, NP_u is the number of pumps that needs to be replaced, and C_{pump} is the cost index of the pump concerning its pumping capacity.

Cost calculation for the implemented measures is based on the literature review, and analysis of cost calculation will be done using the asset's present value. Both sewer pipelines and G-B measures can be considered assets owned by the municipality; thus, the present value analysis can be done to these infrastructures. The present value (PV) analysis considers the total cost needed to be spared today to cover all the expenses of a particular asset during its defined lifetime, also known as the planning horizon [34]. Thus, by using the present value analysis, the investment and maintenance cost for the whole life of each infrastructure is taken into consideration [35]. Different countries used different planning horizons. Typically for public investment in the Netherlands, the value of 30 years is used, along with the discount rate of 4% [34]. The PV can then be derived as the total sum of the present values, which are the investment cost and annual recurring cost (A_k) throughout the entire planning horizon (*t*), based on the discount rate (*dr*). Equation (3-2) shows the PV calculation.

$$PV = CAPEX + \sum_{k=1}^{i} A_k \frac{(1+dr)^t - 1}{dr\,.\,(1+dr)^t} \quad (3\text{-}2)$$

3.1.2 Decision variables

The decision variables (DV) of this optimisation are the size for each implemented measure, *m*. This includes the diameters of each replaced pipe segment, the new pump capacity, and the area of implemented green-blue (G-B) measure. It means that the DV for pipe replacement, pump replacement, and G-B measures implementation depends on the number of pipes (*NP)*, pumps (NP_u), and sub-catchments (*NSC*). For this thesis, each sub-catchment can have one of each selected G-B measure if it is implementable (see also Chapter 4.4 on the G-B-G measures).

Table 3-1 Number of decision variables for each rehabilitation measure

Measure	Decision variables
Pipe replacement	No. of pipe (*NP*)
Pump replacement	No. of pumping station (NP_u)
GB measure	No. of selected GB x No. of SC (*NSC*)

The optimisation algorithm will process and evaluate different alternatives with different sizes of G-B-G measures implemented. Therefore, the DV varies between the predetermined minimum and maximum values. These values were determined through a land-use analysis using aerial images from available sources (*e.g.* Google Earth). Since there are many possible numbers between the minimum and maximum area values, a discretisation of the area value is needed. The discretisation of the area can help to reduce the search space further. The discretisation of the areas of the measurements can be done by using a bin of 10% size for smaller maximum area (<100 m^2) and 5% bin size for larger maximum area. It means that one measure's possible values in a sub-catchment vary with a bin of 5% or 10% of its maximum value.

Meanwhile, the locally available predetermined sets of pipe diameter and pump capacity will determine the range of pipe diameter and pump capacity. The decision variable optimisation for the area of G-B measures will use LID Control tools in SWMM. The codes developed change the areas of each LID Control unit and later evaluate the result of simulation with the objective function.

3.1.3 Optimisation constraints

The primary constraint for this optimisation problem is that no flooding should happen at every node under the given design storm scenarios. The term '*flooding*' will be identified as ponded water above the maintenance hole (junction node) for more than 1 minute of the flooding event (hours flooded). In cases concerning flooding that can cause nuisance, the flood depth around 10 cm is usually used as a reference [36]. However, no flooding situation is expected when using a design storm with a return period of two years. Therefore, the constrain will be the flooding volume of each node (VF), where VF_i indicates the flood volume of node *i*.

Meanwhile, node surcharges will not be used as the constraints in this thesis. Since SWMM have precision up to three decimals behind 0, the flooding volume will be eliminated when the ponded depth is exactly at 0.000 m, *i.e.* ponding lower than 1 mm – which cannot be shown in SWMM – will not be counted as flooding. The ponding depth is used as a parameter since it determines the extent of the flooding effect on a particular area. The higher the ponded depth, the higher the risk of damage and casualties of the flooding; this is because a higher ponded depth can cause a shortage of clean water and more electricity and internet problems [37].

$$VF_i < 0,\ i \in N_N \tag{3-3}$$

For pipe substitution, the common constraint will be the available pipe diameter on the market. Although some authors [38] that focus more on this measure also apply hydraulic constraints, such as peak water depth, velocity as peak flow, *et cetera*. However, for this thesis, only the available pipe diameters on the market will be the constraint for pipe addition as expressed in Equation (3-4), where *D* is a set of commercially available pipe diameters, and *p* is the specific pipe segment of pipe addition (*NP*). The same goes for the pump replacement, as expressed in Equation (3-5).

$$D_p \in \{D\}, p \in NP \tag{3-4}$$

$$PC_k \in \{PC\}, k \in NP_u \tag{3-5}$$

When the no-flooding constraint is breached, a penalty will be given to the fitness value of that specific solution. This penalty function will add to the objective function (Equation (3-1)) and be based on the total volume of flooding, $V_{flooding}$ coming out of flooding nodes. Therefore, the objective function with the addition of the penalty function becomes:

$$Min\left[\sum_{j=i}^{SC}\sum_{i=1}^{M}\left(C_i * S_{ij}\right) + \sum_{k=1}^{NP}\left(C_p(D) * L_k\right) + \sum_{l=1}^{NPu}\left(C_{pump}(Capacity)\right) + \left(\boldsymbol{\alpha}\, \boldsymbol{x}\, \boldsymbol{V_{flooding}}\right)\right] \quad (3\text{-}6)$$

The last term of Equation (3-6) considers a variable, α, that expresses the cost associated with each unit volume of flooding water. The value of α should not be too large to avoid non-convergence in the optimisation and should not be too small to ensure no flooding happens. The desired α value should be able to give a difference of one to two magnitude between the cost of measures and penalty. Therefore, the value should be case dependent.

3.2 Optimisation method

3.2.1 Overview

The optimisation will be done by linking the evolutionary algorithm, Genetic Algorithm (GA), with a hydrodynamic model to find the optimal solution to rehabilitate the urban drainage system (UDS). For the optimisation, a pre-made python package of Genetic Algorithm developed by Ryan (Mohammad) Solgi (2020) [39] will be used in this thesis. GA is one of the most popular evolutionary algorithms or metaheuristics that works based on the evolutionary principle and survival of the fittest individuals within a population. Thus, this method consists of n_{pop} individuals (*i*) within a population, *P*, each with different genes that differentiate them [19]. Each individual, *i*, is associated with a chromosome consisting of several genes, representing the number of decision variables of the optimisation problem. GA works by combining three main processes: selection, crossover, and mutation.

Once each individual in the population, P_i, has been generated, evaluated based on the objective function, and ranked based on its fitness, f_i, the reproduction process starts. A portion from the top elite individual, P_e, are selected to be on the next population (elitism GA) based on the user-defined elite ratio, μ_e, along with the selected parents' portion, μ_p. Furthermore, the offsprings from the selected parents (P_p) are produced based on the defined crossover probability, μ_{co}, and type. Hereafter, the mutation generator plays a role in introducing random values to the genes of the new offspring, P_c, according to the mutation probability, μ_m; hence, reducing the possibility of an early convergence due to local optima. This new population will then undergoes the same evaluation and reproduction process until the termination criteria are met. Two of the most common termination criteria is the number of generations (*i.e.* number of iteration), *nG*, and the number of generations without improvement, *nWI*. The Pseudocode for elitism GA [40] can be seen below. The algorithm takes as input all genetic operator parameters mentioned.

```
Input: $\mu_p$, $\mu_e$, $\mu_{co}$, $\mu_m$, $n_{pop}$, $nG$, $nWI$
Output: Best solution based on the termination criteria
    gen = 0
    Generate $P_0$ as initial population
    while gen < $nG$ or termination criteria are not satisfied:
        Evaluate $f_i$ for each $i$ in $P$
        Sort($F$ for all $i$) -> Select the elite of population ($P_e$) according to $\mu_e$
        Selection of possible parents population ($P_p$) based on $\mu_p$
        for $j$ = 1 to $P_p$:
            Generate random value $Rand$ in range [0, 1]
            if $Rand$ < $\mu_{co}$:
                $P_{p,j}$ is an effective solution for cross-over operator
            End if
```

```
        for $j$ = 1 to ($n_{pop}$ - $P_p$ - $P_e$) / 2:
            Select 2 random solutions with uniform distribution from the effective $P_p$ list
            Generate two new offsprings with the cross-over operator
            Put offsprings to list of $P_c$
        for $j$ = 1 to $P_c$:
            for $k$ = 1 to $nDV$
                Generate random value $Rand$ in range [0, 1]
                if $Rand$ < $\mu_m$:
                    Replace DV $k$ from solution $P_{c,i}$ ($P_{c,i,k}$) using the mutation operator
                end if
        P = $P_e$ + $P_p$ + $P_c$
        gen += 1
    End while
```

3.2.2 Representation of individual solutions

Generally, each individual within the population represents one solution with all relevant information or decision variables (DV) as its genes. The optimisation aims to find the optimal UDS rehabilitation; thus, each decision variable consists of the sizes of possible measures to be implemented. The number of possible values for each decision variable, d_k, will differ based on the pre-defined list, M_k, for grey measures and discretised area values for G-B measures. Thus, the following expressions can be used:

$$M_k = [size\ 1, size\ 2, \dots, size\ d_k] \qquad (3\text{-}7)$$

$$k \in \{1, 2, \dots, nDV\} \qquad (3\text{-}8)$$

$$M_{k,x} = DV_k \qquad (3\text{-}9)$$

$$i = [DV_1, DV_2, \dots, DV_{nDV}] \qquad (3\text{-}10)$$

Since each DV has a prefined list of ranges based on the available materials and land plot, rather than using the actual value of each decision variable (*i.e.* the area, pipe diameter, or pump capacity), usage of integer values will ease the optimisation. For example, suppose DV_1 and DV_2 represent the new diameter value for Pipe 1 and the area of G-B measure in sub-catchment 2, respectively. In that case, the value of DV_1 and DV_2 will have a significant difference. Therefore, in ensuring that the algorithm has access to the pre-defined list, the index number with an integer value, x, of the selected value within the pre-defined list, M_k, will be used instead of the actual values. Therefore, the individual for the optimisation can be represented as:

$$i = [x_{1,} x_2, \dots, x_{nDV}] \qquad (3\text{-}11)$$

$$x \in \{0, 1, \dots, d\} \qquad (3\text{-}12)$$

For this thesis, the order of each gene within one individual is extremely important. This is because each gene represents the new measure size for one particular pipe, pump, or sub-catchment on a particular location.

3.2.3 Optimisation operators and parameters

In order to generate the next population, GA has three main genetic operators: *selection*, *crossover*, and *mutation*. For each operator, several methods can be used. Choosing which method to choose depends on the problem and the individuals of the optimisation. Aside from the three main genetic operators, the population size and number of generations are also essential parameters to be considered. Choosing between higher population size and a higher number of generations needs some trial-and-error, and most of the time, it depends on the problem size.

A high population size provides a *wider* search space, allowing the algorithm to explore most decision variables and escaping local optima solutions. However, when the search space is too wide, the algorithm might result in early convergence. On the other hand, a higher number of generations creates a *deeper* search, enabling the algorithm to find the optimal solutions and better convergence. However, a deeper search comes at the cost of local optima solutions with a high computational burden and significantly increases simulation run time.

Elitism Selection

In general, selection becomes the primary determinant to produce the next population. Elitism selection is one among many methods to do the selection process. Elitism selection ranks each individual within one population based on its fitness to the fitness function, in which f_i indicates the fitness of individual i. Then, according to the defined elite ratio $\mu_{e,}$, a percentage of the best individuals with the best rank are selected and become the new individual for the next population. The μ_e should be set very small to prevent the algorithm from being trapped in local optima. The next best individuals after the elites will become the parent solutions according to the defined parents' portion ratio μ_p. The parent solutions will then become part of the new population as well. With this method, the best solutions are ensured to survive in the population. However, the downside comes with a possibility of early convergence due to the lack of space exploration [41].

Uniform Crossover

Crossover plays a role in mixing the selected solutions from the previous generation and ensuring that the solution can provide convergence. The chosen crossover method for the optimisation is uniform crossover. This is because each gene within the individual represents different measures at a different location; thus, the order of the genes within one individual matters. For example, a decision variable for pump capacity can only be swapped with the same decision variable from another individual. Uniform crossover is one of the most common crossover methods used. This method works by exchanging genes of the parents to create the offspring based on a uniform random real number, $u \in \{0, 1\}$. With this, the uniformity in the crossover process can be ensured. The random real number u creates a binary mask for each gene that determines which parent the first child will inherit each gene [42]. For each set of effective parents (P_1 and P_2) based on the crossover probability μ_{co}, a set of offspring (C_1 and C_2) will be reproduced and added to the population.

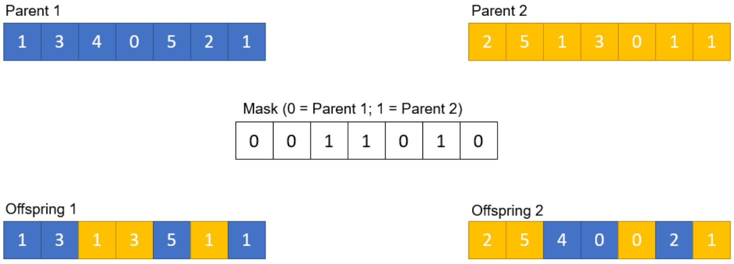


Figure 3-2 Illustration of uniform crossover

Mutation

Mutation can be described as randomly assigned a value of a gene within one individual. Mutation enables the algorithm to explore more diversity within the population and escape local optima. While crossover acts within the algorithm subspace, with mutation, the algorithm can also explore solutions outside of the algorithm subspace [41]. For each offspring generated from the crossover operator, there is a probability of μ_m to mutate each gene. A random value between 0 and 1 will be assigned to each gene, and when it is lower than the probability, that gene will be mutated with a random value.

3.3 Climate change scenarios

Urban drainage systems (UDS) are designed with a specific design storm to test the system's hydraulic capacity in which no flooding should occur. However, due to the change in rainfall intensity caused by climate change, urban flooding might happen even with its design storm. In the Netherlands, the commonly used standard rainfall showers are *Bui01 – Bui10* from the Sewerage Module C2100 (2004) [43]. Nevertheless, these design storms are not sufficient enough to test the hydraulic capacity of the UDS under more extreme showers, which are likely to happen due to climate change. Climate change brings many uncertainties concerning rainfall extremes. The *Koninklijk Nederlands Meteorologisch Instituut* (KNMI) – the Netherlands national meteorological institute – has expected that there will be more extremes in hourly rainfall (short duration) compared to the daily rainfall and an increase of 12% in hourly rainfall intensity per degree of warming due to climate change. This expectation in the increase of rainfall intensity might change the return period (T) of several design storms, like the commonly used *Bui08* (total volume = 19.8 mm) with T = 2 years will become one year instead [44].

As a tool to support the study of impact or develop adaptive strategies in combatting climate change, KNMI derived four climate scenarios known as KNMI’14 climate scenarios, based on the change in air circulation and global temperature rise (Figure 3-3). Taking into account the global findings from the climate model calculation mentioned in the IPCC (Intergovernmental Panel on Climate Change) 2013 report, KNMI performed another calculation using the climate model for Europe. The four scenarios G_L, G_H, W_L, W_H were established with G_L (moderate), and W_H (extreme) becomes the range in which the extreme rainfall is expected to develop. These scenarios are developed as a generic framework for a wide range of climate adaptation development in the Netherlands [45].

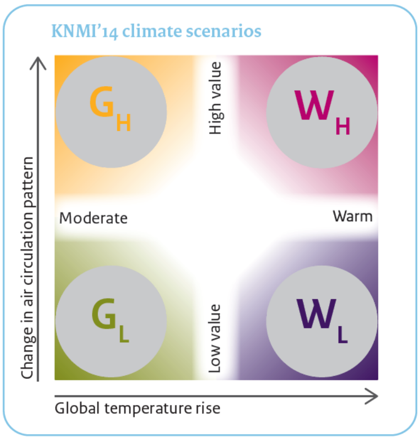


Figure 3-3 KNMI'14 climate scenarios

(Source: KNMI [46])

Table 3-2 Change of extreme rainfall based on KNMI'14 climate scenarios (adapted from KNMI'14 brochure)

Scenario 2050	Indicator	
	Daily rainfall amount exceeded once every 10 years	Maximum hourly rainfall per year
G_L	+1.7 to +10%	+5.5 to +11%
G_H	+2.0 to +13%	+7.0 to +14%
W_L	+3.0 to +21%	+12 to +23%
W_H	+2.5 to +22%	+13 to +25%

Table 3-2 shows a transition jump in rainfall changes between daily and hourly extremes. For example, the W_H scenario for long-duration rainfall has a lower limit of +2.5%, while the short-duration rainfall +13%. To take these maximum hourly rainfall changes into account, STOWA, the centre of expertise of the Dutch Water authorities, developed new six climate scenarios (low and high) for 2030, 2050, and 2085 in relevance to the KNMI'14 climate change scenarios to update the previous STOWA2015 scenarios [47]. In corresponding to these six climate scenarios, six composite rainfall for 2030, 2050, and 2085 with a return period (13 return periods) varying from 0.5 (twice a year) to 1000 years were also derived [45].

This thesis aims to develop an adaptation solution to reduce the risk of urban flooding in changing climate. Therefore, the use of composite rainfall that represents the change in rainfall events due to climate change can address the objective of this thesis. However, the limitation of using these climate change scenarios is that the difference between the lowest and highest KNMI'14 scenarios is less distinct due to the large natural variation in precipitation. It means that designing drainage systems under these composite rainfall might cause an overestimation or underestimation of the new capacity required for the rehabilitation [46]. Another method to incorporate climate change effects is by assuming that there will be an increase to the current design storm's volume by 13% in 2050 and 27% in 2085, according to the KNMI'14 scenarios. This method can be used to check whether the current system can withstand the worst-case scenario or not [48]. However, the assumption on the overall increase in rainfall volume might give a different hyetograph with different peak intensity than the designated composite rainfall. Other than using design storms, climate change scenarios can also be estimated using the time-series historical rainfall data of several years [49], which is useful when looking at the impact of climate change on the emission of sewer overflows.

Nevertheless, since this thesis does not consider the impact of sewer overflows and the rainfall's peak intensity and timing is considered an important factor to rehabilitate the system, which might not be reflected well with the increase of volume rainfall method, the usage of composite rainfalls as a design storms method is chosen. The low scenario composited rainfalls for 2030 (C_2_2030_L), 2050 (C_2_2050_L), and 2085 (C_2_2085_L) associated with the STOWA2019 and KNMI'14 climate scenarios will be used as a projection for future rainfall events. The chosen return period will be two years, which is also the most common return period used in the Dutch sewer system. By using this return period, there is a possibility that the designed system will not be able to withstand rainfall with a higher return period which will not be covered in this thesis.

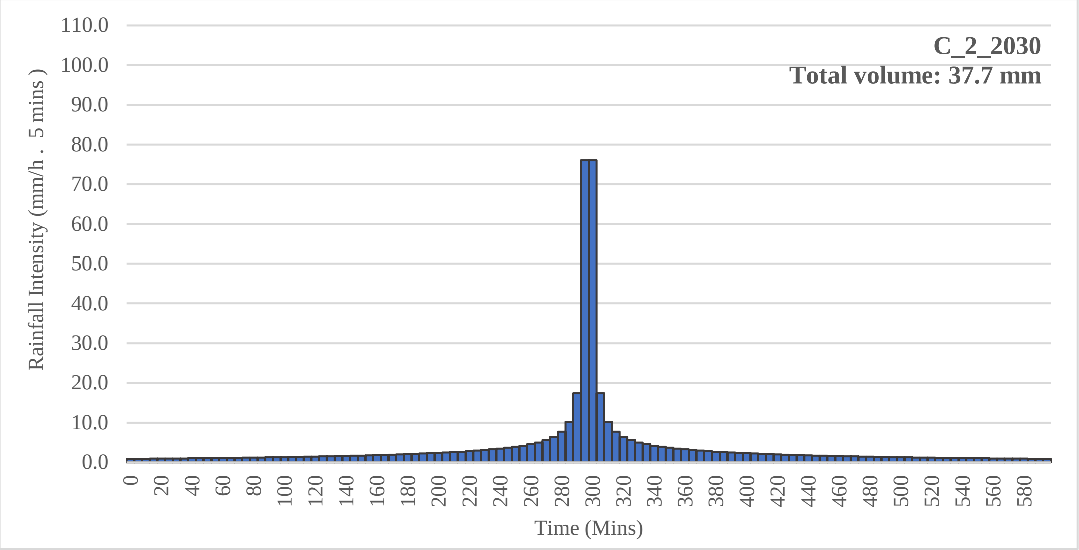


Figure 3-4 Hyetograph of the composite rainfall for the year 2030 with T = 2 years (C_2_2030)

The first design storm for Scenario 2030, C_2_2030, is a 10-hours rainfall with a total volume of 37.7 mm, and the peak comes halfway through the rainfall event, around 290 minutes from the start of the event and ends after 20 minutes. The peak intensity of this design storm is 76.1 mm/(h . 5 mins). Figure 3-4 shows the hyetograph of Scenario 2030. The second (C_2_2050) and third (C_2__2085) design storms for Scenario 2050 and Scenario 2085, respectively, have a similar rainfall distribution over time and peak time with Scenario 2030. Scenario 2050 has a total rainfall volume of 37.9 mm over 10-hours of rainfall, with the peak intensity at 76.1 mm/(h . 5 mins), the same as Scenario 2030. What differentiates these two design storms is the total rainfall volume and intensity before and after the peak. On the other hand, Scenario 2085 comprises 38.6 mm of rainfall over 10-hours with a peak intensity at 78 mm/ (h. 5 mins).

3.4 Selection of Green-Blue-Grey measures

Rehabilitation of the urban drainage systems (UDS) is a unique problem that needs a tailor-made solution. Therefore, the case study needs to be studied further when selecting the most appropriate Green-Blue-Grey (G-B-G) measures to be implemented. However, several measures are commonly implemented in general and can become the obvious choices in some cases. For grey measures, enlargement of pipe, increasing the length of overflow weirs, increasing pump capacity for networks with many pumps, and addition of storm tanks are widely used in studies. Meanwhile, green-blue (G-B) measures are incredibly dependent on the case study area; thus, they cannot be decided before further site characterisation.

3.4.1 Selection of Grey measures

Most review literature (see Chapter 2) mentioned the usage of underground storm tanks to reduce urban flooding. However, although it is a robust grey measure, it is not commonly used for retrofit applications [28]. In addition, underground in-line Storm tanks are usually installed with a large storage capacity, which will be hard to do in a built neighbourhood with many hard surfaces [50]. Meanwhile, pipe substitution with another diameter makes a good choice when considering replacing the existing pipes due to ageing infrastructures. Although another way to implement the increase of pipe diameter can also be done by installing an auxiliary pipe to compensate for the additional volume needed.

Another grey measures to be considered are the replacement of the current pump with a bigger capacity and/or lengthening the overflow weir. Pump replacement can be used when the case study area comprises of segmented area separated by pumps. However, the downside of this measure is that more water will be pumped towards the downstream area of the network. On the other hand, lengthening the overflow weir can reduce the drainage network's hydraulic gradient line, thus reducing urban flooding. Having said that, it comes with the consequences of increasing the sewer overflow towards the surface water.

Since this thesis is assumed to be a retrofitting problem, for this thesis, the grey measures used will be pipe substitution and pump replacement.

3.4.2 Selection of Green-Blue (G-B) measures

While the Grey measure that will be implemented has already been decided as pipe and pump replacement, for the Green-Blue measures (G-B measures) selection, a decision tree is developed based on information of the site characteristics matrix as described in *The SuDS Manual (C697)* [51, 23]. Five decision factors are considered in the decision tree: the size of the sub-catchment area draining to a single G-B measure, the availability of improvable area, site slope, soil permeability, and groundwater depth relative to the ground level. Figure 3-5 shows a general decision tree that can be used for GB measure selection.

In the decision tree, eight G-B measures are considered: retention pond (RP), infiltration trench (IT), infiltration basin (IB), bio-retention cell (BRC), vegetation swale (VS), green roof (GR), rain barrel (RB), and pervious pavement (PP). The first step in the decision tree is related to the size of the drainage area for a single G-B measure in hectares. The second step considers the availability of improvable areas on that. This step can be interpreted as the available space to implement the G-B measures related to the area’s density. In some cases, even though the area has a low-density built area, the plot size that can be used to implement G-B measures is not significant. This is because the available areas are either private-owned, agricultural plots, or serve other purposes. Thus, improvable-space availability becomes the deciding factor for this second step. Step 3 considers the catchment slope, which is an essential factor for some G-B measures (*e.g.* PP, VS). Step 4 then takes into account the permeability of the soil (permeable vs impermeable). Permeability, in this case, is only the general capability of the soil to convey water. When referred to the definition of Hydrologic Soil Groups (HSG), permeable soil can be interpreted as soil Group A and B, while impermeable is soil Group C and D, see also [52]. The last step is related to the water table depth relative to the ground level. For G-B measures that involve infiltration, this last step limits the applicable G-B measures for areas with high groundwater.

Since the decision tree is a more general filter to select proper G-B measures, an in-depth analysis of the case study condition will follow to determine the suitable G-B measures to be implemented on the case study location. This in-depth analysis consists of the local condition and spatial analysis using aerial images to deduct the selected G-B measures(s) actual applicability on each sub-catchment. Afterwards, the selected G-B measures(s) design becomes the basis for determining the minimum and the maximum area of implemented G-B measures using the known case study data and aerial images. Since the decision variable for the selected G-B measures is only the surface area, the other variables (*e.g.* thickness, width) will be decided before the optimisation; see Chapter 4.4.

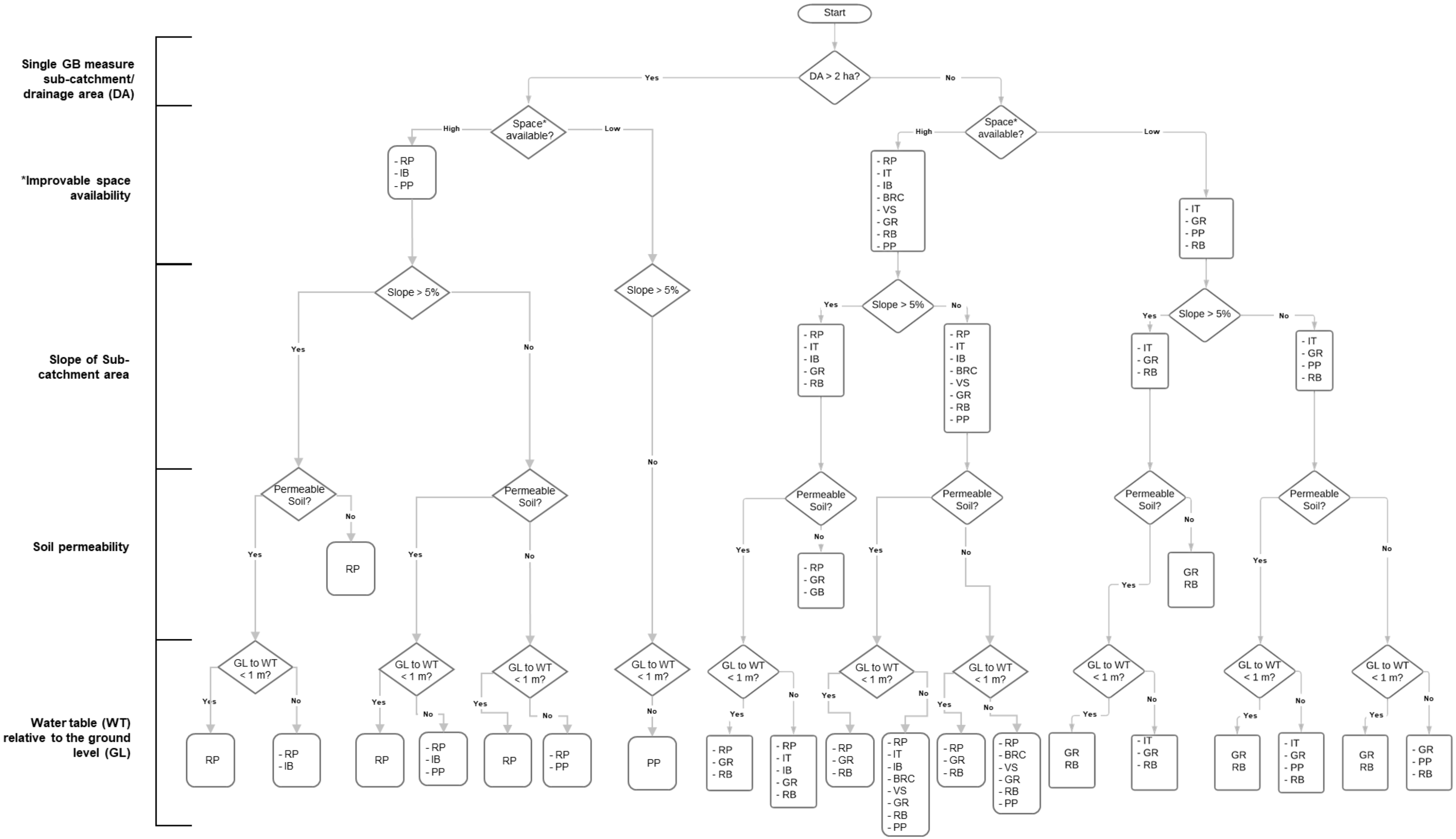


Figure 3-5 Decision tree for Green-Blue (G-B) measures selection

3.5 Simulation Tools

The main purpose of a hydrologic and hydraulic model is to mimic the hydraulic properties and behaviour of the real UDS to be tested with these alternative solutions or scenarios. One widely known model used as a dynamic simulation engine to calculate and mimic the hydraulic behaviour of water runoff and sewer systems is called The Storm Water Management Model (SWMM), developed by the United States Environmental Protection Agency (US-EPA) [53]. SWMM can be used when the user wants to model a 1D flow by using the basic 1D Saint-Venant equations; therefore, SWMM is not meant to model a 2D flow, for example, to see the movement of the overland flood. Since this thesis only focuses on 1D flow from the drainage systems and no flooding should happen; thus, SWMM is a robust tool.

This model is used as a base model in this thesis to simulate the alternative solutions. As a starting point, the simulation needs a calibrated mathematical model of a real UDS network. However, the model needs to be accurate to mimic the rainfall-runoff process of the system to predict flooding. Since the purpose of this thesis is not calibration, a validation of the model with the available monitoring data will be used to justify that the dynamics of the model are good enough to predict the real network.

This chapter presents the hydraulic model used in enabling the optimisation to work, SWMM. First, Chapter 3.5.1 highlights the drainage systems representation in SWMM, followed by the explanation on the modelling of the implemented grey measures in Chapter 3.5.2. Hereafter, Chapter 3.5.3 highlights the implementation of green-blue (G-B) measures in the model. Lastly, Chapter 3.5.4 elaborates on the best way to simulate and evaluate the alternatives solution during the optimisation.

3.5.1 Drainage systems modelling using SWMM

SWMM works by conceptualising drainage systems (DS) as the movement of water and materials through different environmental compartments by solving the hydraulic equations of each process. These compartments can be divided into the Atmosphere (precipitation and deposits pollutants), the Land Surface (sub-catchments), the Groundwater (infiltration and aquifer), and Transport (sewer systems) [53]. Therefore, this thesis focuses only on the rainwater cycle process from the Atmosphere, Land Surface, and Transport compartments, while the Groundwater compartment is not explored further. This chapter detailed the drainage systems representation in SWMM and the computation principles used in some processes.

SWMM modelled and operated the rainfall-runoff and water transport processes using what is addressed by SWMM as visual and non-visual objects. The visual objects can be displayed in the SWMM interface and give a more precise representation of the DS. This includes Rain Gages, Junctions as manholes, Conduit Links as pipes, Sub-catchments, Storage Units, Flow Dividers, Weirs, Orifices, Outfalls, and Pumps. Meanwhile, the non-visual objects are supporting tools that cannot be seen on the drainage map and play a role in operating the dynamics in the DS, *e.g.* Time Series, Curves. Details about each object can be seen in SWMM5.1 Manual [53]. Figure 3-6 shows a schematic representation of a simple drainage network using visual objects in SWMM.

Considering that this thesis aims to reduce the flood risk, an adjustment to the original model needs to be made. This adjustment is needed to incorporate the manholes' capability to retain a certain volume of water when the pipe is surcharged before flooding occurs. This feature currently does not explicitly exist in the Junction nodes object properties. What can be found is the manholes capability to pond water atop it after flooding occurs, which is simulated based on the *Ponded Area* and *Allow Ponding* properties. With *Ponded Area*, the manholes can retain a certain amount of overflowing water on top of it and not immediately diminish the flooding water. In reality, this ponding area can come as surface depressions such as parking lots, backyards, or other areas [53]. After a certain time has passed and the UDS has excess capacity, the ponded water will be conveyed back to the system. This behaviour is considered different from allowing manholes to retain water, which this thesis wants to implement.

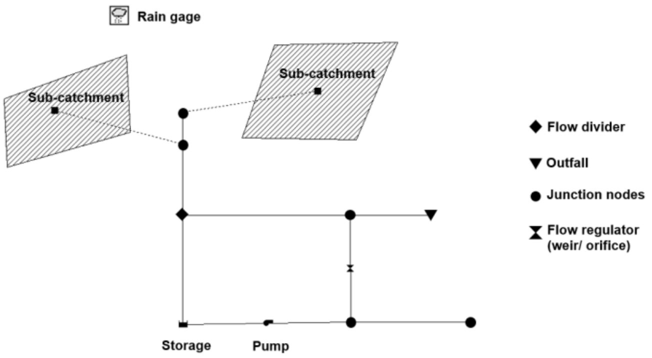


Figure 3-6 Schematic representation of a simple drainage system using visual objects in SWMM

The difference lays in the behaviour of the UDS. With *Ponded Area*, the manholes do nothing to reduce the water profile's hydraulic gradient line (HGL), leading to flooding ponded on top of the manholes. After the UDS gain some capacity, this ponded water flows back to the system. Therefore, in the SWMM output report, Ponded Depth report can be found. On the other hand, with the Storage unit mimicking the manholes to retain water when surcharge happens, the HGL of the overall water profile might not cause flooding in some places. Thus, to properly model this behaviour, some nodes on the system was converted into Storage nodes. What needs to be considered is that the flow attenuation might be affected when the implementation only happened on either the upstream or downstream part of the UDS. Therefore, several Junction nodes on the upstream and downstream part of the UDS in SWMM were converted to Storage nodes to make this flow attenuation more realistic. This thesis needs to calculate each storage unit/manhole area by adding all the manhole volumes in that area covered by that particular storage unit (see Figure 3-7).

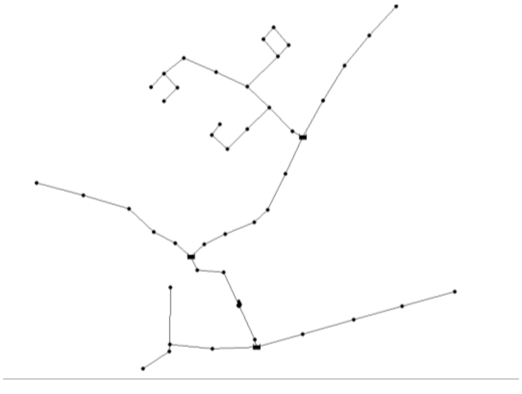


Figure 3-7 Simulating the retained water in the manholes as storage unit

Aside from the visual objects, the non-visual objects are also important in modelling the DS. The most important non-visual objects used in this thesis includes Time Series to input the design storms, Curves for modelling pumps, and LID Control to model the G-B measures.

SWMM uses a series of physical processes to model the dynamics of the rainfall-runoff process. First, it models all the hydrologic processes that resulted in runoff (*e.g.* precipitation, infiltration, evaporation). Also, it models the hydraulic behaviour of the network when it routes the water through pipes, channels, storage units, pumps, and regulators [31]. SWMM has several options for the user to choose the most fitting computational method for each process. In addition, the user can also not use all the process models available. In this thesis, the process models used are the Rainfall/Runoff, Infiltration, Flow Routing, and Surface Ponding. More details on the governing equations for each process can be seen in the SWMM5.1 Manual and SWMM's Model References [53, 54, 55, 56].

3.5.2 Modelling of Grey measures

This chapter discussed the implementation of Grey measures in the model for the optimisation simulation. There are three grey measures chosen as alternative solutions; however, since CSOs weirs lengthening is not part of the optimisation process, it will not be discussed further. Increasing the weir length can quickly be done by changing the Length value in the Weir property for all three CSO weirs. On the other hand, modelling pipes and pump replacements for optimisation needs more work.

Pipes substitution

In the SWMM user interface (UI) page, pipes replacement can be done by easily changing the Conduit link's property, the Max. Depth. The Max. Depth value is used to define the maximum depth of the conduit's cross-section, *i.e.* the diameter of the pipe if the shape is circular. All the pipes that are considered for optimisation are circular. Even though in the SWMM UI, these diameter changes can be done straight-forward by editing the Conduit link's property, it is not the case when adjusting the SWMM input file from an external environment (*e.g.* python).

In the text file (.inp) of the SWMM model, the Max. Depth property belongs under the [XSECTIONS] section rather than [CONDUITS]. [XSECTIONS] gives a complete description of the shape and geometry measurement for each conduit link. When the shape is Circular, the geometry will be the pipe diameter, and when it is in other shapes, the geometry values will change accordingly (*e.g.* becoming two values for width and length for Rectangular pipes). Furthermore, other properties of the conduit link (*i.e.* pipes) can be found under the [CONDUITS] part. Due to this nature, the codes need to look through both [XSECTIONS] and [CONDUITS] parts to calculate the total cost needed during the optimisation.

To model the pipe replacement in the SWMM file within the python environment, the codes rewrite the entire *.inp* file specifically on the [XSECTION] part according to the diameter values from the alternative solution for the optimisation process. Hereafter, for the implementation of the solution, another way can also be done to model the pipe replacement, which is by adding a parallel pipe to make up for the necessary volume increase based on the alternative solution. A way to model this is by manually adding a new pipe using the SWMM UI page.

Pumps replacement

Not as direct as pipe replacement, pumps are described by the pump curves. The pump curve portrays the relation between flow rate and condition of both the inlet and outlet nodes of the pump [53]. There are five types of pump curves in SWMM. According to the original model, the curve that describes the real pumps is the Type 4 curve. Therefore, the Type 4 curve will be used for the new pumps for optimisation as well. More details about the pump curves can be seen in the SWMM5.1 Manual [53].

The curves of each pipe can be made in SWMM by adding a new Curve object and input the maximum capacity (m^3/s) defined and the inlet node depth. The inlet node's depth and flow variable can be inputted accordingly as its effect is insignificant to the overall simulation.

The written codes will rewrite the Pump Curve option in the SWMM input file on the [PUMPS] section during the optimisation run. The pump curves that will be used need to be defined on the [CURVES] section beforehand or manually added in SWMM using the mentioned add Curve object method above.

3.5.3 Modelling of Green-Blue (G-B) measures

The main purpose of the LID Control is to model the behaviour of several G-B measures in SWMM using a unit process-based representation that can work accurately in a dynamic rainfall events simulation [56]. SWMM reckons LID as one of the properties of Sub-catchments. Each LID control is assigned to capture the runoff from a user-defined percentage of the sub-catchments impervious area.

There are 8 G-B measures that can be used explicitly in SWMM: Bio-retention Cells (BRC), Rain Gardens (RG), Green Roofs (GR), Infiltration Trenches (IT), Pervious Pavement (PP), Rain Barrel (RB), Rooftop Disconnection (RD), and Vegetative Swales (VS). Meanwhile, other G-B measures can be modelled by using either modified properties of the available G-B measures, manually calculating and reducing impervious areas, or adjusting other properties that can generate surface runoff.

The LID Control Editor manages all the general information regarding each selected G-B measure. It means that when a particular G-B measure needs to be implemented in a sub-catchment, another tool called LID Usage Editor is used. LID Usage Editor contains all the essential sub-catchment-specific properties to implement each G-B measure. This includes the area of each unit of measure, the number of measures, the width of measure, and the percentage of the impervious area treated. All the values for the selected G-B measures have been pre-defined in the original model's LID Control Editor for the optimisation process. Thus, during the optimisation, the code developed will implement the G-B measures by writing the LID Usage for each sub-catchment under the [LID USAGE] section in the SWMM text file input using the selected design parameters.

3.5.4 Simulating the alternative solutions

The simulation of each alternative solution combines the modelling of the drainage system (Chapter 3.5.1), modelling of grey measures (Chapter 3.5.2), and modelling of the G-B measures (Chapter 3.5.3). Thus, combining the three aspects creates one fully dynamic hydrology and hydraulic model for the optimisation to simulate. However, simulating a complex network with hundreds of conduits and sub-catchments can consume a lot of time to run the optimisation. The next question then be, is it better to run the optimisation using this full dynamic model, or will it be better to simplify the model further?

Simplifying a model can be done in several ways. For example, removing hydraulic components and replacing them with dummy pipes to route the runoff towards the outflow [57]. Another example is skeletonising the model by reducing the number of Junction nodes; thus, reducing the number of conduit links (combining several conduits) [58]. Finally, another way can also be done, like reducing the number of runoff generating areas (dump the inflow immediately to the Junction nodes) or changing the flow routing method into Kinematic Wave Routing to ease the computational burden for the optimisation.

What needs to be considered with simplification of the model is that extreme simplification can cause the model to fail to accurately predict the flooding volume and peak [57], which is the main problem this thesis wants to tackle. Furthermore, since the optimisation is done by implementing grey and G-B measures, the locations of these changes are also critical, along with the sizes. G-B measures are used mainly to delay the peak flow of a rainfall event. Therefore, each implemented G-B measure's location plays a significant role in evaluating the alternative solution, which means reducing runoff generating areas is not a good idea to be used in this thesis. In addition, in most cases, the reduction of Junction can be done for some conduits with almost the same slopes and uniform diameter. However, in the case study area, most conduits receive inflows from sub-catchment along the pathway, which makes it hard to combine the pipelines when considering that the behaviour of inflow from G-B measures implemented in that sub-catchment will change. In other words, the simplified conceptual model can lose details of the optimisation for both grey and G-B measures. These lost details are essential details to be considered for this thesis.

Furthermore, simplifying the model or usage of the Kinematic Wave Routing is usually done when used for a continuous simulation over a long period (*e.g.* 20 years of rainfall data) [59]. With a long-term run, a simplified conceptual model can be used according to the purpose of the analysis. However, this thesis used a 10 hours design storm with a single simulation time of around 10 seconds. This number can still be considered reasonable to be used for optimisation.

In conclusion, even though the full dynamic model simulation results in a heavier computational load and longer simulation time, all details that will be lost from simplifying the model might be resulting in the loss of essential details for this thesis. Furthermore, since locations of measures, especially the overall G-B measures, can become critical in reducing flooding, the best way to evaluate each alternative solution for the optimisation is by ensuring these details exist in the model. Thus, the full dynamic model is a better model for this thesis than a simplified model. Due to this, the dimensionality reduction of the optimisation problem is needed after an analysis of the case study area is done.

Chapter 4

Case study: Riethoven, The Netherlands

Rehabilitation of UDS requires much investment. On the other hand, urban floodings can pose a great threat resulting in further monetary loss. Spekkers *et al.* (2011) [60] analysed data from insurance companies in the Netherlands to look for the pluvial flood damage and found that damage from rainfall, snow, or meltwater between 1992 and 2009 reached € 7.5 million/year. Although the damage cost per year might be lower than other types of flooding like fluvial flooding, which is estimated to reach € 400 million due to heavy downpour across the Netherlands in Summer 2021 [61], the cumulative damage of pluvial flooding can be significant due to its frequent occurrences in lowland areas, like the Netherlands [60].

In this chapter, details about the case study will be discussed. The details will include a brief background and the characterisation of the case study location (Chapter 4.1). Furthermore, the flooding problem in the location will be discussed in Chapter 4.2. The urban flooding issue correlates with the existing urban drainage systems (UDS); thus, Chapter 4.2 describes the urban drainage systems in the case study location. The background information related to the case study location will then be the basis to select the appropriate Green-Blue-Grey measures according to the selection method (Chapter 4.4).

4.1 Case study description

Riethoven is one of the districts (*i.e.* village) of the municipality of Bergeijk (also called *Wijk 03 Riethoven*) and is located in the province of North Brabant, 15 km southwest of Eindhoven, The Netherlands. It is consists of two main neighbourhood areas (*buurt*), Riethoven and Walik, and three smaller neighbourhoods (Boshoven, Broekhoven, and Heiereind), with a population of 2,420 by 2020 [62] and has a total area of 1,754 hectares, of which 1,748 hectares land and six hectares of water. Based on the official address and residential registry, BAG (*Basisregistratie Adressen en Gebouwen van het Kadaster*), the Riethoven district has 1,089 addresses, and 990 are residential homes with a density of 105 addresses per km^2 [63]. When only looking at the neighbourhood areas, the average density of buildings is 192 buildings per km^2 [64]. The term Riethoven used will refer to the whole Riethoven district and not the neighbourhood area for the rest of this thesis.

The nearest weather station to Riethoven is located in Eindhoven, approximately 11 km from the area. It is recorded that the average amount of annual precipitation is 763 mm, with July being the wettest month and April is the driest month. The average annual amount of rainy days is at 175 days, and November has the most rainy days, followed by March, December, and January [65].

4.1.1 Site characterisation

Riethoven mainly consists of homogeneous characteristics due to its small area. Generally, it is a flat area with ground level ranging between 20 – 30 m above sea level (ASL) and slopes ranging from 0 – 4% and an average of 0.3%. With the majority of sandy soil, the soil in Riethoven is generally permeable, with an average permeability rate between 2.5 – 5 cm/ hour [66] (see Appendix B– Case study information).

The groundwater (or water table) is located at approximately between 80 – 140 cm (high) below ground level during the wet season (upper limit) and > 120 cm (low) below the ground level during the dry season in most of the district area (Figure 4-1). On the northern side, the groundwater table becomes much higher and can reach a maximum of 25 cm below ground level. However, this northern part of Riethoven is not a built-up area; see Chapter 4.1.2. The groundwater table is also high along the southern part of the area and can reach < 40 cm below the ground level during the wet season.

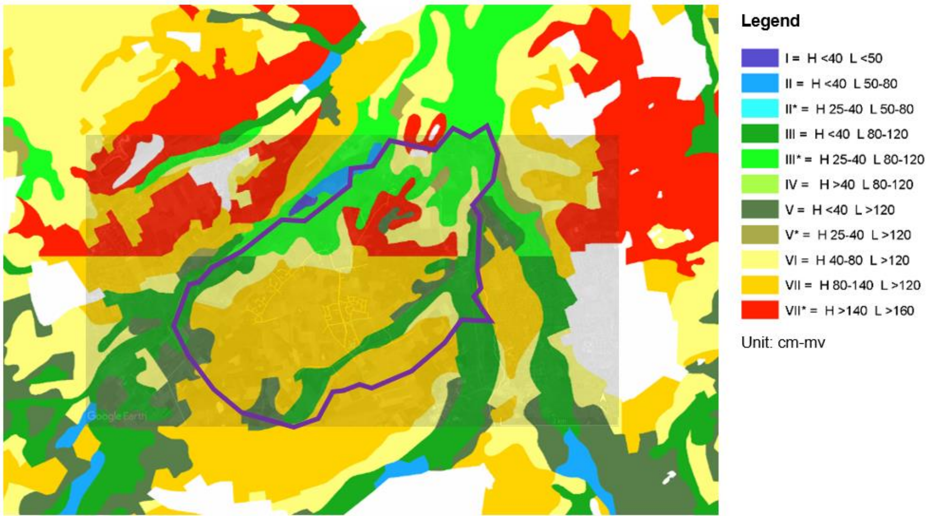


Figure 4-1 Groundwater map of Riethoven overlaid by drainage network map from Google Earth

(Source: Alterra)

4.1.2 Land use

Riethoven's built area is mainly a residential area, with 90% of its built area being residential neighbourhood houses. Among this 90%, around 95% of the houses are single-family houses, and only 5% are multi-family homes. Meanwhile, the 10% is divided into commercial (*e.g.* religious buildings, stores, sports complex) and industrial areas. Figure 4-2 shows the land usage map of Riethoven, and aside from the building areas, forests, grasslands, and arable (agricultural) lands also dominate the area.

Riethoven does not have any greenhouse or high-rise buildings except for the tower of the religious buildings (*e.g.* church, cathedral). Thus, in terms of areas sensitivity, the flooding '*hotspot*' or more vulnerable areas are the locations of critical infrastructures (*e.g.* mast towers) and commercial areas where many people gather. A list of all the notable infrastructures per sub-catchment can be seen in Appendix B.

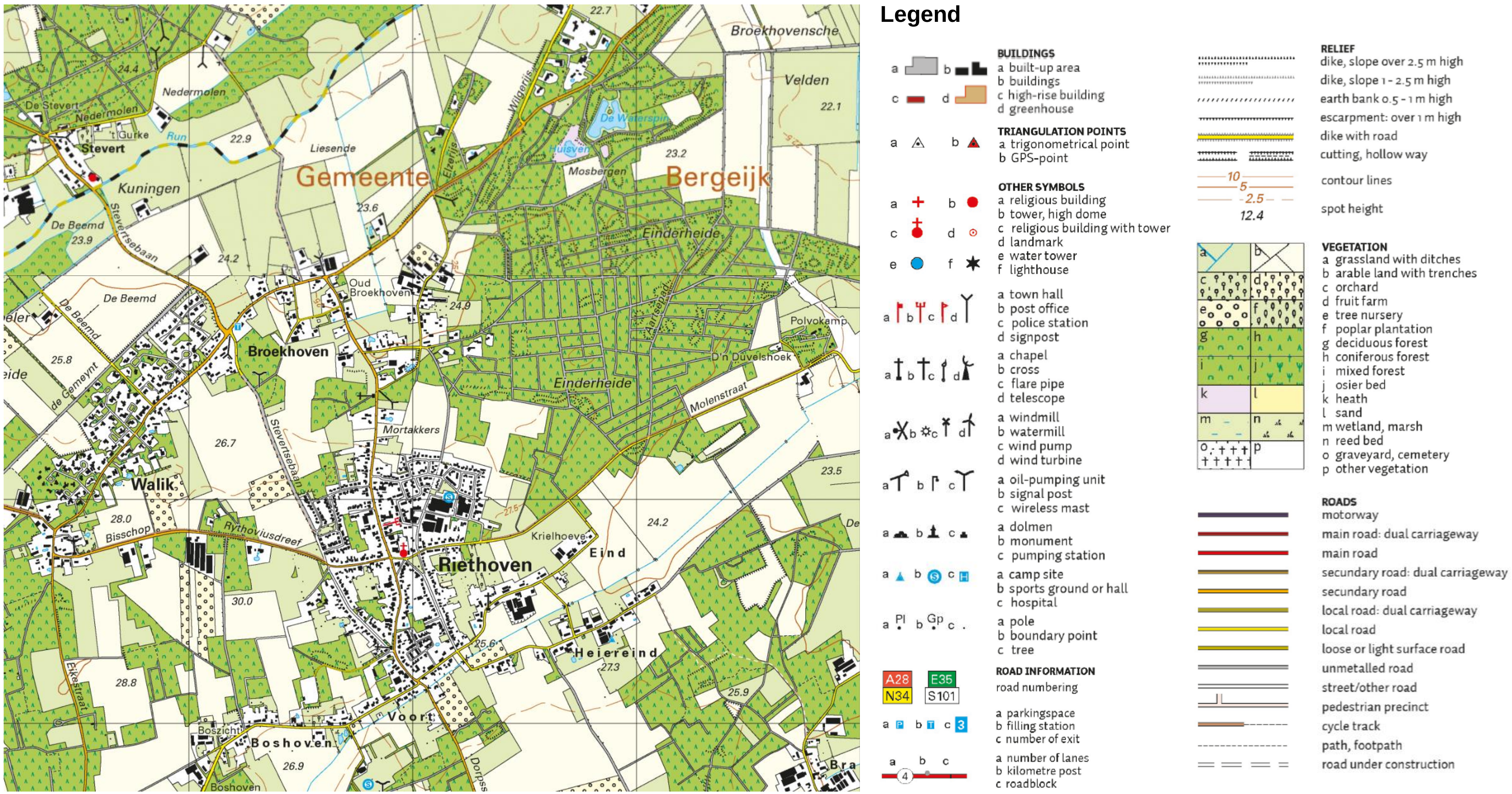


Figure 4-2 ***Basisregistratie Topografie (BRT)*** **of Riethoven 1:25,000**

(Source: pdok.nl)

4.2 The urban drainage system (UDS) in Riethoven

Riethoven is served by 21.9 km of sewer systems which 20.8 km of it is a combined sewer, while 1.2 km of it is the stormwater sewer (separate sewer system) with a total pipe volume of 2,066.3 m^3. The UDS consists of 509 nodes, 521 conduits, eight pumping stations (three for CSO) and six outfalls. Among 489 sub-catchments, the average area imperviousness is 72%, with 194 sub-catchments have an imperviousness of > 90%. These sub-catchments drains the runoff water to the UDS through the nodes. Each sub-catchment has one specific node, which becomes its specific outlet. However, several sub-catchments can drain to the same single node (*e.g.* Sub_205078 and Sub_205079 drain to Jun_G06). The mentioned sub-catchments here are small sub-catchments with an area that varies from 0.0008 ha to 1.2 ha. Thus, the total impervious area covered by the UDS is around 21.26 ha (0.2126 km^2). The overall drainage system then has a storage capacity of 97.17 m^3 / ha of impervious area. Details about each Junction Node, Conduit, and Sub-catchment can be seen in Appendix E, Appendix F and Appendix G, respectively.

Three out of six outfalls are CSO, two are stormwater outfalls (one to infiltration basin and the other one directly to the surface water), while the last one is outfall towards the central pumping station. Each CSO is equipped with peripheral facilities, storm tanks (ST) before the CSO weir called BBB (*bergbezinkbassin*). The outlet of CSO 1 and 2 are located at nearby canals.

These canals are directly connected to the most crucial river in the Bergeijk area, The Keersop, a side stream of the river Dommel and managed by *Waterschap de Dommel* (Water Board de Dommel). Meanwhile, CSO 3 outlet is flowing directly to the River Run, another side stream of River Dommel [67]. The drainage system in Riethoven is primarily a combined sewer (CS) and, just like the majority of drainage systems in Bergeijk, was designed with *Bui08*. *Bui08* is a design storm of 19.8 mm rainfall with a 1-hour duration and a return period (T) of 2 years based on the Urban Drainage Guideline module C2100 [43]. The central part of Riethoven also has separate sewer (SS) systems (stormwater sewer) that collect only the stormwater within that area and convey it to the nearby surface.

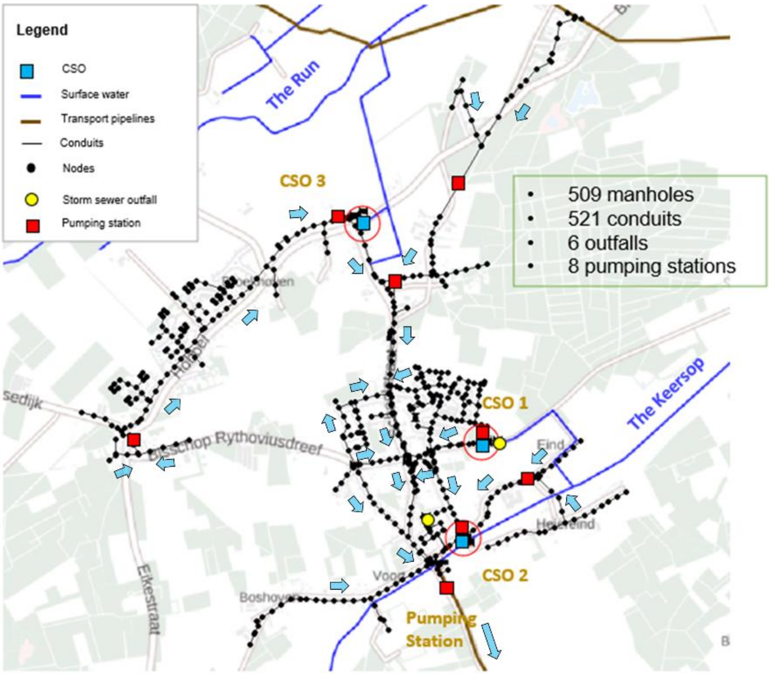


Figure 4-3 The urban drainage systems' layout in Riethoven

(Blue arrow indicating the dry water flow from the upstream to the downstream area)

It can be said that the UDS in Riethoven consists of five sections separated by pumping stations. However, the main sections are the North and South part of the UDS that a bigger pumping station separates with a capacity of 35 m^3/hour. The north section comprises three parts (Section A, B, and C), while the south section consists of two parts (Section D and E); see Figure 4-4. Both wastewater and stormwater will be pumped from the North section towards the South section, then into the pressure pipelines through the main pumping station on the most southern section of the area with 140 m^3/hour capacity. From hereon, all the discharged water from the UDS in Riethoven will be combined with wastewater from other towns/ cities and flow towards the treatment plant. The centre part of the UDS in Section D consists of parallel pipes that are used to increase the detention capacity locally (see Figure B. 4 in Appendix B).

Table 4-1 Pumps maximum capacity in the case study area

Pump ID	Pump Maximum Capacity (m^3/h)	Description
Con_202009.2	25	From Section C to B
Con _204009.1	10	From Section E to D
Con _205019.1	140	Main pump
Con _205231IA.2	19	From peripheral basin near CSO 2
Con _206014.2	35	From Section B to D
Con _206035IA.2	5	From peripheral basin near CSO 3
Con _207011.1	14	From Section A to B
Con _209026.2	25	From peripheral basin near CSO 1

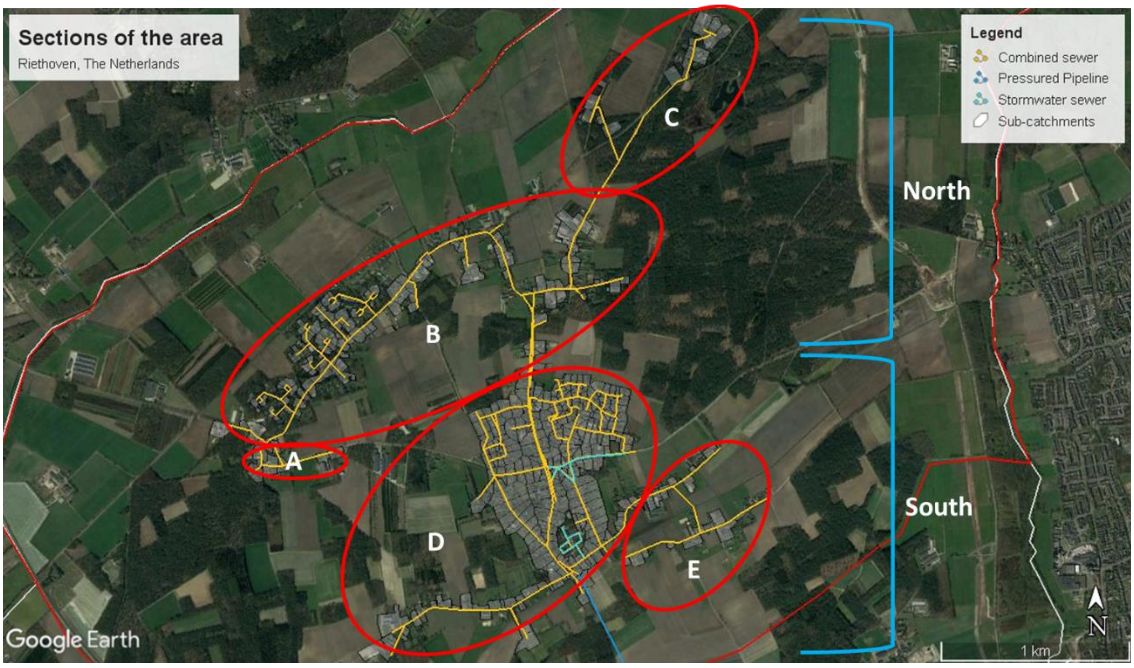


Figure 4-4 Urban drainage system's sections separated by pumping stations

4.3 Urban flooding issues

While sewer subsidence and groundwater infiltration are hardly an issue, the urban drainage systems (UDS) in Riethoven have difficulty handling extreme rainfall events during the wet season. The drainage system in Riethoven is primarily a combined sewer (CS) and, just like the overall drainage system in Bergeijk, was designed with *Bui*08 based on the Urban Drainage Guideline module C2100 [43] with a return period (RP) of 2 years. It was expected that with this design load, the hydraulic line should reach a maximum of ground level (zero floodings. Nevertheless, based on the review of the existing system, even when designed with *Bui*08, there are flooding nodes in Riethoven due to the increase of population, exacerbated by functional deterioration of the sewer system and heavier downpours [67].

The flooding problem in the case study area was further analysed after conducting several climate stress tests (done by the municipality) on the UDS and tests using the selected climate change scenarios for this thesis.

4.3.1 Urban flooding in the existing system

According to the KNMI'14 climate change scenarios, the intensity of heavy rainfall events will increase by 12-25% until 2050. In Bergeijk specifically, approximately an increase of the amount of rainfall up to 6% is expected. Furthermore, the most vulnerable locations are predicted to be Luyksgestel, Riethoven (neighbourhood), and Bergeijk (town), with a possibility of flooding of buildings and streets. Meanwhile, the less vulnerable areas are expected to be Walik, Weebosch and Westerhoven [37]. The vulnerability of the area is categorized based on the number of vulnerable objects. The vulnerable objects consist of buildings where many people can be located (i.e. commercial or industrial areas) or for non-self-reliant people (e.g. hospitals, religious buildings, schools, daycare, clinics, hotels). The municipality then distinguished the flood impacts into three categories; Nuisance (Hinder), Serious Nuisance (Ernstige hinder), and Water Damage (Waterchade). It is approximated that Serious Nuisance flood risk happens once every two years at vulnerable locations, consisting of a more extended period of water on the street, no traffic possible, with a duration of around 30-120 mins. Therefore, the municipality of Bergeijk is planning to tackle this flooding issue within the next ten years (2020 – 2030) [67].

After conducting the climate stress test on the capacity of the UDSwith a 44 mm rainfall event in 2018 (the 1953 rainfall event), it is concluded that several places in the Bergeijk region have a risk of Serious Nuisance and Water Damage (significant economic, health, and material damage). For example, in Riethoven, it includes the area of:

- Dorpsstraat
- Area between Willibrodusstraat and Eind
- Areas on either side of Voorthof
- Area between Boshovensestraat and Dorpsstraat
- Area between Tonterstraat and Dorpsstraat
- Area between Dorpsplein and Hennepstraat
- Area between Schaiksedijk and Lijsterlaan
- Area between Vinklaan and Hobbel

In June 2021, KNMI issued a yellow code warning for several areas in the South of The Netherlands in which North-Brabant was included. This code was released due to the severe weather that led to heavy flooding in parts of the Netherlands. In the province of North-Brabant, severe flooding damage was spotted in Eindhoven, Geldrop, Valkenswaard, Eersel, Waalre, and Bergeijk areas [68]. The flooding caused traffic problems and material damages to the buildings in the area [69].

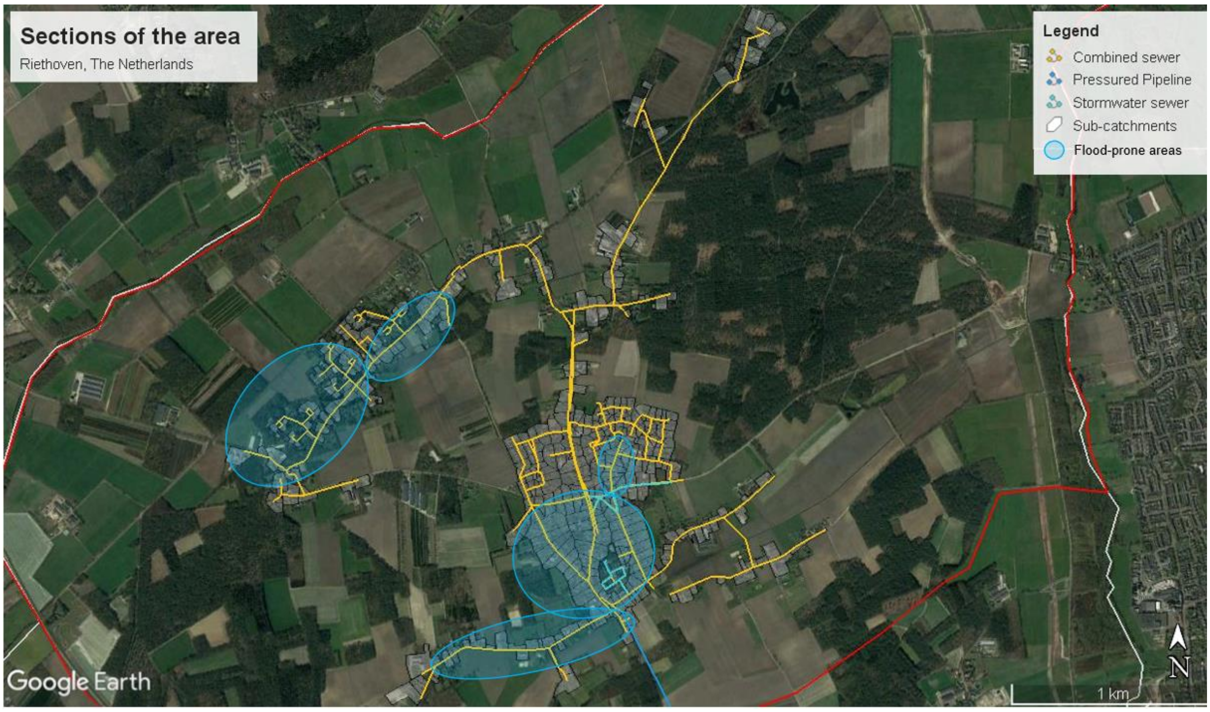
4.3.2 Urban flooding test using the design storms on the UDS model

In order to see the upcoming urban flooding issue, tests on the UDS model using the three climate change scenarios: Scenario 2030, Scenario 2050, and Scenario 2085, was done. The test was done using two setups, the initial model and after increasing the length of the CSO overflow weirs. The second setup was done to see whether increasing the weir length would significantly reduce the flooding or not. The changes were made to all three CSOs: CSO 1, CSO 2, and CSO 3.

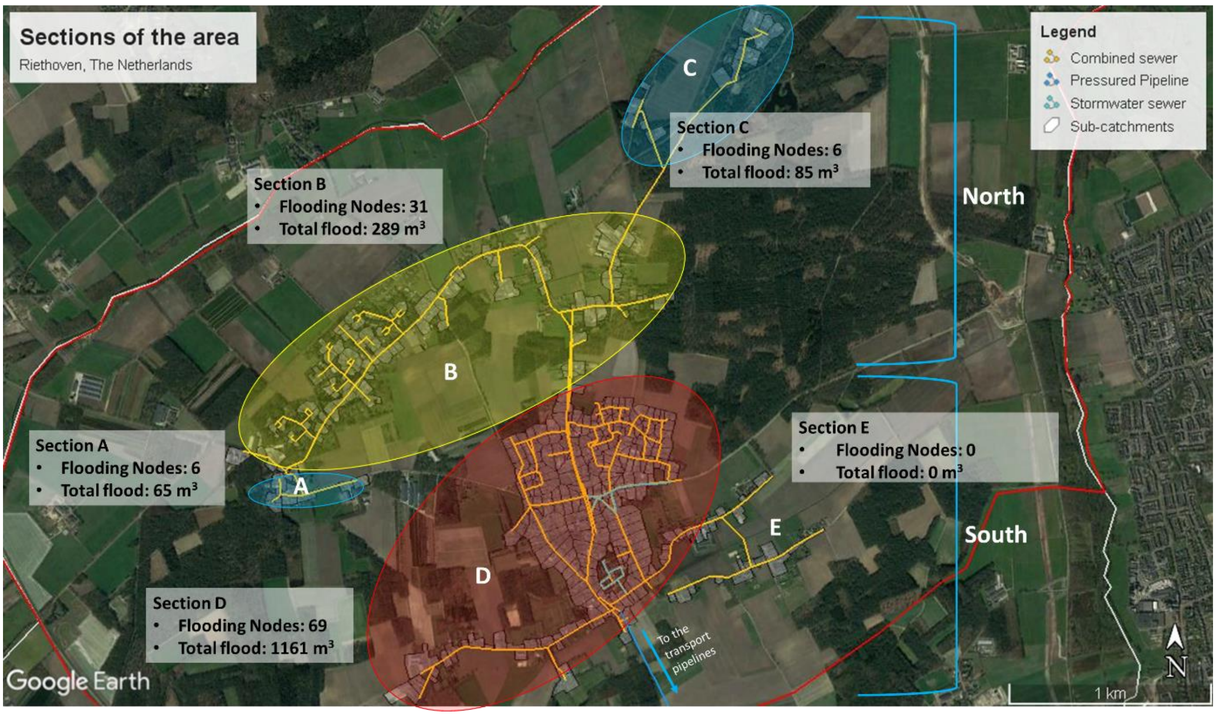
Table 4-2 Flooding test result using the Design storms

Scenario	Design Storm	Design Storm volume (mm)	No. of flooding nodes		Highest Flood (cm)		Node with Highest Flood		Flood volume (m3)	
			Initial model	*After increasing weir length*	*Initial model*	*After increasing weir length*	*Initial model*	*After increasing weir length*	*Initial model*	*After increasing weir length*
2030	C_2_2030	37.7	111	109	15.1	15.3	Jun_205106	Jun_205106	1506	1503
2050	C_2_2050	37.9	109	111	14.7	15.7	Jun_205106	Jun_205106	1498	1516
2085	C_2_2085	38.6	112	112	16.6	15.9	Jun_205106	Jun_205106	1620	1600

Table 4-2 shows the result of the early test using the design storms. It can be seen that the weir addition plays a role in reducing the number and total volume of flooding in 2030 and 2085. Meanwhile, in 2050, the UDS response to the incoming rainfall differs from the other years; thus, the result is also different. Even with the 2030 design storm, there are 109 flooding nodes with a total flood volume of 1503 m^3 (after increasing weir length). It got worse throughout the years and reached 112 flooding nodes with 1600 m^3 of flood in 2085. Just as the flood-prone areas are expected from the climate stress test (Figure 4-5 (a)), the mentioned areas are indeed flooded along with some other parts of the area.



(a)



(b)

Figure 4-5 Flooding issues in the case study area (a) based on climate stress test from the municipality and (b) test using Scenario 2085 per section

4.4 Green-Blue-Grey measures

In the previous chapter (Chapter 3.4), the process of selecting the Green-Blue-Grey (G-B-G) measures has been elaborated. The selected grey measures have been decided and will be re-analyse whether it is suitable for the case study or not. On the other hand, the green-blue (G-B) measures have not been decided. In order to select the suitable G-B measures, the decision tree in Figure 3-5 will be further used according to the study case characterisation. Moreover, the optimisation of the selected G-B-G measures will be discussed afterwards. The comprehensive cost calculation for grey measures can be seen in Appendix C– Cost calculation of the selected grey measures.

4.4.1 Selection and cost of Green-Blue-Grey measures

4.4.1.1 Selected grey measure

The urban drainage systems (UDS) in Riethoven have already existed since years ago; thus, it becomes the problem of retrofitting the existing system. Furthermore, aside from one big parking lot near the commercial area, there are barely enough spaces to install in-line storm tanks. In most cities in the Netherlands, the implementation of underground in-line storm tank addition is considered to be difficult due to the space constraint for a large storage facility, especially in the urban areas with higher density [50]. In the Netherlands, installing peripheral facilities like the storage settling tank (bergbezinkbassins) is more common to abate the sewer overflows and not meant to reduce urban flooding.

For this thesis, the grey measures that will be implemented are replacing the existing pipelines and pumps. In addition, it is assumed that the weir of all three CSOs will be widened from the earliest optimisation period (2030) without the need to optimise for it.

Pipes substitution

Currently, the diameter of the existing pipe in the Riethoven sewer network varies from 151.6 mm to 1000 mm. Table 4-3 shows the value of pipe diameter on the market (locally available) and the replacement prices. It should be noted that the existing pipe can also be replaced with the same diameter value. However, when the same pipe diameter is used, the cost will not be calculated under the assumption that the current pipe can still be used until it needs to be replaced.

Table 4-3 Cost for selected pipe diameter

Pipe Diameter (mm)	Cost			Unit	Notes (Source)
	Capital	O&M (Annual)	PV (30)		
150.6	312.4733	1.19	333.08	€ / m	(RIONED) [70]
188.2	332.5096	1.27	354.48	€ / m	
235.3	359.4305	1.38	383.23	€ / m	
250	368.2709	1.41	392.67	€ / m	
300	400	1.70	429.40	€ / m	
400	471.8948	1.90	504.75	€ / m	
500	556.7117	2.16	594.03	€ / m	
600	656.7734	2.56	701.01	€ / m	
700	800	3.03	852.43	€ / m	
800	898.6654	3.59	960.81	€ / m	
1000	1134.003	5.05	1221.31	€ / m	

Pumps replacement

Pump replacement aims to increase the current pump capacity since the study area comprises several pumping stations. Therefore, the available pump capacity will be based on the current pumps used and the available pumps on the market. Since the coverage area for each pumping station (except for the main pumping station) is small, the maximum pumping capacity that will be used as an option is 80 m^3/hour. The main pumping station will not be considered a pump option because it will not become part of the optimisation problem. Increasing the main pumping capacity means conveying more water towards the transport pipelines, leading to another problem on the transport pipelines or the treatment plant. Thus, no pump needs capacity on par or bigger than the main pumping station (140 m^3/hour). It is assumed that the pumping stations have a wet set-up with various capacities. The pump options will be described using Curves (see also Chapter 3.5.2). For all options, it is assumed that the current pump and the new pump will be centrifugal submersible wet pumps.

Table 4-4 shows the available pumps used for the optimisation and the price index for each pump based on RIONED [71].

Table 4-4 Pump options and price list

Pump Options	Pump Capacity (m3/h)	Capital (€)	O&M (Annual, €)	PV (30) €
Curve_207011.1	14	42,054.58	1170	62,286
Curve_202009.2	25	61,324.86	1170	81,556
Curve_206014.2	35	76,904.54	1170	97,136
Curve_100000.1	45	83,961.44	1170	104,193
Curve_200000.2	50	97,733.32	1170	117,965
Curve_300000.3	80	121,326.8	1170	141,558

Increasing the weir length

Lengthening the CSO weir can reduce the urban flood risk because it can lower the hydraulic gradient line (HGL) of the water profile in the sewer system and release more water into the surface water. However, the CSO spills and effects will not be a part of this thesis.

It is assumed that the current transverse weir's length will be doubled. The current transverse weirs for all CSO chambers are assumed to have either a suppressed or contracted rectangular-shaped weir. After analysing the space availability using aerial images, doubling the weir length can be done to all three CSO chambers. The three CSOs are located in a rather far area from the city centre and dense housing areas. Thus, lengthening of the CSO weirs and chambers are feasible in terms of space. Based on this, the weir lengthening's present value (PV) cost can be calculated according to RIONED [72] (see Appendix C– Cost calculation of the selected grey measures).

Table 4-5 New weirs length

Weir ID	Original length (m)	New length (m)
Con_209026E.1	3	6
Con_205231E.1	3.7	8
Con_206035E.1	2	4

Table 4-6 Cost of replacing CSO weirs

Weir ID		Cost		Unit	Notes
	New Length (mm)	Capital	O&M (Annual)	PV (30)	
Con_209026E.1	6000	€ 195,486.34	€ 586	€ 205,619.47	CSO 1
Con_205231E.1	8000	€ 303,579.67	€ 586	€ 313,712.81	CSO 2
Con_206035E.1	4000	€ 105,122.77	€ 586	€ 115,255.90	CSO 3
Total fixed price addition:				**€ 634,588.18**	

4.4.1.2 Selected Green-Blue (G-B) measures

The selection of G-B measures was made using the decision tree presented in Figure 3-5. All the information regarding the characteristic of the case study site to use the decision tree are described in Chapter 4.1. Based on the case study description: the drainage areas (*i.e.* sub-catchments) of the case study are all smaller than 2 Ha with not many open space areas, and the average slope is lower than 5%, the soil is mainly permeable (Group A and Group B soil), and the groundwater level is mainly > 1 m below the ground level. Thus, using the decision tree (Figure 3-5), four possible measures can be applied, which are infiltration trench (IT), rain barrel (RB), pervious pavement (PP), and green roofs (GR).

Further analysis was done on the case study local conditions. Since 95% of the residential areas have single-family type houses with a steep roof, it is decided to only use three out of the four measures: IT, PP, and RB. While IT and PP can be implemented in the public area (easier access for the municipality to construct and operate), RB can only be installed in individual dwellings. In this case, the municipality can make a program that supplies all the necessary RB and distribute it to the house owners. The list of selected design parameters for each G-B measure can be seen in Appendix C.

Infiltration Trench (IT)

Infiltration Trench is a shallow excavation plot (~1 m depth) filled with gravel or stones that can create temporary storage for rainwater under the plot and is usually used as a rainwater infiltration measure to the lower soil. Although, another design of infiltration trench also includes drains that can convey the stored water back to the downstream UDS, thus delaying the peak flow and the volume of the rainfall event. Ideally, IT should receive lateral inflow water from its adjacent impermeable surface (*e.g.* car parks, roads) [51]. IT can also be protected further using a geotextile membrane and covered with topsoil and planted with grass; in the Netherland, this measure resembles Wadi.

IT is assumed that each meter (length) of a 2 m wide IT can accommodate 20 m^2 of connected paved surface [73]. With a lifetime of 30 years, the cost to implement IT can be estimated using the PV analysis. The maintenance of IT includes mowing the grass cover, removing litter and leaves, filling in empty spots, soil improvement, and replacing the top layer. Due to the system's resemblance with Wadi, the cost to implement and operate Wadi will be used (Table 4-7).

Pervious pavement (PP)

Based on the SuDS (G-B measures) manual [51], Permeable pavement or pervious pavements are systems that are designed to allow rainwater to infiltrate through a pavement layer into the underlying storage layer before being infiltrated or released back to the UDS. In general, pervious pavements are used on low traffic areas and far from areas with a high risk of silt loads. Thus, areas like car parks and sideways are suitable to implement the PP.

Since the case study area has a risk of high groundwater table during the wet period, the Type B – Partial Infiltration system with permeable pavements (porous pavements) will be implemented. With Type B system, an underdrain will be installed below the sub-base storage, above the sub-grade soil. Thus, part of the stored water will be infiltrated, while the rest will be conveyed to the UDS system through the underdrain when necessary. In addition, before the storage layer, a layer of geotextile membrane will also be installed, just like with IT. Since the average road and single parking lot width in the case study location is 4.5 m, this value will be used as the width of implemented PP.

RIONED [74] approximated the capital cost to construct PP is 100 €/ m^2. This capital cost already takes into account the material, labour, groundwork, and also tax. In terms of maintenance, annual inspection and the triennial permeability measurement must be done. In addition, to maintain the performance of PP, sweeping, deep cleaning, and joint filling must also be done periodically. It is assumed that sweeping will be done up to 6 times a year, deep cleaning and joint filling once every five years (Table 4-7).

Rain Barrel (RB)

Rain Barrel or rain harvesting tank (also called Cistern) is one of the G-B measures that act as source control. RB is a container that collects the runoff from the roof during rainfall events [56] and stores it like off-line storage devices [51]. Since RB collects roof runoff, its implementation is limited to the rooftop of individual buildings. RB can benefit when water scarcity is an issue in the area due to the personal storage of water [16]. It is usually used for low-quality water usage, like for gardening regularly [51]. In general, due to the individual implementation, its capacity to reduce both the peak flow and volume of runoff is low. However, when combined with other G-B measures, it can significantly result in peak attenuation in the area.

The RB used on this design will have only one size with a volume of 227 L, a diameter of 60 cm, and 96 cm in height. The drain pipe (spigot) diameter will be 2 cm. These design parameters were based on the existing manufactured rain barrel. The optimal number of implemented RB (total area of RB) on each sub-catchment is based on the total number of houses on that sub-catchment. In this thesis, it is assumed that three people occupy every single house. The number of houses can be estimated from the known population data from the case study area. Each house will get a maximum of two RB.

Since RB are manufactured goods, the cost listed was based on the RB manufacturer price list. RB does not need annual maintenance or operational cost; thus, the O&M cost will be zero. The cost was calculated based on the designed RB that will be used. Table 4-7 shows the cost to implement each G-B measure in €/ m^2.

Table 4-7 Cost of GB measures implementation

G-B Measures	Description	Capital	O&M (Annual)	PV (30)	Unit	Notes (Source)
Pervious (Permeable) pavement	Construction	100			€ / m2	(RIONED) [74]
	Inspection		0.25		€ / m2	
	Measurement of Permeability		1.1		€ / m2	
	Sweeping		2.7		€ / m2	6x per year
	Deep cleaning		0.38		€ / m2	Basis: 1 x per 5 year
	Joint filling		0.09		€ / m2	Basis: 1 x per 5 year
	Total	100	4.52	**178.2**	€ / m2	
Infiltration Trench	Construction	120			€ / m2	(RIONED) [73]
	Inspection		1.9		€ / m2	
	Preventive maintenance		6		€ / m2	Incl. mowing the grass (biweekly), removing litter and leaves (2x per year)
	Corrective maintenance		1.4		€ / m2	Incl. fill in empty spots, soil improvement (1x per 2 years), replacement of top layer (1x 10 years)
	Total	120	9.3	**280.8**	€ / m2	
Rain barrel	RB + Base	102			€ / 0.24 m2	(Regenton.nu)
		425			€ / m2	Simple plastic barrel (227 L) and base
		425		**556.0**	€ / m2	The height will be 0.96 m

4.4.2 Optimisation of the selected Green-Blue-Grey (G-B-G) measures

The optimisation of the selected G-B-G measures includes the process of assessing the implementable of the selected measures, listing all the bottlenecks in the urban drainage systems (UDS), finding a way to elevate the simulation time, and running the simulation itself.

Since time is limited in this thesis, the whole process of assessing the selected measures and the bottleneck of the problem becomes a part of a way to elevate the simulation time. In this thesis, a way to do this is by clustering some measures that can be implemented together. Afterwards, the list of decision variables for the optimisation and the list of non-bottleneck area/ pipe segments are used directly by the codes that have been developed to run the simulation using the GA package in a python environment.

4.4.2.1 Reduction of decision variables and simulation time

In order to reduce the decision variables (DV), assessment of measures implement ability, bottlenecks identification and clustering of several decision variables are done to the original list of decision variables.

Because some measures might not be implementable in a sub-catchment or a specific segment, these decision variables can be further reduced by looking at the characteristic of the case study area and the early test of the network model against the selected design storms. The reduction of decision variables can ease the computational burden needed to explore the search space and accelerate the converging of the optimal solution.

The decision variable for the measures can be reduced when looking at each sub-catchment area and can be seen based on the bottleneck areas after the test using the design storms (Chapter 4.3.2). The bottleneck areas can be identified by looking at the area where flooding happens and its adjacent areas. When a node is identified as a source of the flooding, the water profile plot of that area is analysed to check the possible cause. The cause can be from a limited capacity of either pipe in that segment and the downstream pipelines or the node's location itself (*e.g.* nodes located in sag locations). Therefore, bottleneck identification based on the design storm test was done to reduce the decision variable further. In addition, another decision tree was made to look at the applicability of each G-B measure on a single sub-catchment.

Aside from the direct reduction of DV based on the bottleneck identification and the measure’s implement-ability, clustering the DV is one way to reduce the number of decision variables for the GA optimisation. Clustering of decision variables means combining several DV into one DV with several sub-variables. Modifying the value of that one DV means modifying the values of the entire sub-variables. Clustering can be done when the current size is the same (for conduits) or when the location is near. Although doing so will diminish some details and lessen the probability of finding the most optimal solution, it is essential to reduce the simulation time – which is one of the problems in doing metaheuristic optimisation. Thus, carefully clustering the decision variables can lower the missing details for optimisation.

Reduction of grey measures decision variables

After analysing the case study using the design storms, the result shows that several pipelines are not prone to flooding problems. In addition, the effect of modifying these sections is minuscule to reduce the potential flooding at other locations based on the simulation of the model during early manual optimisation using trial-and-error. Thus, the corresponding decision variables can be removed from the initial list of decision variables.

Based on the simulation, Scenario 2085 resulted in 112 flooding nodes for the whole case study area—most of the flooding nodes located in Section B and Section D (Figure 4-5). However, the nodes with the deepest flood are located in Section D (Jun_205106). Section A and C also has several flooding nodes. The only section without a flooding problem is Section E. Therefore, the apparent non-bottleneck elements will be all conduits from Section E and conduits towards the CSO structures (*i.e.* pipes going in and out of the storage tank and CSO chamber). In addition, all conduits from the separate sewer system and combined sewer system in the south of Section D towards the infiltration basin will also be eliminated because they do not reduce flooding or significantly contribute to the flooding problem. However, the case is different from the other location of the separate sewer system in the northern part of Section D near CSO 1. Several identified flooding nodes belong to the separate sewer systems; hence, it becomes part of decision variables.

Hereafter, further analysis was done to eliminate the non-bottleneck conduits from sections A, B, C, and D by looking at the flooding nodes' water flow pathways and water elevation profile during the peak hours of the design storms (04:40-05.20). A conduit or a pathway that comprises several conduits will be eliminated when it does not contribute significantly to the headloss of the system, and enlarging its diameter is of no use when compared to enlarging other conduits or pathways based on the early manual optimisation. This can be seen from the water elevation profile (hydraulic gradient line (HGL)) of particular flow pathways that do not reach the maximum depth of the pipe despite having a slight slope. Another way to identify this is by eliminating non-flooding conduits connected to small catchments that directly convey water to the main pathways. Therefore, logically, increasing the pipe diameter of this pathway will result in no improvement in reducing the flooding. When looking at the simulation report after the design storm test, these eliminated conduits generally have a low (< 1) ratio of maximum flow to full flow even with maximum to full depth ratio equals 1. It means that they are not using their maximum capacity yet, and thus does not need to be increased. Yet, an exception is made when this conduit is placed downstream of a pathway with flooding problems; then, it needs to become a part of the decision variables to avoid sudden change in pipe diameter within one pathway.

Flow pathway identification is not always obvious. In Section D, with many flow divisions and branches, the flow pathway identification is needed to analyse the water elevation profile. The water flow pathway identification is done by looking at the upstream and downstream nodes of each pipe. The end of a pathway can be either a branch, pump, or flow regulator (*e.g.* weir, orifice). In this thesis, the pathway identification was done by looking at either branch or pumping station. Later on, the flow pathway identification is useful when clustering the decision variables.

Further analysis was done for each UDS section in the case study area. Considering that three pumps are located in the basin storage before CSO, the number of problematic pumps in the decision variable list can be reduced to five from the original eight. All three CSO pumps work by pumping the water stored in the peripheral storage back into the system. Therefore, increasing the capacity means pumping more water back into the system, leading to further flooding. In addition, the current CSO's pumps are not fully utilized with less than 55% of capacity utilization. Another pump removed from the DV list is the pump from Section E to Section D) because all conduits in Section E are unproblematic. The four pumping stations that become the decision variables for this thesis are pumps from Section A to B, from Section B to D, from Section C to B, and the main pump towards the pressured transport pipelines. However, the main pump will be removed from the decision variable because increasing this pump capacity leads to more water pumped out of Riethoven towards the wastewater treatment plant, *i.e.* increasing the treatment load, which is undesirable.

After identifying bottlenecks, the number of decision variables for grey measures is reduced from 521 to 309 for pipe replacement and from 8 to 3 for the potential pump replacement. The next step is to cluster the possible bottleneck 309 conduits and further reduce the number of decision variables.

Clustering the conduits can be done by using the identified flow pathways and assessing the location of each conduit. The main principle for clustering the conduits is that when the conduit diameter within the path is enlarged, other conduits in that pathway must be enlarged accordingly. The smallest diameter pipe will then represent this one DV to ensure that the GA can explore the possible smallest diameter within that pathway. For example, conduits with a diameter of 150.6 mm and 188.2 mm are located in the same pathway and belong to the same DV. The smallest diameter conduit will represent this DV; thus, giving the biggest range of DV value (between 150.6 mm to 1000 mm). However, in some cases, when the pathway is too long, dividing the pathway might give a better optimisation result rather than combining all into the same decision variable. Thus, when clustering conduits, the location, pathway, and the current diameter of that conduit needs to be considered.

Table 4-8 Reduced grey measures decision variables for the optimisation problem

Measure	Initial Decision variables	Reduced Decision variables	Clustered Decision variables
Pipe replacement	521	309	38
Pump replacement	8	3	3
Total	529	312	41

Reduction of green-blue (G-B) measures decision variables

Reducing the decision variables for G-B measures includes the process of assessing the applicability of the measures in each sub-catchment, looking through the problematic sub-catchments based on the design storm test and clustering the sub-catchments.

The decision tree for selecting Green-Blue (G-B) measures mentioned in Chapter 3.4 was applied to the general characteristic of the case study area. Based on that, Infiltration Trench (IT), Pervious Pavement (PP), and Rain Barrel (RB) are selected as the most appropriate measures to be applied. However, each sub-catchment has different characteristics that differentiate them; thus, not all selected measures will be suitable to be implemented in each sub-catchment. Figure 4-6 shows the decision tree that can choose the possible measures for each sub-catchment. It considers the availability of open space (excl. foresty and arable area), residential houses, and high groundwater or hotspot areas. Generally, IT cannot be implemented when there is no open space available, and RB cannot be implemented when there is no house in the area. Meanwhile, for the sub-catchment located on the high groundwater (< 1 m below ground level) or hotspot areas, both IT and PP cannot be implemented.

Using the above rules, out of 489 sub-catchments, IT can only be implemented in 26 sub-catchments with open areas. Meanwhile, PP is applicable in 188 areas with suitable groundwater levels and non-commercial or hotspot locations, and RB is appropriate in 340 sub-catchments with residential homes. This means that from the original 1467 decision variables (489 sub-catchments x 3 types of measures), only 554 decision variables are realistically feasible for the implementation of G-B measures. It should be noted that a single sub-catchment can still have more than one type of G-B measure implemented.

The next step in reducing the G-B measures decision variables is by looking at the problematic area from the test using Scenario 2085 (Figure 4-5). In principle, adding G-B measures intercept the run-off and hence reduce the sewer load, which can help reduce the flooding in problematic sections by reducing the peak flow. Thus, adding G-B measures in non-problematic areas might be able to reduce the flooding. However, this is not always the case when the non-problematic sub-catchments are located in the non-problematic section like Section E. As mentioned earlier, Section E can be considered non-problematic because it is not significantly contributing to the flooding problems, nor can it help reduce the flooding problems. Hence, the addition of G-B measures in this section seems redundant and unnecessary. Therefore, all the sub-catchments in section E can be eliminated from the decision variable list.

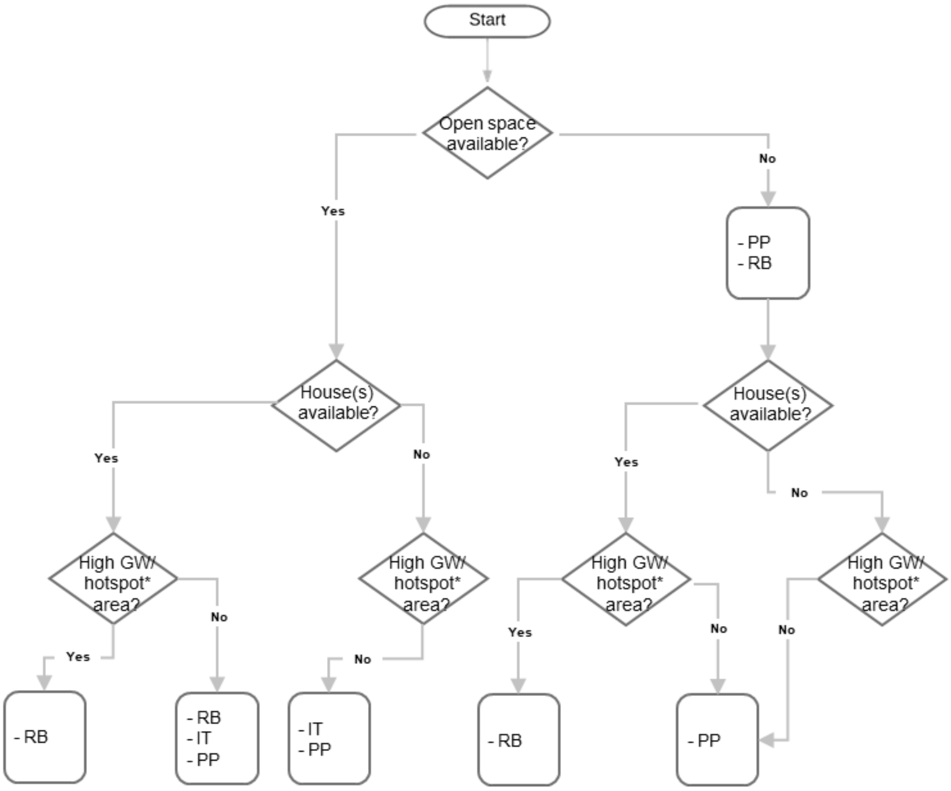


Figure 4-6 Applicability of selected Green-Blue measures decision tree (IT: Infiltration Trench, PP: Pervious Pavement, RB: Rain Barrel)

*Hotspot areas including industrial areas and small areas within a sub-catchment with industrial characteristics (*e.g.* fuel tanks, rubbish skips) [51]

Another way to reduce the decision variables is by looking at the behaviour of the UDS and flooding in each particular pathway. When the flooding issue in a specific pathway is minor (less than 5 m^3), it is assumed that it is unnecessary to implement all three G-B measures and select only the robust one or the most appropriate one. For example, PP, IT and RB can be implemented in one sub-catchment. However, after more profound analysis of the network and water elevation profile, water coming from the Sub-catchment's outlet does not significantly contribute to that area's flooding. Therefore, although the application of PP is more robust in most cases, implementation of IT is more appropriate since there is a park in that area. These kinds of elimination can also be done automatically by the GA optimisation; however, it is manually done to reduce the simulation time and fasten the solution convergence. From reducing the decision variables for G-B measures through this method, the remaining number of decision variables are 435 (IT: 26, RB:264, PP: 145).

Like reducing decision variables for grey measures, the last step is to cluster the reduced list of decision variables. Clustering the sub-catchments for the implementation of G-B measures are slightly more straightforward compared to grey measures. In implementing G-B measures, the only important thing is to look at the streets and neighbourhood areas based on the aerial images. For RB and PP, the clustering is easier because the implementation can be done by looking at each neighbourhood area within the proximity radius of 150 m for RB and 100 m for PP (measured using Google Earth). The radius proximity of PP is smaller because it is more based on the street location. However, exceptions are made under three conditions: when there are a few (less than 5) sub-catchments located outside the proximity radius that does not belong to the next cluster because they are located sparsely when the neighbourhood areas are located in the main street, and when a sub-catchment belongs to a cluster is located in the same street with the other cluster. With the first and third case, that sub-catchment will join the closest cluster or the one located in the same street, and with the second case, rather than radius proximity, the cluster will be based on the row of the houses in that main street, *i.e.* one main street equals one cluster. The reason why street location is an exception is that it is easier to distribute the RB and construct the PP when it can be accessed from the same street in the implementation.

However, since IT can only be implemented in an open area, which might not be close to each other, clustering of IT can be done on a broader scope. Due to the limited space available, the maximum area values of IT are generally small compared to PP. Therefore, even though IT can be implemented in 26 sub-catchments, they need to be clustered to reduce the decision variables. The possible way to cluster it is by making three big clusters: the north, centre-east, and centre-west. The north cluster comprises IT cub-catchments at the north section of the UDS (Section B). Meanwhile, centre-west and centre-east clusters are located in Section D, separated by the main sewer pathway in the centre of Section D.

It is assumed that if IT is implemented in one sub-catchment located within one of the three clusters, all the IT sub-catchments inside the cluster will also have IT—the same principle as the cluster of PP and RB.

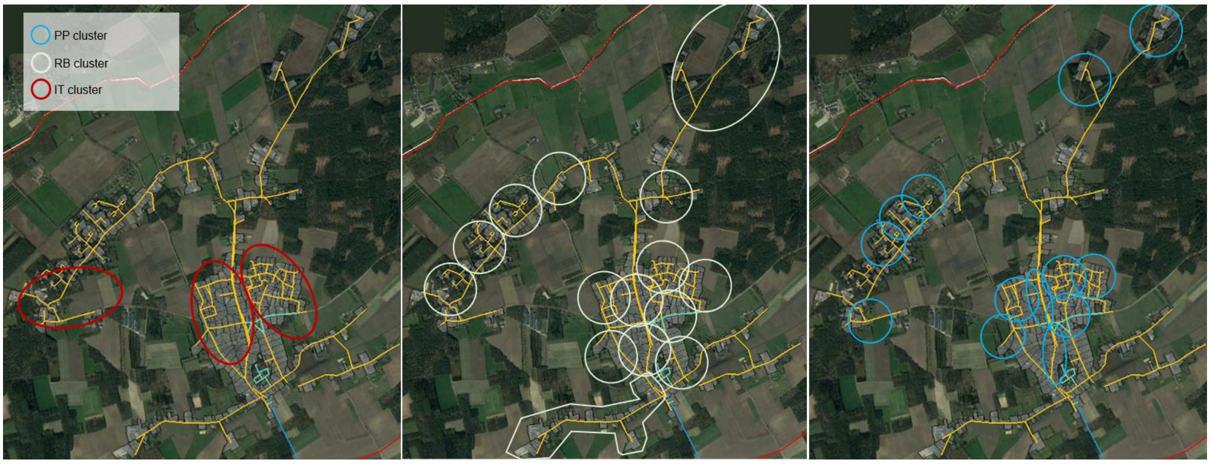


Figure 4-7 Clustering the implementation of Infiltration Trench (IT), Rain Barrel (RB), and Pervious Pavement (PP)

After each sub-catchment has been further analysed using the decision tree (Figure 4-6), reduced based on the design storm test result, and clustered, the decision variable for the implementation of each G-B measure becomes:

Table 4-9 Reduced green-blue measures decision variables for the optimisation problem

Measure	Initial Decision variables	Reduced Decision variables	Clustered Decision variables
IT	26	26	3
PP	188	145	13
RB	340	264	15
Total	**554**	**435**	**31**

Further reduction of simulation time

While reducing decision variables plays a significant role in reducing the simulation time, other things can also be done to ease the computational burden further, reducing the SWMM model's running time.

During the optimization process, the model will run in the SWMM environment enabled by the PySWMM package. Thus, it is essential to reduce the run time of the model. All design storms used are 10-hours rainfall events that peak at around 300 – 320 minutes after the event's start. Ideally, to fully access the behaviour of the UDS, an entire one day run or 10-hours of rainfall plus 1 - 3 hours before and after the rainfall event can help to understand the filling and emptying mechanism as well. However, this resulted in an almost 1 minute run time for a single model. One minute for a single model run takes a lot of time and needs to be reduced. A way to achieve the fastest run will be by simulating only during peak hours. However, based on the initial test of the design storm, doing this might result in a loss of several retained volumes of rainfall in the UDS. Aside from this, the downstream part of the network will have a delayed flow from upstream, resulting in flooding after peak hours. Taking this into account, it is decided to simulate from the beginning until 1 hour before the end of the rainfall event (00:00 – 09:00). This change resulted in an 8 to 10-seconds run time for a single model.

Another consideration to reduce the simulation time can be done by decomposing the overall UDS into sub-systems that can be optimised separately. However, Cant´u-Paz *et al.* (2003) [75], in their study on the investigation of single run vs multiple runs using GA, concluded that in most cases, a single run using a large population size could reach a better solution (global optima) than multiple runs using the decomposed optimisation problem. Although, in doing so, it comes with the price of longer simulation time.

In this thesis, separating the simulation of the whole UDS network means that the model needs to be re-adjusted to include the outflow from one section as an inflow to another section, which will take more time to do that. Furthermore, since the optimisation written in Python uses hard coding, the codes need to be adjusted to suit each sub-system. In addition, separating the simulation might work when more than one computer can simulate the optimisation. Therefore, due to the time and resource limitation, this method of simulation time reduction is not chosen.

4.4.2.2 Optimisation process

The optimisation process starts with the final list of decision variables (DV) and non-bottlenecks list of pumps and conduits (unchanged pump capacity and pipe diameter). The unchanged list is necessary to ensure that the code does not change the value of non-bottleneck pumps and conduits. For the optimisation, there are 72 DV from the initial 1083, which each has several sub-DV, *i.e.* several sub-catchments or conduits for each DV (see Appendix H).

Table 4-10 Final number of decision variables

Measure	**Number of Decision Variables**	
	Initial	**Final**
Pipe replacement	521	**38**
Pump replacement	8	**3**
IT	26	**3**
PP	188	**13**
RB	340	**15**
Total	**1083**	**72**
No changes (pump + pipe)	*0*	*213*

The overall process of GA optimisation is explained in Chapter 3.2. After the reduction of decision variables, the final decision variable list, along with the list of possible values of each decision variable, can be made as an input for the simulation (see Appendix J– Data input for the simulation of the optimisation problem). The possible values list is made from the known maximum value of each sub-catchment and conduit. For the G-B-G measures, the maximum area values are discretized using 5% or 10% bin sizes. Meanwhile, the possible values for conduits are the available pipe diameter ranging from the current diameter to the maximum available diameter for each conduit. The primary process of the GA optimisation lays on the main function that inputs the generated index number of DV from the GA algorithm and runs it to find the total cost (objective function) of that specific optimisation individual until the termination criteria are met.

Before starting with the full run of the optimisation, a trial-and-error was done using the optimisation set up to find the value for penalty coefficient, α, which is an important parameter to find the objective function and calculate the penalty cost per m^3 of flooding (see Equation (3-6)). The principle of the trial-and-error process is to make sure that the flood cost is not too large to avoid the possibility of non-converging optimisation and not too small to avoid solutions with flooding nodes. Thus, the penalty cost should have a difference of about one or two magnitudes larger than the solution. Based on this, the penalty coefficient α is decided to have a value of € 200,000 per m^3 of flooding.

To initialize the optimisation, the GA parameters mentioned in Chapter 3.2.3 needs to be defined. Since this thesis is quite a large size problem, it is decided that a wider search space will be used. Vrajitoru (2000) [76] mentioned in her study that a higher population size is better to be used than a higher number of generations when using GA for large size problems. Therefore, as this thesis has many decision variables that vary in values, the following operators and optimisation parameters are chosen for the GA run after several trials with different combinations of population size and the number of generations. Also, when considering the time limitation for this thesis, the following values based on literature [35, 23, 6, 33, 41, 77] for each parameter will be used:

Table 4-11 Optimisation parameters for the formal optimisation

Parameter	Typical Range	Value
Population size (n_{pop})	20-600	550
Crossover probability (μ_{co})	0.7-1.0	0.9
Mutation probability (μ_m)	0.001-0.05	0.03
Parents portion (μ_p)	-	0.1
Elite ratio (μ_e)		0.01
No. of generation (nG)		40
Ideal no. of generation without changes as stopping criteria (nWI)	-	10

Chapter 5

Results and Discussion

Using the optimisation methods and simulation modelling described in Chapter 3.2 and Chapter 3.5, respectively, a case study based on a real network in Riethoven, The Netherlands, is performed. The conditions and characteristics of the case study play an important role in the selection process of green-blue-grey (G-B-G) measures to be used for optimisation, which is elaborated in Chapter 3.4. With the selected measures to be optimised, the optimisation is then conducted.

This chapter highlights the result and discussion of the optimisation. Aside from the formal optimisation using GA optimisation, manual optimisation using the same approach and decision variables as the formal optimisation has been done to be compared with the result from the formal optimisation using GA for all design periods (2030, 2050, and 2085). As a result, the most optimal solution after several GA runs will be displayed. The discussion elaborates on the analysis of the optimisation process and results, comparison between both optimisations, and the best way to implement the optimal solution for all design periods. Chapter 5.1 describes the results and analysis of both optimisations for all design periods, while Chapter 5.2 elaborates on the comparison between manual and formal optimisation, and Chapter 5.3 discuss the comparison of results between each scenario from the formal optimisation. Finally, Chapter 5.4 gives an overview of how the optimal solution should be implemented considering all three climate change scenarios, and Chapter 5.5 elaborates on the future projection to rehabilitate UDS based on the optimisation results.

5.1 Optimisation results and analysis

The result from both the manual and formal optimisation shows that the solution generated by formal Genetic Algorithm (GA) optimisation produced a more optimal solution than manual optimisation. This proofs that the early hypothesis on the reliability of optimisation using hydrodynamic model linked with an optimisation tool to solve complex urban drainage systems (UDS) problems are higher when compared to the traditional trial-and-error method. This chapter shows and elaborates on the optimal solutions found from both the manual and formal optimisation.

5.1.1 Manual optimisation

Based on the result of the manual optimisation for all design periods (2030, 2050, and 2085), the objective function value, *i.e.* the implementation cost of the optimal solution using manual optimisation, can be summarised in Table 5-1.

The manual optimisation was performed using the same principle as the formal GA optimisation with the clustered decision variables for all climate change scenarios. The same principle means that the trial-and-error process was based on the ‘clustering of decision variables’ principle and not for individual pipe or sub-catchment. All decision variables (*i.e.* type of interventions and their locations), the set of options for the values (*i.e.* minimum and maximum pre-defined sizes), and the optimisation objective are also the same as the formal optimisation. This is done to make sure that the comparison between both optimisations can be done *apple-to-apple*. Additionally, during bottleneck identification, an early manual optimisation (trial-and-error) was also done to the model to rule out some initial decision variables. The manual optimisation done in this chapter is different from the early manual optimisation.

Table 5-1 Summary of the cost to implement the manual optimisation solutions

Measure	Cost per needed per design period		
	2030	2050*	2085*
Green-Blue (G-B)	€ 1.17 million	€ 0.00	€ 5,871.00
Grey (Pipe & Pump)	€ 6.16 million	€ 0.00	€ 362,670.00
Weir addition	€ 634,600.00	€ 0.00	€ 0.00
Flooding Penalty	€ 0.00	€ 0.00	€ 0.00
Total cost:	**€ 7.97 million**	**€ 0.00**	**€ 368,540.00**

(* The cost stated for the years 2050 and 2085 is the additional cost needed based on the solution cost for the year 2030)

The manual optimisation was done to compare how the human brain tried to solve this rehabilitation problem compared with automated optimisation. The optimisation was done simultaneously in the case study area, meaning that it does not follow any specific pattern or rules, just like how the formal optimisation was programmed. Therefore, it was performed by looking at the flooding prone areas in the case study area thoroughly.

All the non-bottlenecks decision variables have been eliminated from the decision variable lists; thus, the remaining decision variables can be. Since the main objective for optimisation is to find the minimum cost needed to achieve zero floodings, the cheapest interventions possible are tested first. The cheapest interventions can mean implementing minimum G-B measures in areas with low floodings or enlarging pipe diameters when severe flooding problems exist in that area. As expected, using the cheapest interventions cannot eliminate all the flooding problems. Hereafter, adjustments to the still flooded areas were done using either bigger G-B measures, another type of G-B measures or pipe diameters.

Amongst all three G-B measures, the implementation of IT is the most robust one to reduce flooding when compared using the same budget. Furthermore, RB comes in second, followed by PP. However, IT can only be applied in a few sub-catchments with generally low maximum value, while RB can only be implemented in small numbers for each sub-catchment. Thus, PP is the most flexible to be applied and has the highest maximum area value compared to the other measures because it can be implemented on the pavements. When the G-B measure implemented in one area is near its maximum size, a test is done to check whether it is cheaper to implement all the necessary G-B measures or replace the pipe/ pump. A closer view of the water profile and HGL (Hydraulic Gradient Line) is needed when pipe replacement is considered. Analysing the water profile plot can give a better understanding of the bottleneck problems, the water flow, and the UDS response to inflow during peak flow. When the pipe/ pump replacement cost is cheaper than the G-B implementation cost to eliminate the flooding in that area, then pipe/ pump replacement is chosen or the other way around.

Scenario for 2030

The result of the manual optimisation shows that the optimal solution for Scenario 2030 costs € 7.97 million (incl. the addition of a fixed price to increase weir length). The cost consists of € 1.17 million for green-blue (G-B) measures, € 6.16 million for pipes replacement, and € 634.6 thousand for lengthening CSO weirs. Based on the manual optimisation for 2030, G-B-G measures are needed for 52 out of 72 decision variables to eliminate the flooding problem. These 52 decision variables consist of the implementation of Rain Barrel (RB) in 231 sub-catchments (out of 264 sub-catchments), Infiltration Trench (IT) in 26 sub-catchments, Pervious Pavement (PP) in 138 sub-catchments (out of 145 sub-catchments), pipe replacement for 198 pipelines (out of 309 pipelines), and one changes of pump needed. With this solution, no flooding is detected in the system using Scenario 2030 with a total rainfall of 37.7 mm.

The optimal solution of the manual optimisation for the year 2030 can be seen from Figure 5-1 and Figure 5-2. Figure 5-1 shows the manual optimisation result using a comparison map for pipe replacement, while Figure 5-2 illustrates the location of G-B measures implementation, respectively. The comparison pipe map shows five different colours that indicated different pipe diameters with line thickness proportional to the values of pipe diameter. Not all changes can be seen from the map due to the limitation in SWMM to display more than five different ranges. Thus, the dark blue line comprises a diameter value of 150.6 mm or 188.2 mm, and the light blue line indicates a diameter value of either 235.3 mm, 250 mm, or 300 mm. The green and yellow lines indicate a diameter value of 400 mm and 500 mm, respectively. Meanwhile, the red line indicates a pipe diameter of either 600 mm, 700 mm, 800 mm, or 1000 mm. The comprehensive list of optimal solutions from the manual optimisation can be seen in Appendix K- Manual Optimisation Result.

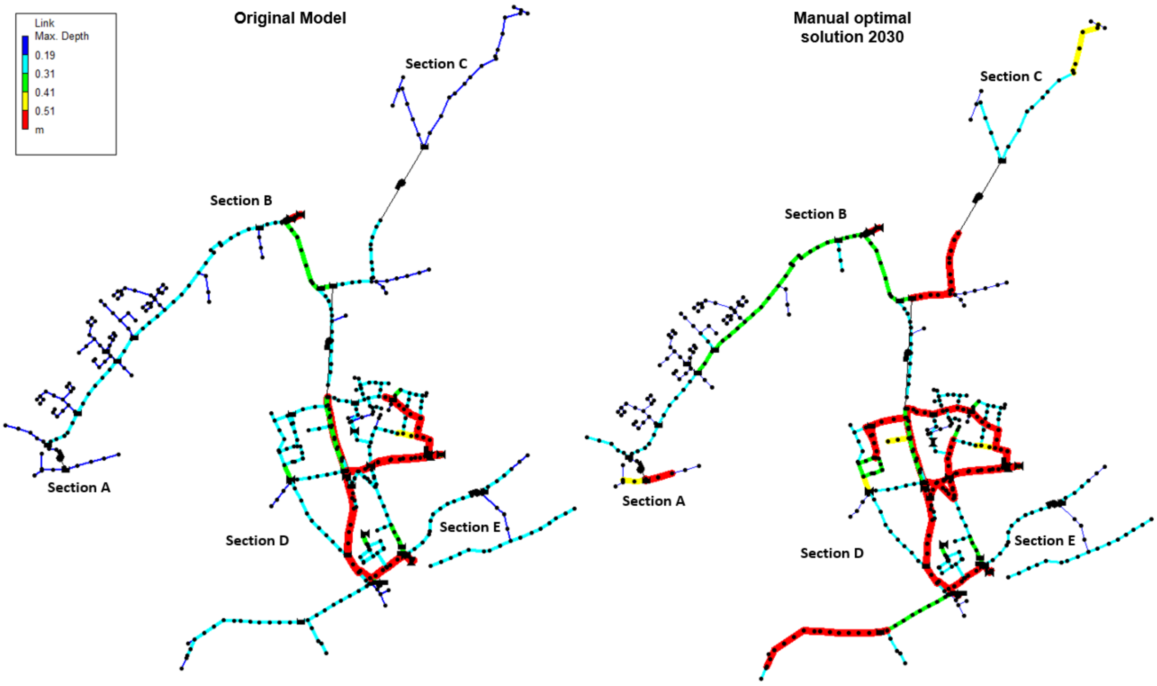


Figure 5-1 Pipe diameter comparison map of the original model (left) and manual optimal solution for 2030 (right)

From the comparison map of the original network and the optimal solution in Figure 5-1, it can be seen that the replaced pipes are located mainly in the main pathways. Using the division of the sections mentioned in Chapter 4.2, as shown in Figure 4-4, each section (excl. Section E) has several pipes that need to be replaced. For example, from the northern sections, in Section A as shown in Figure 5-1, all pipes near the pumping station have to be substituted with bigger diameters. In addition, both RB and PP will be implemented in Section A to reduce the incoming runoff to the sewer. Among all the northern section pipelines, the highest increase of diameter can be found in Section A, which is indicated by the thick red lines in Figure 5-1. The previous diameter of 150.6 mm needs to be replaced with 600 mm pipes, while the yellow line indicates the changes from 188.2 mm to 500 mm. Although PP can also be implemented, the total cost will be more expensive than increasing the pipe diameter to 600 mm.

On the other hand, in Section B from the map in Figure 5-1, several pipes in the main pathway up until the inlet to the CSO 3 should be replaced to reduce flooding risk. In addition, to eliminate flooding problems in the most upstream part in Section B, near Section A, enlargement of the current pipes is also necessary due to the lack of G-B measures that can be implemented. No secondary branch pipes ought to be replaced in Section B since many G-B measures can be implemented. Figure 5-2 shows that parts in Section B that do not need pipe replacement, although having flooding problems, have both RB and PP. Section B also includes all pipes on the northeast side, downstream of the pump from Section C (see Figure 4-4and Figure 5-1). Due to the increase in incoming water from Section C, these pipes also need to be replaced.

Pipe replacement is also necessary for some pipes in Section C, as shown in Figure 5-1, located in the upper northeast (yellow line) from the initial of 188.2 mm to 500 mm. The pipes enlargements are especially needed on the upstream pipelines because most of the water inflow into that pathway comes from the upstream sub-catchments and barely from the downstream junction nodes. Thus, while the upstream pipelines have 500 mm diameter, the downstream pipelines only need 300 mm diameter. Furthermore, in this part of Section C, implementation of G-B measures only cannot solve the flooding problem; thus, the need to substitute the pipes along the primary path down until the pumping station arises.

Moving to the southern sections (Section D and Section E in Figure 5-1), many interventions are needed to tackle flooding problems in this city centre area (Section D). Figure 5-2 illustrates the concentrated G-B measures implementation in Section D. All available G-B measures (RB, PP, and IT) are implemented on the centre part of Section D. Since the implementation of ITs are constrained by open space availability, all the available spots for IT implementation in Section D (*e.g.* parks, vegetated pathways, grass plots) are being used. Meanwhile, RB's implementation in Section D is necessary for almost all areas except for the centre of the main pathway, indicated by the non-shaded area in Figure 5-2 (Center). Furthermore, along the southern part of Section D, no G-B measures aside from RB can be implemented due to the high groundwater level.

Figure 5-2 Locations of Green-Blue measures from manual optimisation for 2030

(**Left:** Infiltration Trench (IT) implementation areas; **Center:** Rain barrel (RB) implementation areas; **Right:** Pervious Pavement (PP) implementation areas)

However, G-B measures alone can not solve the flooding problem, leading to the need of increasing the pipe diameters in the main pathway with (red line) from 600 mm to 800 mm as can be seen in Figure

5-1. Therefore, pipe replacements are also needed in Section D's southwest, northwest, and northeast areas. Pipes enlargement are needed for the pipe branches going to the main pathway. This is indicated by the light blue lines in the northwest, northeast, and southwest parts (Figure 5-1 left), now changed into either green, yellow, or red lines (Figure 5-1 right).

Although the highest recorded flood happened on a node near the pumping station that connects Section B and Section D, the city centre's current drainage systems with a separated sewer system (the ‘W’-shaped network) could not handle Scenario 2030 rainfall. In this part of the case study area, the highest area of PP implementation is needed, along with the increase of stormwater sewer’s pipe diameters of from 300 mm to 600 mm, and towards the outfall from 600 mm to 700 mm. Finally, no changes are needed to Section E at all.

It is assumed that the optimal manual solutions for all design scenarios can be applied incrementally. It means that the optimisation for the years 2050 and 2085 will be based on the solution for 2030.

Scenario for 2050

Based on the solution’s incremental implementation assumption made for the manual optimisation, the optimal solution for 2030 is then tested with Scenario 2050 (total rainfall = 37.9 mm), which resulted in 0 m^3 flooding. Therefore, it can be said that the optimal solution for 2030 can still comply with the design scenario for the year 2050 and no changes or addition needed.

Scenario for 2085

The optimal solution for 2030 was then tested using Scenario 2085, with a total rainfall volume of 38.6 mm. Based on this test, it turns out there is a total of 18 m^3 flooding from 5 nodes shown in Figure 5-3, with the highest ponded depth of 3 cm from node Jun_205106. Thus, another optimisation was done to find the optimal solution for Scenario 2085 based on the optimal solution for Scenario 2030.

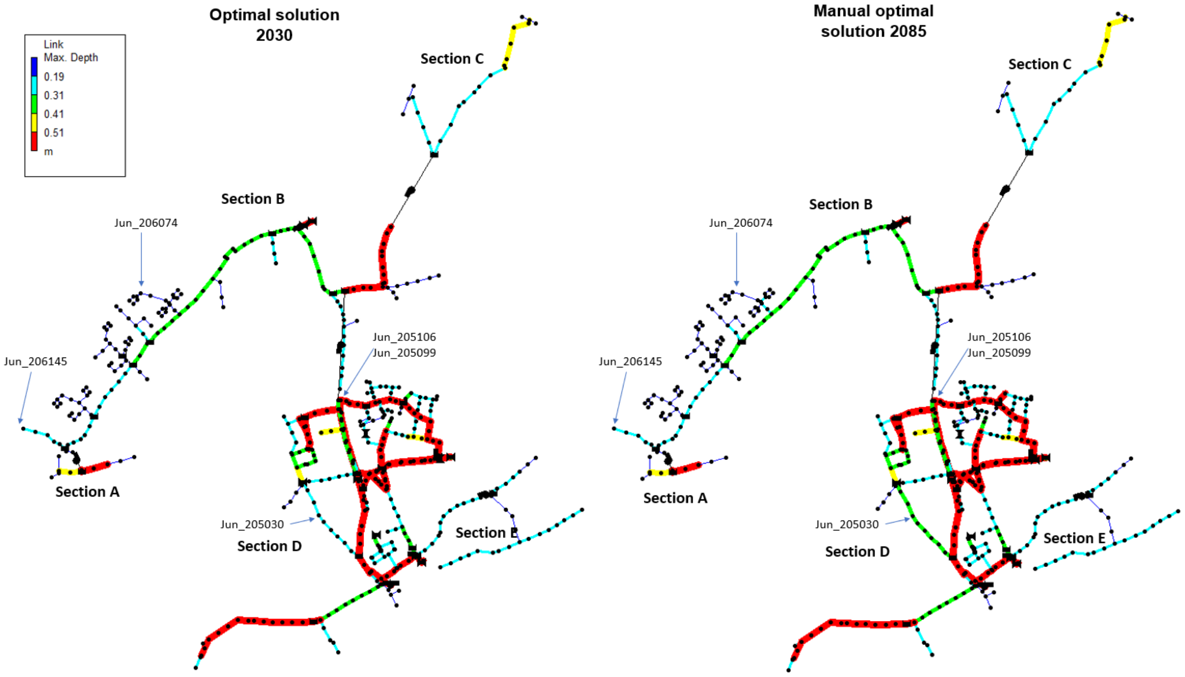


Figure 5-3 Pipe diameter comparison map of the manual optimisation solutions for 2030 (left) and 2085 (right)

Figure 5-3 highlights the differences between the pipe diameters for Scenario 2030 and 2085. In terms of pipe replacements, to comply with Scenario 2085, pipes on the left side of the 'V'-shaped network at the centre of Section D, where Jun_205030 exists as shown in Figure 5-3, needs to be changed from 300 mm to 400 mm (green lines). However, in the optimal solution 2030, this specific pathway until the junction that connects the big 'V'-shaped network still uses the original pipe diameter. Thus, the pipe changes are only required to comply with Scenario 2085. Furthermore, additional units of RB are needed for the two areas to eliminate flooding on the northern sections, and pipe replacements from 150.6 mm to 188.2 mm and 188.2 mm to 235.3 mm are also needed to eliminate the flooding from Jun_206074.

Meanwhile, eliminating the flooding from the other two nodes (Jun_205106 and Jun_205099) is done by increasing the pipe diameters on one of the problematic branches located in the northeast area of Section D, leading towards CSO 1. Originally, these two pipes had 400 mm pipes (green line), which were then replaced with 600 mm pipes (red line). By taking all the necessary measures, no flooding is detected in the drainage systems, and an additional cost of € 368,540 is needed.

5.1.2 Formal optimisation

The formal optimisation was simulated using the available 1.30GHz Intel(R) Core(TM) i7-1065G7 CPU with 8 GB of RAM. With the chosen population size of 550 and 40 generations, one full optimisation run has a computation time of around 51 hours. Based on the formal optimisation simulation results for two scenarios, 2030 and 2085, the objective function of the optimisation, *i.e.* the implementation cost of the optimal solution for each design period, can be summarised below.

Table 5-2 Summary of the cost to implement the formal optimisation solutions

Measure	Cost per needed per design period		
	2030	2050*	2085
Green-Blue (G-B)	€ 956,050	€ 0.00	€ 927,350
Grey (Pipe & Pump)	€ 5.41 million	€ 0.00	€ 5.51 million
Weir addition	€ 634,600	€ 0.00	€ 634,600
Flooding Penalty	€ 0.00	€ 0.00	€ 0.00
Total cost:	**€ 7.01 million**	**€ 0.00**	**€ 7.08 million**

* the scenario 2050 was not simulated

The formal optimisation was done based on the method combining Genetic Algorithm (GA) and SWMM, using the selected G-B-G measures discussed in Chapter 4.4. However, the simulation was done only for Scenarios 2030 and 2085 because of the insignificant differences between design storms for scenarios 2030 and 2050. Hence, it is hypothesised that the optimal solution for the year 2030 might be complied with the 2050's scenario, just like the result from the manual optimisation.

In principle, the formal optimisations can also be done by finding adaptive solutions within a period of 55 years (2030 – 2085), like the manual optimisations. However, there are possibilities that more or fewer interventions are needed to prepare for Scenario 2085 than Scenario 2030, and the solution for Scenario 2085 might not be as a simple incremental of Scenario 2030. Since the response of the UDS might differ with both design storms, running the full simulation for each scenario can give a bigger picture of the required interventions for each time horizon. Then, an adaptive solution might be implemented based on the optimisation results by adjusting the optimal solution for Scenario 2030.

Table 5-2 shows the cost to implement the optimal solution for both 2030 and 2085. The simulation for scenario 2030 resulted in an optimal solution with an objective function value of € 7.01 million, while the 2085 simulation resulted in a solution cost of € 7.08 million. Both results show 0 m^3 of flooding and 0 cm of flood depth at all nodes using their respective design storms.

Scenario for 2030

The simulation for the optimisation of scenario 2030 resulted in a solution with a total cost of € 7.01 million. This total cost can be broken down into € 956,050 for G-B measures, € 5.41 million for pipes and pump replacements, and an additional fixed cost of € 634.6 thousand for lengthening the CSOs weirs.

Figure 5-4 shows two graphs obtained after the simulation ended. The top graph shows the average value of the objective function over the iteration number, while the bottom graph depicts the best objective function value for each iteration. Both graphs show that the algorithm convergence gradually, meaning that the search space is not too small, which can result in early convergence of solution due to the local optima solutions.

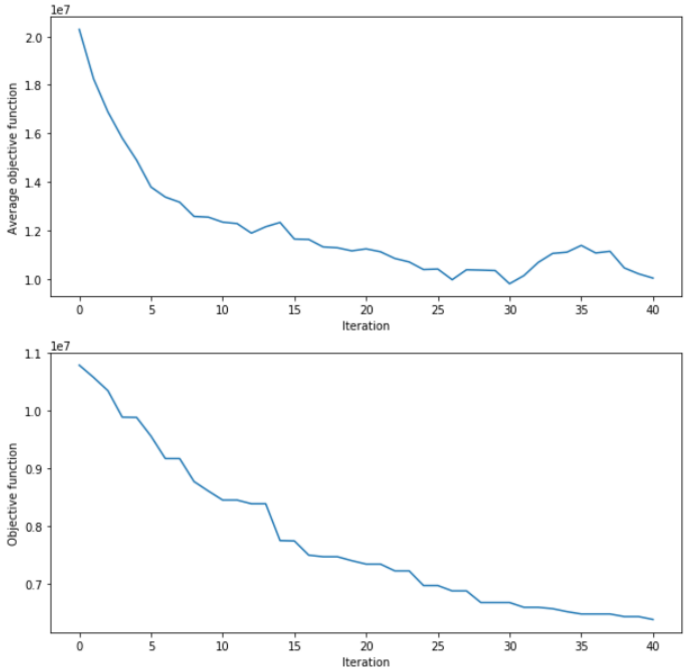


Figure 5-4 The value of the objective function over the number of iteration for scenario 2030

(**Top:** Average value of the objective function for each iteration; **Bottom:** The best objective function value for each iteration)

The simulation starts with an average value of the objective function at around € 20 million, and the best objective function in the first iteration costs € 10.9 million. The simulation managed to make the algorithm converges gradually until a significant decrease in the objective function best value from iteration 13 to iteration 14, which can also be seen from a slight increase of the average objective function value during these iterations. This gradual decrease of the objective function best solution (*i.e.* increase of the fitness) over the iteration (Figure 5-4 top) makes the use of elitist GA differ from standard GA. When the algorithm is not trapped in the local optima solutions, the convergence curve of the solutions will either stay equal or move towards the most optimal solution (*i.e.* decreasing for minimisation problem) due to the reproduction of the elite individual for each generation. Thus, the best solution found is always the best solution in the last iteration; meanwhile, with standard GA, the best solution found will be the best solution found amongst all generations [39]. However, when the algorithm encounters too many local optima, the global optima might not be found.

The first five simulations depict a faster reduction in the average objective value because the earlier populations still have many random individuals from the initial population. After the 30th iteration, the average value of the objective function rose again and decreased after iteration 35. However, this slight fluctuation in the average value of the objective function does not necessarily mean bad because the algorithm managed to find a better solution through each iteration.

The simulation was done using 550 populations and 40 generations; nevertheless, it can be seen that the graph line is not flattening out yet even after the last few iterations. This can mean that there is a possibility of finding a better solution using a slightly larger number of generations with the current population.

Based on the simulation, the best solution found shows that amongst 72 DV, 49 DV are changed from their initial values. These 49 DV consists of the implementation of RB in 253 sub-catchments (out of 264), IT in 23 sub-catchments (out of 26), PP in 112 sub-catchments (out of 145), replacing 2 out of 3 pumps, and enlarging 163 out of 309 pipes. For more details of which object needs to be changed, Appendix L shows the comprehensive table of the simulation results.

Figure 5-5 illustrates the comparison of pipe diameters between the original layout and the optimal solution for the year 2030. Again, the difference between both pipe diameter layouts can be seen clearly. Several pipe segments have to be enlarged to tackle the flooding issue in the north sections (Section A, B, C). These segments are the left pipe segments before the pumping station (red line in Section A) – 188.2 mm to 700 mm, left upstream part of Section B (yellow line) – 188.2 mm to 500 mm, along the pathway towards the CSO 3 in Section B (green line) – 300 mm to 400 mm, downstream of Section C after the pump (red line) – 300 mm to 60 mm, and the top upstream of Section C (red line) – 188.2 mm to 800 mm. In this solution, the Section A pump's capacity is increased from the original 14 m^3/hour to 45 m^3/hour. Also, the pump from Section C capacity increased from 25 m^3/hour to 35 m^3/ hour – the same pump capacity used to pump water from Section B to Section D.

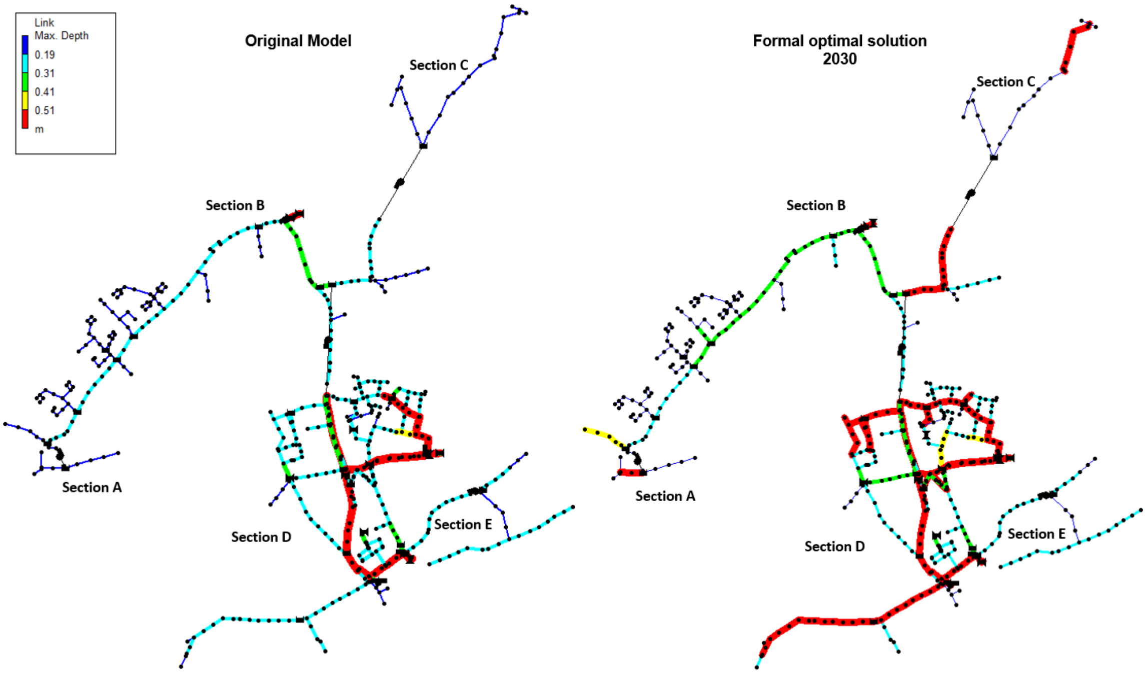


Figure 5-5 Pipe diameter comparison map of the original model (left) and formal optimal solution for 2030 (right)

Figure 5-6 Locations of Green-Blue measures from formal optimisation for 2030

(**Left:** Infiltration Trench (IT) implementation areas; **Center:** Rain barrel (RB) implementation areas; **Right:** Pervious Pavement (PP) implementation areas)

Figure 5-6 shows that no IT is implemented in the upstream part of Section B. Furthermore, the pipe diameters in that section downward until the change of diameter is expected (Figure 5-5 right, green line in Section B) are not changed at all. This indicates that with this solution, to make up for the less runoff capturing (G-B) measures, the solution came up with a bigger pipe diameter upstream (500 mm) to act as storage due to the smaller pipes downstream. In addition to this, more water is being pumped out of Section A; therefore, enlarging these pipes can retain water from Section A, resulting in the cheapest solution to reduce the flooding risk of the downstream sub-catchments until CSO 3. As a test, a slight modification to this solution was performed by reducing the diameter of these 500 mm pipes to 250 mm and reducing the pump's capacity into 35 m^3/ hour. The test shows that reducing pump capacity only, left a 5 cm flood depth in Section A, while only reducing the pipe diameters left a 6 m^3 of flood with 6 mm flood depth upstream of Section B. Thus, it seems like, for this simulation, the optimal solution with the best fitness value is by taking these quite extreme measures. Furthermore, the extreme diameter change of pipes in Section A from 188.2 mm to 700 mm also acts as storage to retain water.

The same case happens for the upstream areas of Section C. Although G-B measures can be implemented there, it seems like the solution shows that it is more expensive to implement G-B measures than enlarging the pipe diameter upstreams that can act as storage for additional in-pipe volumes. This lack of G-B measures can be seen from Figure 5-6 that there are no G-B measures implemented upstream of Section C. In this part of Section C, most inflows come from these upstream areas since the nodes downwards are not the sub-catchments outlet. Therefore, no additional inflow means that as long as the upstream pipes can retain more water, there is no need to increase the pipe diameter all the way downstream until the pumping station.

Moving towards the south sections, Figure 5-5 shows several notable changes in pipe diameter. On the northwest side of Section D, it can be seen that the original 300 mm pipelines are changed into 800 mm and 600 mm (Figure 5-7). All the water from the northwest area is conveyed to the centre part of the network, which consists of two parallel pipes. No pipe changes are expected for the central pipes until it reaches the end of the 'V'-shaped network, where the pipe diameters going to either the main pumping station or CSO 2 are changed from the initial 600 mm into 1000 m.

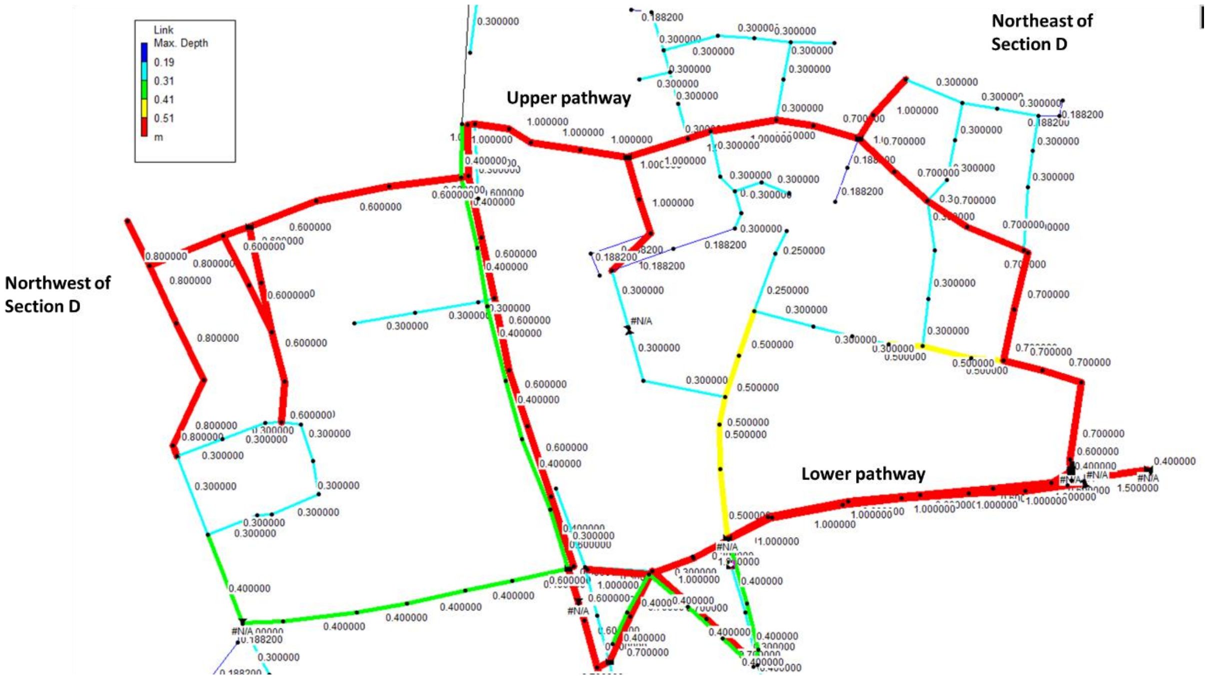


Figure 5-7 Detailed pipe diameters* from the formal optimal solution for the northwest and northeast of Section D in 2030

(*unit of pipe diameter in the figure is meter)

In the northeast area, the upper pathway pipes to the centre pipelines are changed from 300 mm to 1000 mm. The downstream of these pipe segments during wet weather flow are both CSO 1 and CSO 2, where the pipelines until CSO 1 have a diameter of 700 mm, and pipelines towards pumping station/ CSO 2 have parallel pipes of 400 and 600 mm. Thus, the original layout for this segment has a bigger pipes diameter towards CSO 1 and CSO 2 than towards the main pathways pumping station to increase the network capacity during wet weather flow. Therefore, increasing the 300 mm pipes to 1000 mm means retaining more water before it flows toward the CSOs during rain events. Although the centre pipelines have smaller diameters (400 mm and 600 mm), the implementation of 1000 mm pipes diameter in this segment can still be done. It is also supported that from the simulation report that the conduit that connects the 1000 mm pipe to the centre pipelines with a diameter of 600 mm still have a < 1 ratio of maximum flow to the full flow during the peak hour. It means that the conduit still has not reached its full capacity yet. Furthermore, the pipes from the commercial areas towards the lower pathway in the northeast area are increased from 300 mm to 500 mm (yellow vertical line in Figure 5-7).

On the other hand, all the stormwater sewer going to the surface water near CSO 1 needs to be enlarged from 300 mm (branches) and 600 mm (mains) to 400 mm and 1000 mm, respectively. Although the stormwater sewer from this area has already been replaced with a larger diameter, there are still flooding in the combined sewer nearby. Thus, the diameter of the combined sewer in this area is increased from 300 mm to 700 mm.

The last notable pipes enlargement is on the southwest side of Section D, as shown in Figure 5-5. It is expected that there will be pipe replacement in this segment because no other than RB can be implemented in this area due to the high groundwater level. The new pipe diameter will then be 600 mm until halfway through the pathway and 800 mm until it connects to the pipe towards the main pumping station from the original 300 mm.

In conclusion, from the optimal solution for 2030, from Figure 5-6, we can see several implementations of G-B measures throughout the case study area. However, the sizes of the implemented G-B measures are small, around the minimum area to implement the measures (see

These small G-B measures are compensated with larger pipe diameters and increased pump capacity throughout the case study area. The simulation for the year 2030 using formal optimisation shows that implementing G-B measures to tackle the flooding issue in this area will cost much more than increasing the pipe diameter.

Scenario for 2050

The optimal solution for Scenario 2030 (37.7 mm rainfall) was tested against Scenario 2050 (37.9 mm rainfall). This test was done to check whether the optimal solution for 2030 can comply with Scenario 2050 or not. Since the rainfall peak for both design storms has the same intensity, the solution for 2030 is expected to withstand Scenario 2050 or at least no major modification to the UDS is needed.

Based on the test result, the hypothesis is confirmed that the formal optimal solution for 2030 can also handle Scenario 2050. Several optimisation solutions for Scenario 2030 were simulated using Scenario 2050 to test the hypothesis further. However, it turns out this hypothesis is not always true. Out of four GA simulations, only two solutions shows that the optimal solution for 2030 can comply with scenario 2050. Thus, it is concluded that even with similar rainfall events and the same peak intensity, the behaviour of the system is not always the same. However, it also depends on the optimal solution found.

Nevertheless, since the best solution found for Scenario 2030 shows that it can produce the best objective value amongst the other simulation and can comply with Scenario 2050, it is assumed that for Scenario 2050, the solution for 2030 is the optimal solution. Therefore, no simulation using GA was done with the design storm 2050.

Scenario for 2085

After several simulations were done to find the optimal solution for the year 2030, another simulation was done to look for the optimal solution using Scenario 2085 (38.6 mm of rainfall). With the same 550 population and 40 generations, the optimal solution for scenario 2085 gives an objective function value of € 7.08 million. This cost includes a total of € 927.3 thousand for G-B measures and € 5.51 million for grey measures (lengthening of CSO weirs and pump and pipe replacements).

The simulation took around 54 hours to reach the 40th iteration, which is 3 hours longer than simulating scenario 2030. Figure 5-8 displays two graphs: average objective function per iteration and the best objective function per iteration.

The initial population shows an average cost of around € 22 million, with the best fitness value of around € 11.5 million. Although when looking at the average objective function value, the first ten iterations shows a steeper slope, the algorithm is gradually converging to the best solution for each iteration. Thus, it can be said that the chosen population size helps the solution to converge step-by-step and not too fast. Furthermore, the large population size helps the algorithm explore the vast search space for this optimisation problem.

While the average value of the objective function over each iteration fluctuates after the 15th iteration, the graph trend follows the converging solution trend based on the bottom graph of Figure 5-8 (best objective function within the population per iteration). From the 30th iteration, the graph starts to flatten, although it is not flattened out until the end of the simulation. Thus, like the simulation for scenario

2030 (Figure 5-4), it seems like a better solution can be found with more iteration. Nevertheless, the simulation result can be considered good as the gradient of the curves already flattening towards the end of the simulation. At the end of the last iteration, the final objective cost value is € 6.44 million (excl. fixed price for the weirs).

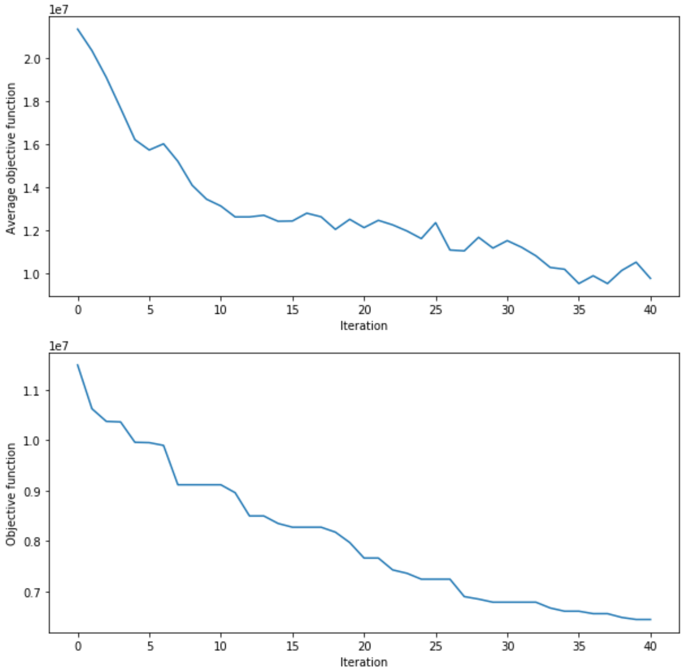


Figure 5-8 The value of the objective function over the number of iteration for scenario 2085

(**Top:** Average value of the objective function for each iteration; **Bottom:** The best objective function value for each iteration)

The simulation shows that amongst 72 DV, 53 DV can be implemented. This 53 includes 15 DV for RB (all possible sub-catchments), 3 DV for IT (26 out of 26 possible sub-catchments), 11 DV for PP (128 out of 145 possible sub-catchments), one pump replacement, and enlargement of 186 out of 309 pipes in the list of DV. Appendix L0 detailed each decision variable in the solution and its corresponding sizes.

Figure 5-9 compares the pipe diameters layout of the current UDS system with the formal optimal solution for 2085. In this solution, the pump that needs to be changed is only the pump from Section A to Section B. The new pump needs a capacity of 25 m^3/hour to replace the current 14 m^3/hour. Aside from the diameter increase from 150.6 to 800 mm (red line) and from 188.2 mm to 300 mm (light blue line) in Section A near the pump, the most notable changes are in the branches of Section B, as can be seen in Figure 5-9. Section B has a straightforward network layout that goes from upstream (after Section A and Section C) towards the downstream – the pumping station from Section B to Section D. This solution came up with enlarging almost all of the branch pipes flowing towards the main pathway of Section B. To compensate for the increase of conveying capacity, the diameter of the lower half of the main pathway needs to be replaced from 300 mm to 400 mm (green line). However, increasing the branch pipes' diameter means that the G-B measures implemented in Figure 5-10 are not enough to resist enlarging the pipes to handle the peak flow with its area or shifting the peak time and causing flooding at a different time. Hence, the option becomes only two: increasing the primary pathway diameter to reduce HGL in these branches pipes or adding local storage capacity by enlarging the branches pipes. Based on the simulation result, increasing both pipes diameters with a moderate diameter value is the most optimal solution compared to increasing the area of G-B measures.

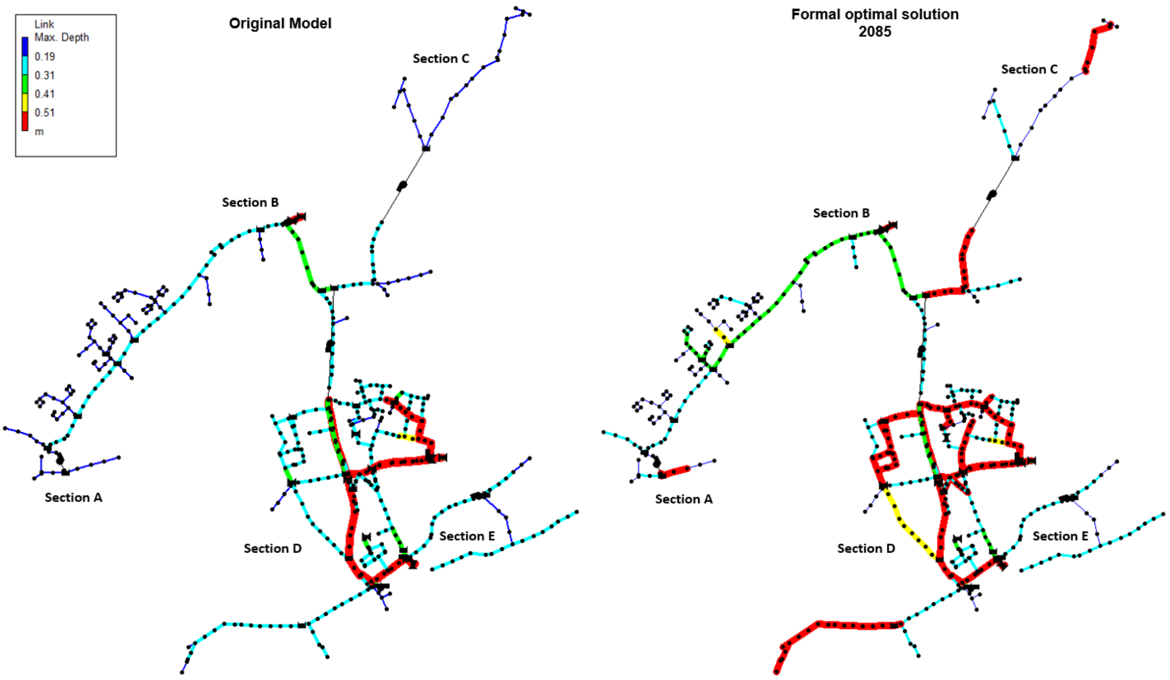


Figure 5-9 Pipe diameter comparison map of the original model (left) and formal optimal solution for 2085 (right)

Figure 5-10 Locations of Green-Blue measures from formal optimisation for 2085

(**Left:** Infiltration Trench (IT) implementation areas; **Center:** Rain barrel (RB) implementation areas; **Right:** Pervious Pavement (PP) implementation areas)

Section C has no G-B measures implemented other than RB, as shown in the middle picture of Figure 5-10. As robust as RB can be compared with the same area size as PP using the design parameters in this thesis (see Appendix D– Design parameters of the selected Green-Blue measures), in reality, RB implementation is limited due to the available RB in the market and the number of houses in the sub-catchment. Hence, RB implementation is not enough to reduce the peak flow and tackle flooding in most cases. In addition, the upstream areas of Section C do not have many houses. Thus, the inexistence of PP in this area leads to the necessity to increase the local pipe's capacity from 188.2 mm to 600 mm. However, since the inflow only comes from the upstream, there is no need for the downstream pipes to be enlarged. The drastic change in the upstream pipes’ diameters can act as storage and reduce the overall HGL in that pathway.

A similar case happens with the branch pathway of Section C. Although PP and RB are implemented (Figure 5-10), the optimisation shows that it is better to implement G-B in minimum sizes and increase the pipe diameters moderately from 188.2 mm to 300 mm (Figure 5-9). High groundwater table and lack of houses make the G-B implementation on the other end of the pump from Section C to Section B ineffective to reduce the upcoming flood risk in 2085. Hence, replacing the pipes' diameters from 300 mm to 700 mm (red line) in that area is necessary until the pump from Section B to Section D (see Figure 4-4 to see the sections perimeter of the case study area).

Figure 5-9 and Figure 5-10 also shows that many interventions are needed using grey and G-B measures in Section D due to the high flood risk in this section. Starting from the northern parts of Section D, although Figure 5-10 shows the implementation of all available G-B measures, many pipes still need to be replaced. Figure 5-11 shows detailed pipes' diameters for the northern part of Section D. The most significant diameters increases are for the pipes on the main pathway of that part that conveys water toward the centre pipelines of Section D. Figure B. 4 in Appendix B highlights the water flow pathways in this area.

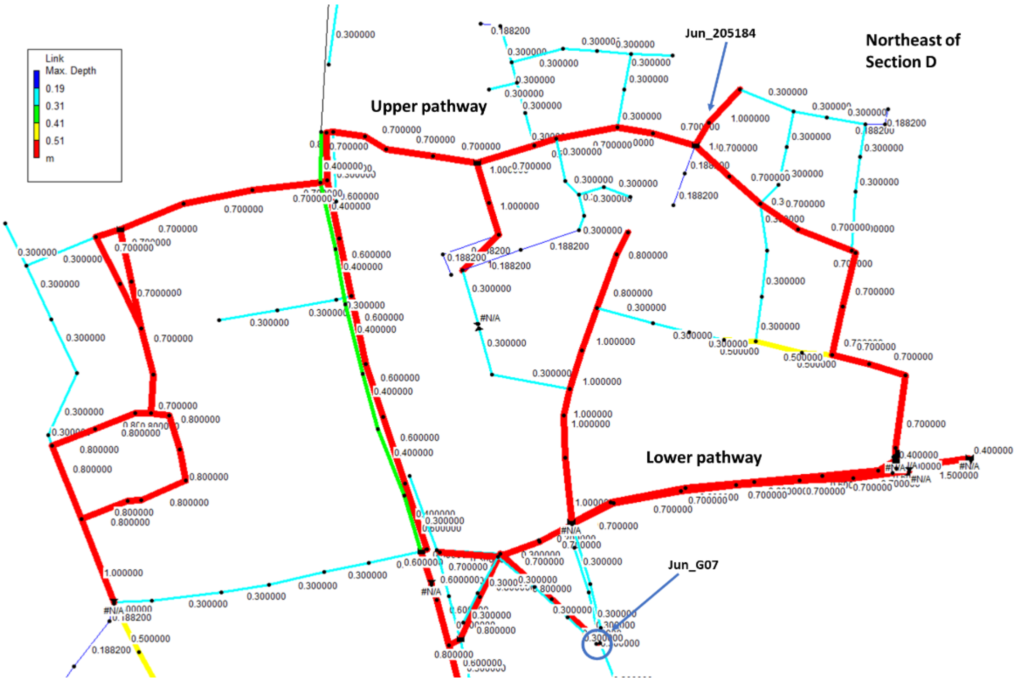


Figure 5-11 Detailed pipe diameters* from the formal optimal solution for the northwest and northeast of Section D in 2085

(*unit of pipe diameter in the figure is meter)

In the northwest part, the current diameters of 400 mm and 300 mm need to be changed to 1000 mm, 800 mm, and 700 mm. The 700 mm pipes will then connect to the centre pipelines consisting of parallel pipes with 400 mm and 600 mm diameter, as shown in Figure 5-11. In addition, 686 m^2 of PP will be installed.

Moving towards the northeast part of Section D, from CSO 1, two main pathways connect the northeast part to the centre pipelines on Section D. The upper pathway through the residential areas and the lower pathway through the commercial areas along the stormwater sewer pipelines. For the upper pathway, the half of the pathway towards the central pipelines currently has a pipe diameter of 300 mm, and the optimal solution shows that it should be increased to 700 mm – like the downstream diameters towards CSO 1, to manage the flood risk in 2085. However, the branches of this upper pathway have a more significant upgrade from 300 mm to 1000 m. The reason for this is that one branch with Jun_205184 is located in a sag location (see Figure 5-11). It means that the ground level of that node is lower than its surrounding nodes. Thus, the optimal solution shows that enlarging the diameter of these pipes is the best way to reduce the flooding from Jun_205184. Meanwhile, the 1000 mm pipes act as storage for the other branch, delaying the water flowing towards CSO 2 through the 'W'-shaped segments in the city centre. A test was done to check the effect of reducing the pipe diameters in this branch, which resulted in flooding from one of the downstream nodes toward CSO 2, Jun_G07, as shown in Figure 5-11. Therefore, the 1000 mm pipes are important for this branch as well.

For the lower pathway parallel with the stormwater sewer, the replacement of pipes is needed in the branch pathway from the commercial area from 300 mm to 1000 mm, and the pipes towards the centre from 300 mm to 800 mm. In this area, there is a flow division that separates the incoming flow from the commercial areas. Therefore, some of the water from upstream will be conveyed to the centre, and some will flow towards the other pathway going downstream, parallel with the centre pipelines with a diameter of 300 mm (light blue line underneath the 'W'-shaped network in Figure 5-11).

Looking back on Figure 5-11, other significant changes are the pipes along the pathway on the left side of the 'V'-shaped network and the southwest of Section D. The left side of the 'V'-shape needs to be replaced from 300 mm to 500 mm (yellow line) to compensate for the lack of area available for G-B measures.

On the southwest part of Section D, the upstream segments of that pipe branch need to be replaced with a diameter of 600 mm from the original 300 mm. The 600 mm pipe that connects to the 300 mm pipe towards the main pumping station has a 50 cm invert level difference. Hence, increasing the pipe diameter in the upstream part is the optimal solution to reduce the flood risk – which mostly will happen in this upstream part based on the flood test using the design storms.

Replacing the current pipe with a much bigger diameter pipe will surely impact the performance and maintenance of these pipes, especially during dry weather flow, *i.e.*, no rain. Although the population will increase in the upcoming years due to the plan to develop a new residential area with around 40 new houses near the city centre [78], it is unlikely that there will be a massively significant increase in the inflow to the drainage systems within 55 years from now in Riethoven. Therefore, these pipes will barely be utilized to their maximum capacity during the dry weather flow.

A comparison was done between the original layout and the optimal solution during the dry weather flow. Most conduits, especially when greatly oversized, have a lower maximum velocity and Max/ Full Depth compared to the original layout behaviour during the dry weather flow. Due to this, the self-cleansing velocity, which is approximately 0.6 m/s [79], cannot be reached. Therefore, settling of sediments will very likely happen, and it means a high-pressure cleaning is needed. In addition, the accumulation of other materials, such as fats, oils, greases, will likely happen as well. The cost calculated for the optimisation considers this aspect and assumes that each sewer will need an annual cleaning using high-pressure and suctions as proactive maintenance. However, this assumption in maintenance can lead to either over-maintenance or under maintenance in some segments. Therefore, the pipes should be monitored when implementing these oversized pipe diameters, and the cleaning schedule should be adjusted based on the real conditions. In some cases, a reactive unscheduled cleaning might be needed as well.

To conclude the optimal solution for 2085, since G-B measures only are unlikely to counter the peak flow, and enlarging the overall UDS capacity becomes necessary to reduce the flood risk in 2085.

Therefore, the optimal solution suggests that it is better – in terms of cost – to implement a wide coverage of G-B measures with moderate area sizes and increase the network capacity in the upstream parts as it is the identified location of most future flooding from Scenario 2085.

5.2 Comparison between manual and formal optimisation

The manual and the formal optimisation results show an absolute difference in the objective value function by a margin of € 962 thousand for Scenario 2030 and € 1.26 million for Scenario 2085.

Table 5-3 Optimal solutions cost comparison between manual and formal optimisation

Measure	Total cost needed per design period					
	2030		2050*		2085**	
	Formal	Manual	Formal	Manual	Formal	Manual
Green-Blue (G-B)	€ 956,050	€ 1.17 million	€ 956,050	€ 1.17 million	€ 927,350	€ 1.18 million
Grey (Pipe & Pump)	€ 5.41 million	€ 6.16 million	€ 5.41 million	€ 6.16 million	€ 5.51 million	€ 6.50 million
Weir addition	€ 634,600	€ 634,600	€ 634,600	€ 634,600	€ 634,600	€ 634,600
Flooding Penalty	€ 0.0	€ 0.0	€ 0.0	€ 0.0	€ 0.0	€ 0.0
Total cost:	**€ 7.01 million**	**€ 7.97 million**	**€ 7.01 million**	**€ 7.97 million**	**€ 7.08 million**	**€ 8.34 million**

*The costs of the optimal solution for the year 2050 for both optimisation are the same as the scenario for 2030 because the 2030 solutions comply with the 2050 scenario.

** The cost of the optimal solutions for the 2085 scenario is the total cost and not the additional cost based on the scenario for 2030.

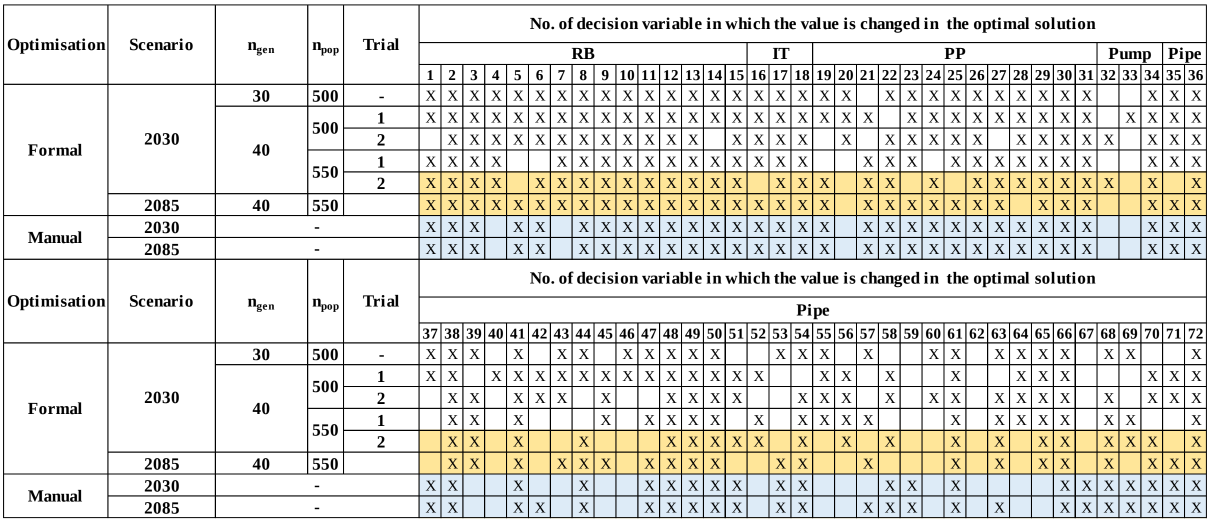
Based on the significant difference between the two values of the objective function for both optimisation in the case study, it is confirmed that the formal optimisation using a metaheuristic approach by linking a hydrodynamic model of the UDS with an evolutionary algorithm can produce a better solution.

With manual optimisation, the human brain plays a significant role in determining the optimal solution while performing the optimisation even under the same set of options and procedures with automated optimisation. In addition, the machine intelligence and the algorithm's capability to explore more combinations of the solution will most likely exceed human's capacity to do the same. For example, when doing trials with a different value for only one sub-catchment, the algorithm can quickly evaluate the effect of each value. At the same time, it takes more time to change, run, and document each change manually. Thus, the exploration of search space is limited to the capacity of the human. While utilizing the human brain might not be the most effective method to do the optimisation, during the reduction and clustering of decision variables, the human brain needs to be involved in finding the reasonable final list of decision variables for the case study area in order to limit the search space of the optimisation and help the algorithm to converge. It is, of course, also possible to make all the optimisation processes fully automated. However, the trade-offs in doing this are a higher possibility for the algorithm to be trapped in local optima solutions due to the wide extend of search space, longer time to find the optimal solution and the need for more complicated coding. Therefore, the optimisation needs both the human brain and automated optimisation to find the most reasonable and optimal solution in practice.

Table 5-3 depicts this significant difference in the objective function value from the manual and formal optimisations. The difference in cost to implement grey measures from the manual and formal optimisations are higher than the cost difference for G-B measures for both scenario 2030 and 2085. While the margin in G-B measures cost is around € 230 thousand for all scenarios, for grey measures, the difference reaches € 746 thousand and € 1.01 million for Scenario 2030 and 2085, respectively. By looking at these costs, it can be seen that both manual and formal optimisations show that the implementation of grey measures to achieve zero flooding with the lowest cost is still the most optimal solution. Nevertheless, both optimisations also prove that the implementation of G-B measures plays an important role in reducing the peak flow and incoming water to the sewer system, thus reducing the dimension of the needed grey measures in some areas in the case study location.

In terms of the value of the decision variables, a sensitivity analysis on both optimisations was done by comparing the decision variables modified for the optimal solutions. Figure 5-12 shows the result of sensitivity analysis on the modified decision variables' value for different numbers of generations, population size, and optimisation method. The light orange lines result from the formal optimisation's optimal solutions, the light blue lines result from the manual optimisations, while the rest show the results of the formal optimisation using different combinations of n_{gen} and n_{pop}.

The sensitivity analysis validates that some of the decision variables that contribute and do not contribute to reducing the flood risk with both formal and manual optimisation. Out of 72 DV, 26 DV are consistently either chosen or not chosen as part of the optimal solution from all simulations. On the other hand, when focusing only on the optimal solutions from the formal optimisation (light orange lines in Figure 5-12) and manual optimisation, 45 out of 72 DV are either chosen or not chosen. The decision variables that have no contribution to reducing flooding are no. 56, 69, 40, 46, 55, 60, 62, and 64 – which all belongs to pipe replacement decision variables. However, when looking at all formal simulations, the non-contributing decision variables are only no. 62.



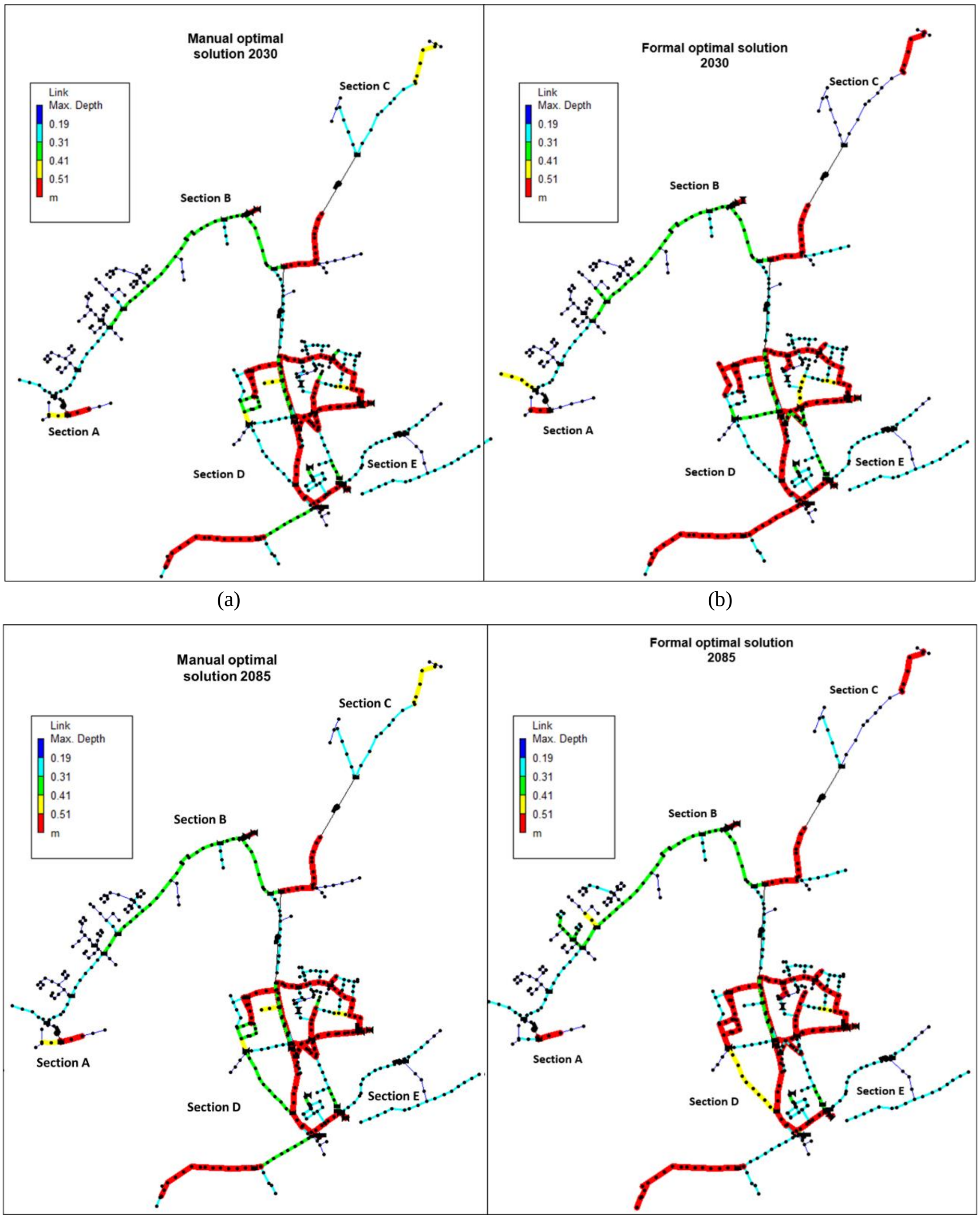
Optimisation	Scenario	n_{gen}	n_{pop}	Trial	No. of decision variable in which the value is changed in the optimal solution																																		
					RB															IT			PP													Pump			Pipe	
					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Formal	2030	30	500	-	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X			X	X	X
		40	500	1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X		X	X	X	X
				2		X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X		X		X	X	X	X	X		X	X	X	X	X		X	X	X
			550	1	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X			X	X	X		X	X	X	X	X	X	X			X	X	X
				2	X	X	X	X		X	X	X	X	X	X	X	X	X	X		X	X	X		X	X		X		X	X	X	X	X	X	X		X		X
	2085	40	550		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X		X	X	X			X	X	X
Manual	2030	-			X	X	X		X	X		X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X			X	X	X
	2085	-			X	X	X		X	X		X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X			X	X	X

Optimisation	Scenario	n_{gen}	n_{pop}	Trial	No. of decision variable in which the value is changed in the optimal solution																																		
					Pipe																																		
					37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
Formal	2030	30	500	-	X	X	X		X		X	X		X	X	X	X	X			X	X	X		X			X	X		X	X	X	X		X	X			X
		40	500	1	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X			X	X		X			X			X	X	X				X	X	X
				2		X	X		X	X	X		X			X	X	X	X			X	X	X		X		X	X		X	X	X	X		X		X	X	X
			550	1		X	X		X				X		X	X	X	X		X		X	X	X	X				X		X	X	X	X		X	X			X
				2		X	X		X			X				X	X	X	X	X		X		X		X			X		X		X	X		X	X	X		X
	2085	40	550			X	X		X		X	X	X		X	X	X	X			X	X			X				X		X		X	X		X		X	X	X
Manual	2030	-			X	X			X			X			X	X	X	X	X		X	X				X	X		X					X	X	X	X	X	X	X
	2085	-			X	X			X	X		X			X	X	X	X	X		X	X			X	X	X		X		X			X	X	X	X	X	X	X

Figure 5-12 Sensitivity analysis on the decision variables with different n_{gen}, n_{pop}, and optimisation method

Looking at the decision variables dedicated to G-B measures (no. 1 – 31), the manual optimisation used less RB (no. 1 – 15) than the formal optimisation results. However, when looking at the implementation area, the implemented RB using formal optimisation has a higher total area than the manual optimisation's solutions. DV no. 4 and 8 were thought to be ineffective in reducing flood risk during the manual optimisation. However, the formal optimisation found a better combination that includes the implementation of RB in these areas.

The next three DVs (no. 16 – 18) belong to IT implementation, in which almost all methods agree that it is necessary to reduce the flood risk for all scenarios, with the manual optimisation solutions have a higher area compared to the formal optimisations. DV no. 19 – 31 correspond to PP implementation, which resulted in different results. Nevertheless, the most intriguing result is DV no. 20, not chosen by all optimal solutions (light orange and light blue rows). Decision variable no. 20 consists of PP implementation on the upstream sub-catchments of Section C as shown in Figure 4-4 and Figure 4-7. Th optimal solutions show that increasing the pipe diameter on this segment (DV no. 36) is far more effective in reducing the flood and cost-efficient than implementing PP. Furthermore, DV no. 32 – 34 represents each pump that is considered a possible bottleneck. All optimal solutions show that the pump from Section A (see Figure 4-4) needs to be upgraded to comply with all scenarios.



(a) (b)

(c) (d)

Figure 5-13 Comparison of pipes diameters between the manual optimisation and the formal optimisation for Scenario 2030 (a and b) and 2085 (c and d)

The rest of the DV (35 – 72) represents clusters of pipes. DV no. 37, 39, 42, 43, 45, 52, 56, 59, 65, and 67 display that while none of the formal optimisations considers it an optimal solution, the manual optimisation does, or the other way around. DV number 37 represents the main pathways pipes towards the pumping station from Section C as shown in Figure 5-13 a, b, c, and d. While the manual optimisation solutions show that the increase of these pipes (light blue line in Figure 5-13 a and c) are the most optimal solutions, the formal optimisation solutions display more optimal solutions by further increasing the upmost upstream pipe. Due to this extra storage from the enlarged pipes, DV no. 39 (in Section B, downstream of Section C) for the manual optimisation has a value of 0, meaning that it can maintain its current pipe diameter. However, for the formal optimisation, these pipes need to be enlarged; otherwise, flooding will happen.

While most of the differences are located in the pipe branches, another interesting difference between the pipe replacements from both optimal solutions are for DV 65 and 67. The city centre that is located near the 'W'-shaped pipe segment is quite prone to flooding. During the manual optimisation, it is assumed that increasing the pipe diameters towards the CSO 1 can reduce the flooding in this area – which is true, and it is shown by DV number 67. However, the formal optimisation shows that in exchange for not increasing the pipe towards the CSO, the cheapest solution can be achieved by adding extra storage to the upstream pipelines to delay the peak flow and avoid flooding in this area – which is represented by DV number 65 and also mentioned in Chapter 5.1.2.

As sustainable G-B measures can be, when not considering the co-benefit of its implementation, its effect in flood risk reduction is minuscule compared to grey measures. The optimal solutions from both optimisation methods show that it can find a better solution regarding the objective function value when focusing mainly on increasing the capacity of grey measures. However, the implementation of G-B measures cannot be diminished fully due to their capability to reduce and delay the peak flow and allow the grey measures to convey the inflow gradually. Thus, a certain degree of G-B measures still needs to be implemented to reach the optimal solution.

Table 5-4 Comparison of peak flow reduction between the manual and formal optimisation solutions

Scenario	**Total Peak Flow (m^3/s)**			**Peak flow Reduction (%)**	
	Original	**Manual Optimisation**	**Formal Optimisation**	**Manual Optimisation**	**Formal Optimisation**
2030 & 2050	5.56	5.25	5.27	5.6	5.2
2085	5.69	5.36	5.44	5.8	4.4

The manual solutions give a similar but slightly higher peak reduction than the formal optimisation due to the implementation sizes of G-B measures, which are quite bigger than manual optimisation. Table 5-4 highlights the peak flow reduction of 5.6 % for 2030 and 5.8 % for 2085 using the manual solutions, and 5.2% (2030) and 4.4% (2085) for the formal optimisation solutions.

It can be summarised that the main difference between the manual and formal optimisation results mostly lies in the sizes of implementation and not the location of implementation. This can be seen from the sensitivity analysis that in most cases, the DV chosen as part of the optimal solution are the same for both formal and manual optimisation with several exceptions. Compared with the optimal formal solutions, the manual optimisation has a 74% similarity in selecting the location of interventions for 2030. Meanwhile, the 2085 optimal solution from the formal optimisation has an 81% similarity with the manual solution regarding interventions' location. Therefore, it is clear that the margin from both optimisations' costs mostly comes from the difference in replaced pipe dimensions and the pipe locations in several parts.

In general, the manual and formal optimisation give similar optimal solutions patterns in terms of their locations. This can be expected with a small and straightforward case study location like Riethoven. In some cases, the best intervention to eliminate a flooding problem in one sub-catchment can be estimated quite straightforwardly by looking at the HGL, the surrounding sub-catchments, and the volume of flooding. However, another problem arises when the case study location becomes more complex and bigger. Then, the optimal manual solutions might significantly differ compared to the formal optimisations. With complex case study locations, it might be hard to explore possible combinations for the decision variables values and link a flooding node to its flood contributor; thus, the margin in the objective cost can be a lot higher.

5.3 Comparison between formal optimisation results for 2030 and 2085 scenarios

The results from the formal optimisation for 2030, 2050, and 2085 scenarios have been detailed in Chapter 5.1.2. Since the optimal solution for 2030 can be considered the optimal solution for 2050, this chapter will focus on comparing the results of the optimal solution for 2030 and 2085.

Based on the simulation results, the optimal solutions from both GA runs show somewhat similar values. The optimal solution for scenario 2030 costs € 7.01 million, while the solution for 2085 costs € 7.08 million. Approximately, there is only a difference of € 70,000. However, the interesting part is the solution itself despite its similar objective function value. It is decided to test the formal optimal solution for 2030 against Scenario 2085, and the result shows that this solution cannot withstand the future rainfall from 2085. If this solution is implemented until the year 2085, there will be a total of 5 m^3 with a flood depth of 6 mm from Section A, B, and D. Meanwhile, as expected, the 2085 solution can withstand all three scenarios.

Table 5-2 compares the cost needed to implement the optimal solution for the years 2030 and 2085. Although the magnitude and ratio of grey to G-B measures are similar, the 2030 solution has a higher cost of G-B measures than the 2085 solution, which uses more expensive grey measures. Despite this higher cost of G-B measures for solution 2030, solution 2085 implements more G-B measures in other areas, although with the total area lower than solution 2030. Therefore, it can be said that the solution 2085 has a more spread out G-B measures implementation. Amongst 72 DV, the solution for 2030 utilised 49 DV, while solution 2085 utilised 53 DV. This is reasonable as the design storm for 2085 is more extreme than 2030, which makes more interventions needed.

Figure 5-14 shows the value of each decision variable based on the simulations results. The value is represented by a number 0 or > 0. When the decision variable's value is 0, it means that the measures will not be implemented in that location. By measures, it can mean the pipe diameter will be increased, pump capacity will not be upgraded, or the G-B measures will not be implemented. The shaded area indicates the decision variable where only being implemented by one of the solutions. In addition, Figure 5-15 compares the pipe diameters between the two formal optimal solutions.

Scenario	**The value of decision variables in the optimal solution**																																			
	RB															**IT**			**PP**													**Pump**				
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**
2030	1	3	2	2	0	9	17	13	13	3	3	10	16	5	12	0	1	4	17	0	5	2	0	4	0	10	1	6	1	7	6	1	0	3	0	8
2085	10	11	7	21	5	7	13	18	11	8	1	3	15	6	15	9	2	2	1	0	9	9	2	1	3	5	4	0	2	2	4	0	0	1	3	6

Scenario	**The value of decision variables in the optimal solution**																																			
	Pipe																																			
	37	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**	**61**	**62**	**63**	**64**	**65**	**66**	**67**	**68**	**69**	**70**	**71**	**72**
2030	0	3	3	0	1	0	0	4	0	0	0	7	3	3	5	5	0	3	0	1	0	3	0	0	6	0	5	0	6	2	0	4	1	3	0	5
2085	0	4	1	0	1	0	1	5	4	0	9	3	6	3	0	0	5	4	0	0	2	0	0	0	4	0	5	0	6	8	0	5	0	1	1	2

Figure 5-14 Comparison of the decision variables' values between the formal optimal solution for 2030 and 2085

0 : no changes to the original UDS
> 0 : there are implementation of grey or G-B measures in which the higher the number, the bigger the size of implementation

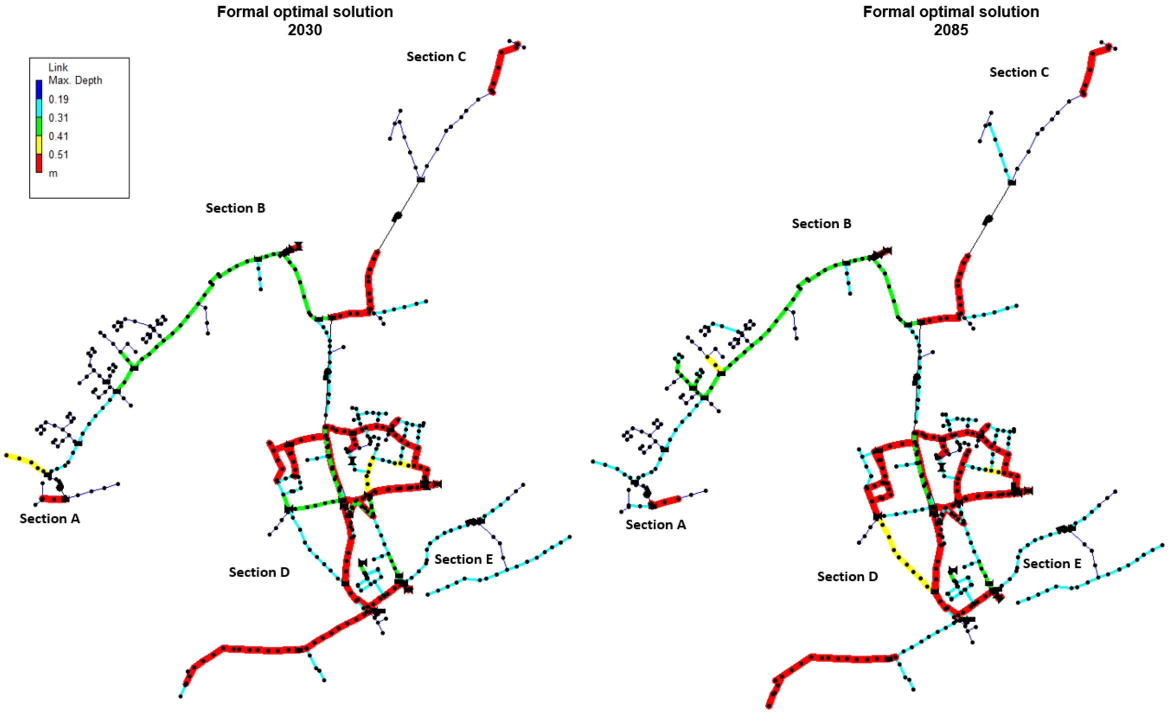


Figure 5-15 Pipe diameters comparison of the formal optimal solutions for 2030 (left) and 2085 (right)

Some of the interesting differences between the two solutions are the upstream and branches of Section B, a branch of Section C, and Section D. The inexistence of IT on the upstream of Section B (DV no. 16 in Figure 5-14) atop of the increase of pump capacity (DV no. 34) from Section A in solution 2030 is causing the need to increase the pipe diameter to 500 mm. This diameter shift seems extravagant when considering that the downstream pipes are only 235.5 mm and 400 mm. In addition, the increase of pump capacity to 45 m^3/hour for such a small section might seem extreme as well. Which in this sense, the solution from 2085 makes more sense to be implemented.

Section B's branches also have intriguing differences that can be seen from DV no. 2, 3, 4, 28, 29, and 30 in Figure 5-14. These DV represents the area of RB and PP implementation upstream of Section B. While DV 2, 3, and 4 show immense values for solution 2085 – which means more storage from RB, DV 28, 29, and 30 show higher values for solution 2030, meaning that solution 2030 implements more PP in these branches sub-catchments. However, solution 2085 compensated this by increasing the pipe diameters of the branch pipes. Therefore, due to a lot of pipe diameter increase and RB implementation in Section A and Section B, solution 2085 costs more than solution 2030.

The optimal solution for Section C from both scenarios is also quite different, especially in the branch of Section C. Solution 2030 decides to implement a large area to implement PP that can be seen from the value of 17 for DV no. 19 compared to the value of 1 for solution 2085, in which solution 2085 rectifies by replacing the pipe diameters. However, solution 2030 also increases the upstream pipe diameter by 800 mm, which seems extravagant aside from increasing the pump capacity to 35 m^3/hour (DV no. 31). As a result, the total cost to reduce the flood risk in Section C for solution 2030 reaches € 490.6 thousand, while solution 2085 costs € 364.7 thousand. Therefore, just like with the upstream of Section B, it seems more reasonable to implement solution 2085 for Section C.

The last thing to look at when comparing the two formal optimal solutions is Section D (see also Appendix L). The solution 2030 shows that many pipes need to be enlarged by quite a lot, especially with the 1000 mm pipes on the upper pathway of the northeast section and the RC_Plan pipes. When looking into all intervention cost in Section D, it is found that with solution 2030, all the interventions in Section D cost € 4.03 million. Meanwhile, implementing all interventions in Section D using the solution 2085 costs € 3.96 million. Therefore, it can be concluded that in Section D, the implementation of solution 2085 is more reasonable as well.

5.4 Implementation of the optimal solution

Based on a more profound analysis of the difference between the two formal optimal solutions in Chapter 5.4, it can be concluded that the € 70,000 difference of both solutions mostly comes from Section B (see Figure 4-4 for the sections). In addition to this small margin from both solutions' costs, it should be noted that solution 2085 can tackle Scenario 2085 with a peak intensity of 78 mm/ (h. 5 mins) and a total volume of 38.6 mm, while solution 2030 can only withstand Scenario 2030. Therefore, it is decided to implement the optimal solution for 2085 from the beginning of the design period, as its overall effect in managing flood risk until the scenario for 2085 is more beneficial than solution 2030. Although in return, implementing this solution means less peak flow reduction from G-B measures and more grey measures. However, since the objective function of this thesis is to find the optimal solution with the minimum total cost without considering the co-benefits of the interventions, this result is expected due to the incapability of G-B measures to tackle extreme rainfall events.

The best implementation of solution 2085 can be differentiated between the grey and G-B measures.

5.4.1 Implementation of the grey measures

Implementing the new pump capacity for the pump from Section A can be straightforward by immediately changing the pump and renovating the pumping well while also arranging all the pump's mechanical and electrical needs. Since the pump is assumed to be a submersible centrifugal wet pump, the setup includes chains along the rail to lift the pump during maintenance or replacement, and since there is no control room, a weatherproof switch box will be needed as the house for the electrical system, *e.g.* the main power supply, main fuses, switch and electricity meter [79]. A measuring device such as a water level sensor can also be reused if it is currently available.

Furthermore, increasing the weir length means rebuilding the current CSO chambers, or in the study case, the storage basin (peripheral facilities), for all CSO. Since using the aerial image analysis on the location of all CSO, it is assumed that there are available spaces to increase the length of CSO transverse weirs and increase the dimension of the CSO chambers. Another way to do this is by making the overflow weir a double-sided weir; however, the cost calculation assumes that the current outlet weir's length will be doubled and there are spaces available.

The pipe replacement implementation cannot be as straightforward as the other two grey measures. Since the optimal solution to be implemented is expected to comply with Scenario 2085, no modification for the year 2085 needs to be done because pipe replacement can be installed from the first design period of 2030. The municipality of Bergeijk mentioned that they want to tackle the urban flooding problem within the next ten years from their last Sewerage Plan 2020-2024; thus, the pipe replacement can be done gradually until the year 2030. Due to the high cost of pipe replacement, the project is usually combined with road maintenance. No known information about road maintenance projects in Riethoven can be used as a reference. However, after the flooding issue in July 2021 (Chapter 4.2) and the flooding report from the municipality sewerage plan [67], it is assumed that the municipality can see the urgency to increase the system's hydraulic capacity within the next ten years.

Most changes can be implemented directly by changing the current pipelines with the new diameters – pipe replacement. This direct implementation fits with the description from the Sewerage Plan of the

Municipality of Bergeijk that stated most combined sewer was built between 1970-1980 with a lifespan of 60 years; thus, it should have been replaced by 2030-2040 [67].

However, exceptions are made for pipes that are better added with new pipelines parallel to the current pipes rather than replacing the current pipe. Since installing 1000 mm pipes for quite a long segment (approximately 265 m) can be costly, the exceptions are referred to these pipes near the commercial areas in Section D as shown in Figure 5-16. In reality, implementing these significant pipe diameters increase in the branch part of the network scheme is not recommended due to the possibility of blockage from the sudden changes in diameter sizes towards the CSO 1 (towards right from Figure 5-16). Thus, what can be done with this solution is to install parallel pipes. Installing parallel pipes can be interpreted as an in-line storage system to locally increase network capacity [26]. This parallel pipes layout is similar to the current pipe layout in the city centre in Section D (see Figure B. 4 in Appendix B).

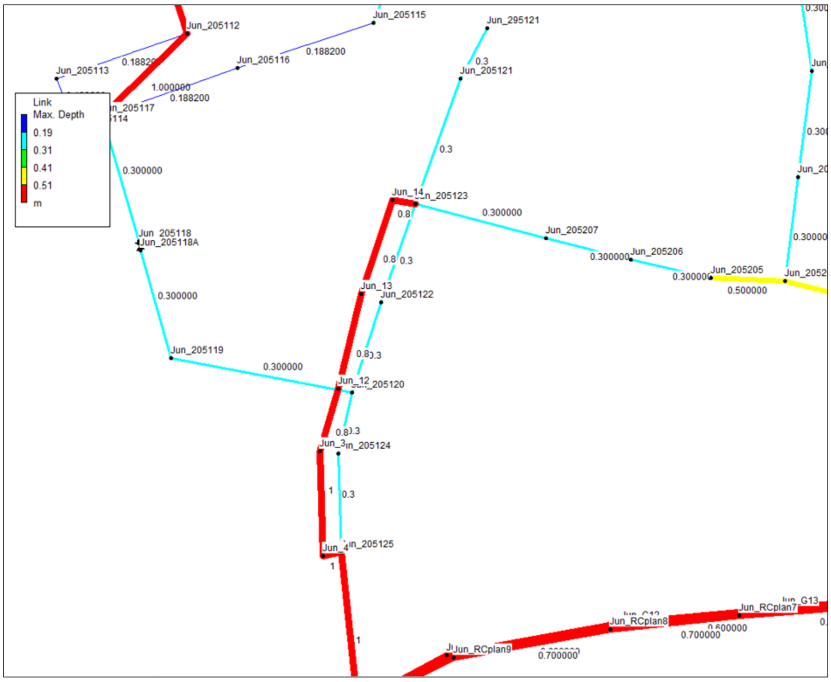


Figure 5-16 Illustration to implement parallel pipes and the needed diameters*

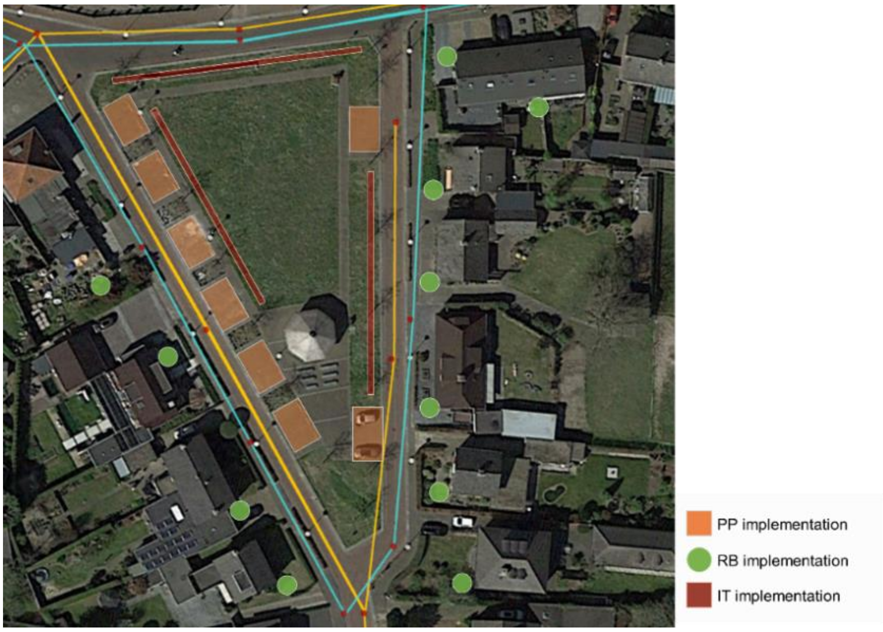
(* the pipe diameters are in meter)

From Figure 5-16, the new parallel pipes can be seen from the red lines that connect to Jun_205123 and Jun_205125. The original pipe diameters are 300 mm, and these pipes can be kept as it is. The parallel pipes can be installed with diameters of 800 mm, with some pipes towards the junction that connects the two segments have a diameter of 1000 mm. However, some replacements are still needed with the upstream pipes from Jun_295121 and Jun_205121(light blue line) from the original 188.2 mm to 300 mm, and the last pipe after the connection between the parallel pipes, from 300 mm to 1000 mm. The optimal diameters for these two pipes from the formal optimisation are supposed to be 800 mm. However, due to the parallel pipes that can divert the incoming flow from the upstream pipes, the increase to 800 mm are no longer necessary. A test has been done on the system by using this scheme, and the report shows that it can comply with all climate change scenarios.

Having said that, when installing parallel pipes, additional costs might be needed to construct the new manholes as well. However, since the cost to remove the current pipe is not relevant anymore, the total cost would probably still similar or maybe even less. RIONED indicates that the basic prices to construct new pipelines for expansion plans are slightly cheaper than replacing the current pipes [80]. However, due to the road width limitation, the distance of the parallel pipe can only be up to 3.5 meters. For the replacement procedure of sewer systems, refer to [75] or other replacement guidelines for more detailed information.

5.4.2 Implementation of the green-blue measures

The implementation of G-B measures can also be straightforward for RB and IT. For RB, once the municipality decides on the RB that the residents will use, the municipality needs to start with the campaign or other approaches to make sure the residents understand how to use and install the RB properly, then the distribution can start (or incentive-based approach can also be done). As mentioned in Chapter 3.4.2, each house will be allocated with a maximum of two RB with a dedicated size.



(Location: Sub_RCplan3, Sub_RCplan4, Sub_RCplan5, Sub_RCplan11)

(Location: Sub_206108, Sub_206109, Sub_206110, Sub_206111)

Figure 5-17 Illustration of the implementation of the selected Green-Blue measures

Since each area of the implemented IT is not that big, the construction can start on all the open space dedicated to implementing IT. The IT needs to be constructed in the area of the park that is the closest to the street [51]. Meanwhile, the implementation of PP that is planned to be implemented on the street and not the pavements or parking lots can be combined with replacing the pipe. This is the case with PPs that are located in Section A, branches of Section B, and the northwest and northeast branches of Section D as shown in Figure 5-10. For more details regarding the implementation of RB, IT and PP can refer to the SuDS manuals [51].

5.5 Optimisation projection for the future

It has been discussed that with the most optimal solution from the formal optimisation using Scenario 2085, the UDS should be able to manage a rainfall event with a total volume of 38.6 mm with a peak intensity of 78 mm/ (h. 5 mins). When looking at the solutions obtained from both manual and formal optimisations, it can be summarised that when the main objective of the rehabilitation is to manage the flood risk from extreme events with the minimum cost, then increasing the hydraulic capacity of the UDS might be a better solution. However, the result of this thesis proved that a certain degree of combination between grey and green-blue measures produce the most optimal solution and can compete with the traditional grey measures only, as mentioned by other studies that combine the implementation of G-B-G measures [16, 17, 18, 23]. The optimal solutions using both the formal and manual methods show that from scenario 2030, an upgrade is needed for scenario 2085. Furthermore, both methods show that the needed upgrade consists of adding more G-B measures and increasing more pipe diameter; thus, the combination of G-B-G measures.

Due to the consideration of climate change scenarios, the rehabilitation projects might be more substantial than the usual rehabilitation projects. For example, the Municipality of Bergeijk spends around € 40,000 per year for pipe replacements projects within a time horizon of 60 years. Assuming the average price to replace a pipe of any diameter is € 450 per meter, normally, around 89 meters of pipes are replaced per year. Meanwhile, from the optimal solution, when the solution needs to be implemented within the next ten years, then a pipe replacement rate of around 700 meters/ year is needed. It means the pipe replacement rate increases by almost eight times the normal replacement rate. However, it should be noted that the normal pipe replacement rate might not consider the enlargement of pipes and only replacing the current pipe to maintain its performance; that is why the cost is constant each year.

In the case study location, the grey measures from the optimal solution can still be implemented; nevertheless, in the future, the expansion of hydraulic capacity might be constrained as the rate of urbanisation will also grow atop extreme rainfall events due to climate change. Therefore, another test on the optimal solution was performed to see the capability of the solution to overcome the high scenario design storm for 2030 with a total volume of 39.4 mm and a peak intensity of 78.9 mm/ (h . 5 mins). The result shows that there will be a flooding of 7 m^3 with a flood depth of 5 mm in in Section D with the current optimal solution. Since the pipes in that part of Section D have been enlarged in this solution, with more extreme rainfall, such as design storms with higher return periods, the future rehabilitation can no longer rely on grey measures. More G-B measures need to be utilised as the current solution only implement small sizes of G-B measures.

The manual optimisation that includes the sustainability thinking process not introduced for the formal single-objective optimisation shows a much higher peak reduction, which means that implementing G-B measures can effectively reduce flood risk when used on a larger scale and combined with the grey measures for resiliency. However, it is true that implementing a larger scale combination of G-B-G measures results in a costly solution. Yet, what should be considered by the decision-makers for the future is that other than the sustainability aspect, G-B measures can introduce other co-benefits, such as groundwater recharge, water pollution reduction, water supply, as studied by Alves *et al*. (2020) [16].

The municipality of Bergeijk is already considering implementing more G-B measures throughout the area of Bergeijk, and the optimisation result of this thesis can become a pathway towards a more sustainable rehabilitation of the urban drainage system. Furthermore, other types of G-B measures outside of the ones mentioned in the selection's decision tree (Chapter 3.4.2) can be considered, such as rooftop disconnection or retention/ detention ponds when there are available spaces in the future. To fully assess the benefits of implementing more G-B measures in the future, a multi-objective optimisations framework can be made to consider the trade-off between resiliency and sustainability properly.

Chapter 6

Conclusions and recommendations

6.1 Conclusions

The main purpose of this thesis is to develop a method to find the optimal way to rehabilitate or adapt an existing urban drainage system (UDS) to reduce the risk of flooding under climate change rainfall scenarios to make the system more resilient to withstand extreme storms by minimising the duration and magnitude of urban flooding, with the minimum cost of intervention. A calibrated hydrological model of a real urban drainage network in Riethoven, The Netherlands, is used to test the method. To achieve the main purpose of this thesis, one main research question and six sub-research questions have been developed and answered in this thesis, as elaborated in Chapter 1.3. Based on the objective of this thesis, the main research question was:

"What is the optimal way to rehabilitate or adapt an existing urban drainage system (UDS) to a changing climate with respect to managing the risk of urban flooding?", which was answered through the following sub-questions.

1. *How can the above UDS rehabilitation problem be formulated as an optimisation problem?*

   The UDS rehabilitation problem was formulated as an economic optimisation problem of the cost needed to implement the measures to reduce the risk of flooding under certain design storms. Reducing flood risk can then be formulated as a constraint; thus, making the UDS rehabilitation problem a constrained single-objective optimisation. The objective function of this optimisation problem becomes the minimisation of the total cost to implement the measures for the rehabilitation of UDS, under the constraint that no flooding can happen anywhere on the system when tested against the climate change rainfall scenarios. The '*no flooding'* constraint can be incorporated into the objective function as a penalty cost for each m^3 of flooding.

   The objective function for the optimisation problem then consists of two terms, the intervention cost and the cost of constraint violation. Meanwhile, the decision variables of this optimisation will be the size and location for each implemented measure.

2. *What are the appropriate climate change rainfall scenarios to be used to solve the above urban drainage rehabilitation problem?*

   Addressing the climate change in the rehabilitation problem can be done by either using the developed composite rainfall scenarios by STOWA according to the KNMI'14 climate change scenarios, assuming an overall increase of rainfall volume from the current design storms, or by using the estimation from the historical rainfall data which is useful when looking at the impact of climate change on the emission of sewer overflows.

   Since this thesis does not consider the impact of sewer overflows and the rainfall's peak intensity and timing is considered an important factor in this rehabilitation problem of the UDS, which might not be reflected well with the increase of volume rainfall method, the usage of composite rainfalls as a design storms method is chosen. Therefore, the appropriate climate change rainfall scenario to solve the UDS rehabilitation problems are by using the new composite rainfall for years 2030 (C_2_2030) – Scenario 2030, 2050 (C_2_2050) – Scenario 2050, and 2085 (C_2_2085) – Scenario 2085, with a return period of 2 years, which is the most common return period used in the Dutch sewer system.

All three chosen design storms are a 10-hours rainfall event, with the peak coming halfway through the rainfall event. Each design storm has a different total volume and peak intensity representing the increase of hourly rainfall from 2030 to 2085.

3. *What is the definition of 'flooding' used to evaluate the performance of the alternative solutions during the optimisation?*

   The term '*flooding*' is identified as ponded water above the maintenance hole (junction node) that flooded for more than 1 minute. Thus, manholes and pipe surcharges that do not result in water coming out of the manholes will not be considered as flooding. The flooding volume with flood depth lower than 1 mm will also not be counted as flooding since SWMM only have a precision of up to 1 mm of ponding. In other words, when the ponded depth equals 0.000 meters, and it is flooding less than 1 minute, it is not counted as flooding. The ponding depth is used as a parameter since it determines the extent of the flooding effect on a particular area. The higher the ponded depth, the higher the risk of damage and casualties of the flooding.

   During the optimisation, each solution will be evaluated based on the objective function value. The penalty cost in the objective function is associated with the total flood (m^3) calculated based on the definition of flooding.

4. *What interventions should be considered (Green-Blue or Grey), and how could these be characterised for optimisation when considering the respective locations and sizes? How can these be discretised best to reduce the optimisation search space?*

   Both grey and G-B measures have their pros and cons when it comes to a rehabilitation solution. While grey measures can give resilience to withstand extreme rainfall events, their application is constrained by environmental issues and the limitation to keep increasing their capacity for the future. On the other hand, G-B measures can reduce the size of grey measures needed (*e.g.* reduce the diameter of the pipe needed) and offer several benefits in terms of adaptability and sustainability, even though they are incapable of handling extreme rainfall events and are constrained by space availability. Therefore, the combination of both grey and G-B measures should be considered to rehabilitate the existing UDS.

   The implementation of grey and G-B measures can be characterised for optimisation as the decision variable of the optimisation problem. Each decision variable represents the implementation of one measure in one location, and the value of the decision variable represents the implementation size of the measure. When the value of the decision variable is 0, it means that there will be no grey or G-B measure implemented in that specific location. The implemented sizes for each measure can vary depending on the selected measures, which is pipe and pump replacements and implementation of rain Barrels (RB), Infiltration Trenches (IT), and Pervious Pavements (PP) for this thesis. For pipe and pump replacements, the value of the decision variable is the new pipe diameter, new pump capacity based on the available pipe and pump in the market. Meanwhile, for the installation of RB, the implemented size also represents the number of RB in that location because RB is a manufactured good. On the other hand, the implementation of PP and IT depends on the available space in the case study area. Therefore, land-use analysis using aerial images was done to decide on the maximum and minimum area to implement both measures.

Since there are many possible numbers between the minimum and maximum area values to implement IT and PP, quantisations of the area values are needed. The quantisation of the area can help to reduce the search space further. The discretisation of the areas of the measurements can be done by using a bin of 10% size for maximum area <100 m^2 and a 5% bin size for maximum area > 100 m^2. It means that one measure's possible values in a sub-catchment vary with a bin of 5% or 10% of its maximum value. However, that alone is not enough when considering hundreds of decision variables left associated with each measures placement. Therefore, it is best to reduce the number of decision variables further by identifying the bottleneck locations based on the hydraulic performance of the overall UDS in the case study location and then clustering the remaining decision variables based on the location proximity of each sub-catchment or pipes.

5. *What is an appropriate method to simulate and evaluate the alternative solutions during optimisation?*

   One possible way to simulate and evaluate the alternative solutions is by using a metaheuristic method that links a hydrodynamic model and an optimisation tool. One widely known model used as a dynamic simulation engine to calculate and mimic the hydraulic behaviour of water runoff and sewer systems is Storm Water Management Model (SWMM). Paired with one of the most popular evolutionary algorithms, Genetic Algorithm (GA), the combination of both SWMM and GA is used in this thesis to simulate and evaluate the alternative solutions, which is called formal optimisation. Since this thesis is a single-objective optimisation problem that focuses on 1D flow, combination of SWMM and GA is a robust method and is used in other studies related to rehabilitation optimisation problems – which might not be an appropriate method when the 2D flow is considered or when it is a multi-objective optimisation problem.

   Another method to simulate and evaluate the alternative solutions is by using the human brain, *i.e.* the manual optimisation. However, manual optimisation is very limited to the capacity of the human and less likely able to find the most optimal solution due to the wide search space in this kind of optimisation problem. From the case study, the result of the formal optimisation using this metaheuristic approach has been confirmed to outperformed the result from manual optimisation using the traditional trial-and-error method.

6. *What is/are the most appropriate green-blue (G-B) and grey measure(s) to be implemented in the analysed case study? How can the optimisation results be used to project suitable G-B-G measures to be implemented in the future?*

   Based on the analysis of the case study, the most appropriate G-B measures to be implemented is Rain Barrels (RB), Infiltration Trenches (IT), and Pervious Pavements (PP). Meanwhile, for grey measures, it is best to consider pipe replacement, upgrading the current pumping capacity, and increasing the CSOs' weirs length. Thus, the combination of all measures is needed to produce the economically optimal solution with no flooding, based on the optimisation result in the case study area. Since the optimisation problem only considers the system's capability in handling climate change rainfall scenarios to achieve zero floodings, the G-B measures' implementation costs are much smaller than the grey measures costs. However, based on the available decision variables list, G-B measures are implemented in more locations compared to grey measures in the case study area. Almost all possible locations for G-B measures implementation are chosen to become part of the optimisation solution; however, only slightly more than half of the decision variables for grey measures are utilized. This is because the implemented G-B measures per sub-catchment have a small area of implementation – thus, the low cost.

   The optimal solutions using both the formal and manual methods show that from scenario 2030, an upgrade is needed for scenario 2085. Furthermore, both methods show that the needed upgrade consists of adding more G-B measures and increasing the diameters of more pipes, thus combining G-B-G measures. The pipe diameters that need to be upgraded for Scenario 2085 are pipes located in areas that are not flooded when using Scenario 2030 but flooding with Scenario 2085.

When it is not possible to increase the hydraulic capacity of the sewer system in the future, more G-B measures can be implemented to reduce the peak flow of extreme rainfall. In addition, the optimisation result shows that implementing G-B measures, especially in upstream sub-catchments, can reduce the need to increase the pipe capacity from upstream. Since G-B measures can reduce and delay the incoming peak flow, thus, it can reduce the needed capacity of the grey measures. Therefore, by looking at the tendency of the optimisation solutions from both manual and formal optimisation, it can be projected that in the future, the combination of G-B-G measures can produce an economically optimal solution to be implemented in order to achieve zero floodings in the case study location.

6.2 Recommendations

While working on this thesis, some interesting things can be done to improve or research in the future regarding the rehabilitation of urban drainage systems in changing climate. Most of the recommendations include the need to do more computational to look for the possibility of finding a better solution, either for this case study or when applying the developed method in other case study locations – which becomes the limitation in this thesis in terms of time and resources. Although running more simulations with the recommended setup might give a slightly better solution for the case study location, based on the sensitivity analysis of the decision variables with several simulations, the difference in the locations of implemented interventions might not be substantial. On the other hand, the difference in the objective function value and the measure sizes (*i.e.* the area of G-B measures, pipe diameters, and pumping capacity) might not be marginal. Therefore, this chapter elaborates on the improvement suggestions and side-topics to be researched for future practices.

1. *Parallel computing*. The method developed in this thesis can benefit from the usage of parallel computing. In particular, when doing the formal optimisation using Genetic Algorithm, parallel computing can fasten the converging of the optimal solution by evaluating each individual solution simultaneously. For example, the current run time for one simulation using the available device is 51 hours. Only six individuals generated by GA can be evaluated within one minute. With parallel computing, this run time can be reduced; thus, allowing more simulation to be used within the time limitation frame.
2. *A slightly deeper search for GA*. From the optimisation results, it can be seen that even though the algorithm is converging, a slightly deeper search might result in a more optimal solution. However, due to the time limitation of this thesis, this cannot be done. Therefore, a slightly deeper search by increasing the number of generations can be done for future practice with similar problem sizes with different case study locations since the difference in the objective function value might be marginal for this case study location.
3. *Separating the simulation for each UDS section*. With the analysed case study in this thesis consisting of several sections, separation of each section and simulating them individually might increase the chance of finding an overall better solution. However, due to the time limitation in this thesis, it is hard to modify the data and codes and adjust the model. Therefore, it is recommended to try this in future studies with this case study or other similar case studies. Furthermore, when combined with parallel computing, it might reduce the computational time by a lot.

4. *Sensitivity analysis on the reduction and clustering of the decision variables*. The reduction and clustering of decision variables play an important role in deciding the optimal solution. Clustering, in particular, can remove some important details from the optimal solution, which might be overlooked in this thesis. Therefore, sensitivity analysis can be done by running the simulation with the initial list of decision variables and analysing the effect of reduction and clustering of decision variables. This could be really interesting to analyse when parallel computing can be applied.
5. *More simulation and population seeding*. The current optimisation results were obtained by running the simulation five times for scenario 2030 and one time for scenario 2085. Yet, scenario 2085 gives a more optimal solution, which is probably due to a good initial population by GA. Therefore, more simulation and introducing seed individuals as the good and bad parameters for optimisation might result in a better solution, which will be interesting to analyse.
6. *Assessing the impact of increasing the weirs length and possible water pollution*. The optimal solution for the rehabilitation includes increasing the CSO weirs length, which might impact the sewer overflows and possibly, also surface water pollution. Increasing the weir length might be able to increase the weir's flow capacity. Therefore, it is recommended to look further into whether this measure increases the overall overflow volume or not, and, if applicable, its implication to surface water pollution.
7. *Testing on another network*. The result of this thesis is case dependent and might not be possible to be implemented in other case study areas with different characteristics. The case study location can be considered as a small area with not too complex urban drainage systems. Therefore, the optimal solution might be straightforward, as seen from the similarity of the chosen decision variables between the formal and manual optimisations. However, the same approach to formulating and solving the optimisation problem can be applied in another case study with retrofitting rehabilitation problem to see whether the formal optimisation can be used when the problem sizes are bigger and more complex than the case study area and whether it is more reliable than manual optimisation using human brain or not.
8. *Multi-objective optimisation to assess the trade-off between Green-Blue-Grey measures in the future*. The optimal solution shows that the combination of both Grey and G-B measures produce the optimal solution. However, as the implementation of grey measures in the future might be constrained due to construction limitations, more G-B measures might be the solution. Therefore, multi-objective optimisation can be done to assess the trade-off between grey and G-B measures in tackling future extreme rainfall events.

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Glossary

List of Acronyms

UDS	Urban Drainage Systems
CSO	Combined Sewer Overflow
DV	Decision Variable(s)
GA	Genetic Algorithm
SWMM	Storm Water Management Model
RB	Rain Barrel
IT	Infiltration Trench
PP	Pervious/ Permeable Pavement
G-B	Green-Blue
G-B-G	Green-Blue-Grey
LID	Low Impact Development

Appendices

Appendix A - Comparison of Literatures

Source	Problem			Objective(s)				Objective Function(s)			Operating Algorithm	Hydraulic Model Simulation	Decision Variables	Constrains	Notes
	Flooding	CSO	Design	Location	Size/ Area	Type	Others	Cost	Quantity	Performance					
Ngamalieu-Nengoue et al., 2019 [6]	✓	x	x	✓	✓	x	x	✓	x	x	PGA (Pseudo-Genetic Algoritm)	SWMM	Size of pipes, Node storage capacity	Commercially available pipe diameters	Search space reduction by pre-selecting locations using single-objective optimisation
Ngamalieu-Nengoue et al., 2019 [1]	✓	x	x	✓	✓	x	x	✓	x	x	NSGA-II (Non-dominated Sorting Genetic Algorithm)	SWMM	Nodes potentially becoming ST and conduits potentially be replaced	-	No search space reduction; Computationally challenging.
Alves et al., 2020 [15]	✓	x	x	✓	✓	✓	x	✓	x	x	NSGA-II	SWMM	Areas covered by the different G-B measures measures	Real data and land use analysis (max. value for every application of the measures)	To reduce the search space, the data was pre-processed using MCDA. Needs the cooperation from stakeholders
Duque et al., 2016 [21]	x	x	✓	✓	x	x	Routing	✓	x	x	DP using Bellman-Ford Algorithm	-	Pipe length; Density and viscosity of water; Pipe roughness	Min. pipe diameter; Max. the filling ratio of pipes; Min. wall shear stress; Min. and max. velocity; Min. and max. slope	The first modules optimising the properties of the pipes and the location of pumping stations. The second submodule works on the most optimum route of the flow.
Li et al., 2015 [5]	✓	x	x	✓	✓	x	x	✓	✓	x	Non-dominated Sorting Particle Swarm Optimizer (NSPSO)	SWMM	Location; No. of installed tanks	Hydraulic conditions; Max. area of each tank; Min. total volume of ST; Total no. of inundation-prone and risky flooding nodes.	Introduced to a lot of constraints related to local design criteria.

Source	Problem			Objective(s)				Objective Function(s)			Operating Algorithm	Hydraulic Model Simulation	Decision Variables	Constrains	Notes
	Flooding	CSO	Design	Location	Size/ Area	Type	Others	Cost	Quantity	Performance					
Cunha et al., 2016 [13]	✓	x	x	✓	✓	x	x	x	✓	x	Simulated Annealing (SA) algorithm	SWMM	Flow in and out; Local flooding volume at each node; Flow at outfall; Volume of ST; Diameter of hydraulic control	Hydraulics; Flood and capacity of the ST;	A lot of constraints and considerations of weighting need to be tested. No cost is explicitly mentioned.
Baek et al., 2015 [20]	x	✓	x	✓	✓	x	x	x	✓	x	Diversity-guided, Cyclic-networking PSO	XP-SWMM	Location of ST; No. of installed ST; Volume of installed ST	Physical weir structure on the CSO; Outfall flow to the intercepting pipe	Pre-selection of tank possible location based on ground elevation and network characteristics. The network is simplified.
Alves et al., 2016 [22]	x	✓	x	✓	✓	✓	x	✓	✓	x	NSGA-II	SWMM	Areas covered by the different G-B measures measures; Areas covered by ST	-	Using parallel computing through NSGAxP to reduce computation time
Bakhshipour et al., 2019 [16]	x	x	✓	✓	x	✓	x	✓	x	x	Hanging gardens algorithm and GA	SWMM	Degree of Centralisation; Layout; Hydraulic measures; G-B measures measures	Min cover depth; Max. excavation depth; Min.and Max. slope; Hydraulic constraints;	The optimisation process was done twice. First for decentralisation of the Grey measures and the second one was for the combination of G-G infrastructure.
Barreto et al., 2010 [18]	✓	x	x	x	✓	x	x	✓	x	x	NSGA-II and ε-MOEA	MOUSE	Diameter of pipe	-	Although NSGA-II performs better with a smaller population, it can maintain the diversity of solutions and the computational time is slightly better than ε-MOEA
Bennett and Mays, 1985 [23]	✓	x	x	✓	✓	x	x	✓	x	x	DP Algorithm	-	Detention basin volume; Overflow weir length and height; No. and diameter of outlet pipes; Downstream channel design	Max. surface water elevation; Peak discharge;	-

Source	Problem			Objective(s)				Objective Function(s)			Operating Algorithm	Hydraulic Model Simulation	Decision Variables	Constrains	Notes
	Flooding	**CSO**	**Design**	**Location**	**Size/ Area**	**Type**	**Others**	**Cost**	**Quantity**	**Performance**					
Cimorelli et al., 2016 [24]	✓	x	x	✓	✓	x	x	✓	x	x	GA	Hydrologic-Hydraulic Semi-Distributed Model (HHSDM-2)	Location of ST; Diameter of the parallel pipes; No. of parallel pipes; Length of ST's core	Filling ratio; Max. velocity; Net flow depth; Max. no ST that can be applied	The detention tank consists of *n* parallel augmented pipes to result in extra capacity rather than the common rectangular chamber
Delelegn et al., 2011 [2]	✓	x	x	x	✓	x	x	✓	x	x	NSGA-II	SWMM and BreZo	Size of 4 detention basins	-	Coupling 1D2D to assess the flood damage (because of surcharged sewers), which is implemented as a mass exchange at point sources
Duan et al., 2016 [4]	✓	x	x	✓	✓	x	x	✓	✓	x	NSPSO	SWMM	Location; No. of installed tanks	Hydraulic conditions; Max. area of each tank; Min. total volume of STs; Total no. of inundation-prone and risky flooding nodes.	Exploring factors with uncertainties (*e.g.* rainfall intensity, pipe size, roughness, etc.) before going into the optimisation problem. Uncertainty analysis can give more things for stakeholders to consider.
Duque et al., 2020 [25]	x	x	✓	✓	x	x	Routing	✓	x	x	DP	-	Flow rate; Flow direction; Pipe size; Invert level	Layout constraints; Hydraulic constraints	-
Giacomoni et al., 2017 [7]	x	x	✓	✓	x	x	x	✓	x	Hydraulic metrics alteration	NSGA-II	SWMM	number of LID to be installed in each sub-catchment	-	The MOO was done 3 times each with 2 different objective functions. Might not be suitable for large and more complex study area.
Iglesias-Rey et al., 2017 [14]	✓	x	x	✓	✓	x	x	✓	x	x	Pseudo-genetic algorithm (PGA)	SWMM	The replacement of existing pipes; Location of ST; Size of ST; the initial state of the existing pumping units; The start and stop levels of each pump	-	It includes the pumping aspect in the optimisation and the damage cost from flooding also takes into account the water level for different areas, however, it might be too complex from a large network.

Source	Problem			Objective(s)				Objective Function(s)			Operating Algorithm	Hydraulic Model Simulation	Decision Variables	Constrains	Notes
	Flooding	**CSO**	**Design**	**Location**	**Size/ Area**	**Type**	**Others**	**Cost**	**Quantity**	**Performance**					
Bayas-Jiménez et al., 2019 [3]	✓	x	x	✓	✓	x	Hydraulic control	✓	x	x	NSGA-II	SWMM	The diameter of pipes; Cross-section area of ST; Hydraulic control	-	This paper shows that the addition of Hydraulic Control at ST can significantly reduce the total cost needed to implement the measures.
Li, 2020 [26]	✓	x	x	x	x	x	Real-time control	x	x	Deviation of different rainfall scenarios	GA	SWMM_ FLC	Water level; Flow; Status of hydraulic controls	-	Rather than rehabilitating the sewer network, this paper wants to implement an effective RTC to control urban flooding
Lin et al., 2020 [27]	✓	x	x	x	✓	x	x	✓	✓	The standard deviation of relative peak water depths in pipes	Borg	SWMM	Size of pipes; Slope of pipes	No flooding; Peak water depth; Velocity at peak flows; Min. slope; Practicality of pipe; Available diameter; Min. cover depth	This paper aims to lessen the burden of computation for MOEA using an engineering-based design method (EBDM) – where the initial solutions should already be close enough to the final solutions
Oxley and Mays, 2014 [28]	✓	x	x	✓	✓	x	x	✓	x	x	SA	HEC-Hydraulic Modelling System	The orifice sizes and centerline elevations; The weir length and elevation; The reservoir surface area;	Max. water surface elevations; Max. allowable flow at specified locations	The constraints are based on the difference of pre-development and post-development flow and water level; Usage of MS Excel to store data for each optimisation result – not quite practical.
Park et al., 2012 [8]	✓	x	x	x	✓	x	Outlet structures	✓	x	x	GA	-	Pond capacity; Outlet diameters; No. of pipe for the outlet	Max. water surface elevations; Max. allowable flow at specified locations	The solution is not applicable for a dense urban area. Single-objective function with only cost and the performance control as constraints.
Saldarriaga, et al., 2020 [29]	✓	x	x	✓	✓	x	x	✓	x	x	SA and PGA	SWMM	Storage volume; No. of ST; Diameter of ST outlet orifice	Flooding limit; Max. no of ST; Min. and Max. volume of ST; Min. and Max. diameter for orifice	This paper first addresses the suitable extreme rainfall scenarios due to climate change to be applied as a design storm

Source	Problem			Objective(s)				Objective Function(s)			Operating Algorithm	Hydraulic Model Simulation	Decision Variables	Constrains	Notes
	Flooding	CSO	Design	Location	Size/ Area	Type	Others	Cost	Quantity	Performance					
Tao et al., 2014 [30]	x	x	✓	x	x	x	x	✓	✓	x	NSGA-II	SWMM	ST size; No. of ST; Peak flow	No. of flooding nodes	-
Ngamalieu-Nengoue et al., 2019 [9]	✓	x	x	✓	✓	x	x	✓	x	x	PGA and NSGA-II	SWMM	ST cross-section area; Selected nodes' area; Pipe diameter	-	Reduction of DV with 2 scenarios (10% best solution and 5% best solution). Can be applied with any MOO optimisation.
Vojinovic et al., 2014 [31]	x	x	✓	x	✓	x	x	✓	x	X	NSGA-II	SWMM; Non-inertia 2D model	Pipe diameter	-	Uncertainty scenarios are developed through unknown parameters sampling.
Wang et al., 2017 [32]	✓	x	x	✓	✓	x	x	✓	x	Flood and TSS reduction efficiency	Scatter search	SWMM	Location of ST; No. of installed ST	-	Usage of an uncommon algorithm. Introduced the quality objective (TSS reduction).
Xu et al., 2018 [33]	✓	x	x	x	✓	x	Pumping capacity	✓	x	x	GA	HEC-RAS	Storage and pumping capacity at each design stage	Max Investment; Min and Max storage volume; Min and Max pumping capacity	The term staged here means that the implementation will be done in several periods.
Yazdi, J., 2018 [34]	x	x	✓	x	✓	x	Weir properties	✓	x	Resiliency index	Non-dominated Sorting Differential Evolution (NSDE)	HEC-HMS and SWMM	Side weir properties; the Unit cost of culvert/ bridge; Depth of detention ponds and diameter of axillary channels	Properties of axillary culvert/ bridges; Hydraulic constraints	Emphasised the resiliency of UDS from unexpected blockage incidents.
Zhang et al., 2013 [17]	x	x	✓	✓	✓	✓	x	✓	✓	x	ε-NSGA II	SWMM	Size of each LID implementation (as a sizing ratio)	Max. implementation area; Possible location for implementation; Peak flow rate	The small area size and possibly has a small search space due to pre-selection of the location of LID implementation based on the real condition

Appendix B – Case study information

Site characterisation

In general, Riethoven is located in a relatively flat area ranging between 20 – 30 m ASL.

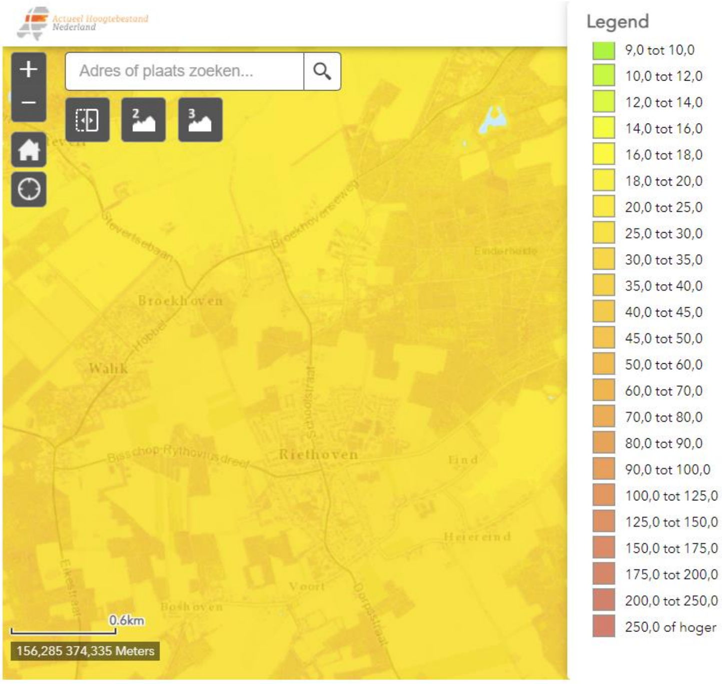


Figure B. 1 Elevation map of Riethoven

(Source: ahn.nl)

Located in the southern part of the Netherlands, the soil in Riethoven is mostly loamy sand, consisting of 70 - 86% sand, 0 - 30% silt and 0 - 15% clay based on the USDA textural classes of soils [55].

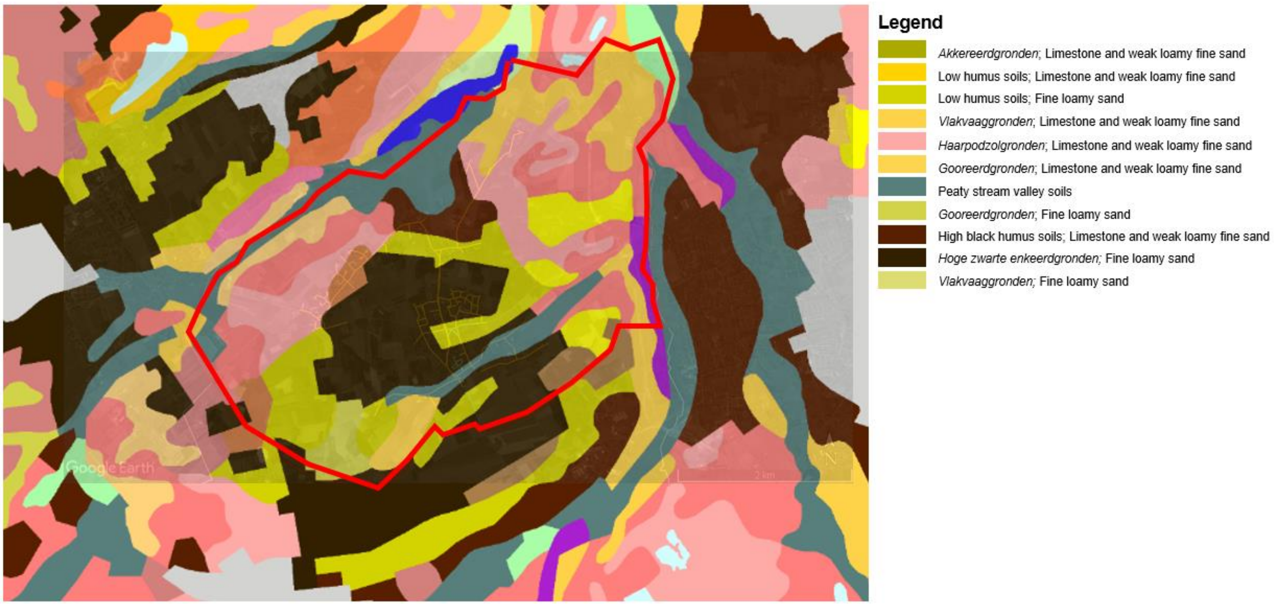


Figure B. 2 Soil map of Riethoven overlaid by drainage network map from Google Earth

(Source: Alterra)

Land use

Table B. 1 lists all the notable infrastructures in Riethoven and their location based on the sub-catchments. Some sub-catchments share a part of infrastructures; for example, the water flowing from the graveyard area is expected to be divided into two sub-catchments.

Table B. 1 Notable infrastructures per Sub-catchment

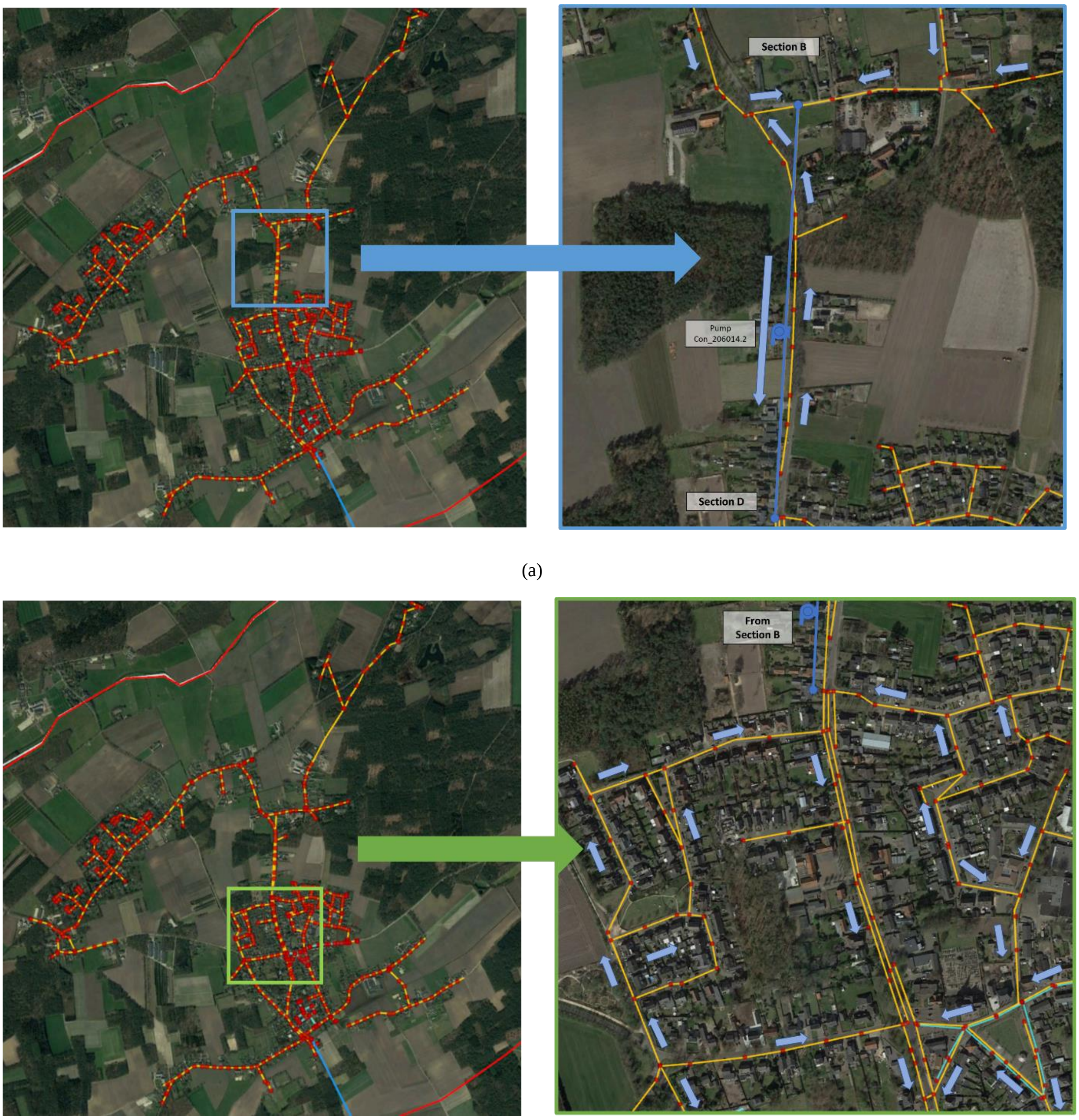
No	Subcatchment_ID	Notable_Infrastructure(s)	Details
1	Sub_205138	Sports ground	
		Wireless mast tower	
2	Sub_205024	Chapel	
3	Sub_204026	Camping site	
4	Sub_205006	Chapel	
5	Sub_205086	Church with tower	
		Graveyard	
6	Sub_205088	Graveyard	
7	Sub_205100	Post office	
8	Sub_295205	Sports hall	
9	Sub_205183	Sports ground	
10	Sub_205196	Sports ground	
11	Sub_205123	Commercial area	Battery supplier
12	Sub_205207	Commercial area	Metal construction company
			Textile printing company
13	Sub_205206	Commercial area	Metal construction company
14	Sub_205203	Commercial area	Farm equipment supplier
15	Sub_205204	Commercial area	Metal processing company
16	Sub_205202	Commercial area	Farm equipment supplier
17	Sub_295205	Commercial area	House remodeler
18	Sub_215098	Commercial area	House remodeler
20	Sub_205122	Commercial area	Industrial equipment supplier
22	Sub_290008	School	
23	Sub_206007A	Chapel	
24	Sub_206050	Gas station	
25	Sub_207011	Wireless mast tower	

Urban drainage system

The urban drainage systems (UDS) in Riethoven consists of both combined and separate sewer system. There are two particular locations in which the separate sewer systems are located: the city centre (near CSO 1) and between CSO 2 and the pumping station. While the outfall of Stormswer 1 (Figure B. 3 top) is directed towards the surface water near CSO 1, the outfall of Stormsewer 2 is a dedicated infiltration basin near the area (Figure B. 3 bottom).

Figure B. 3 Stormwater sewer locations

(**Top:** Stormwater sewer near CSO 1 discharging into the Keersop River; **Bottom:** Stormwater sewer discharging into the infiltration basin.; Source: Google Earth)



(a)

(b)

Figure B. 4 Details on the centre part of the drainage network

(Blue arrow indicating the water flow pathway in the drainage system)

Appendix C – Cost calculation of the selected grey measures

Pipe substitution

The cost of pipe replacement is the combination of capital and maintenance cost. The capital cost (C_c) is derived based on the basic price for replacing 300 and 700 mm pipe as described by RIONED [67]; see Equation (C-1) and (C-2). When the pipe diameter is below 700 mm, the material type influence on the cost index is relatively small. However, this is not the case for a pipe with a larger diameter > 700 mm. Therefore, the basic price to replace 300 mm and 700 mm concrete pipe is 400 €/ m and 800 €/ m, respectively. This basic price already includes material cost, groundwork (incl. the addition of new soil), labour cost, hardening of the road/ cover, various activities (*e.g.* traffic measures, access to buildings), and tax.

For diameter < 700 mm: $$C_c\ (€/m) = 400\ (basic\ price\ of\ 300\ mm)\ x\ 1.25^{\frac{D-300}{135}} \qquad \textbf{(C-1)}$$

For diameter > 700 mm: $$C_c\ (€/m) = 800\ (basic\ price\ of\ 700\ mm)\ x\ 1.17^{\frac{D-700}{135}} \qquad \textbf{(C-2)}$$

The annual recurring cost (C_M) for the pipelines includes the high-pressure cleaning, which combines the high-pressure and suction of the pipeline. This maintenance cost depends on the pipe diameter and the daily deposition production, approximately €1,500 per day [83]. However, the cost can be translated into € / m value with the Equation developed by RIONED below.

$$C_M = 6.15\ x\ 10^{-4}\ x\ 1500\ (basic\ price) x\ 2.718^{D\ (mm)\ x\ 0.0017} \qquad \textbf{(C-3)}$$

Furthermore, the PV for each pipe diameter can be calculated by adding the annual recurring cost using the PV equation (Equation (3-2)) to the capital cost.

Pumps replacement

The price capital cost calculated consists of the price for mechanical, electrical, structural and miscellaneous. Based on RIONED [68] cost breakdown for wet pump set-up, the replacement cost will be up to 20% higher than the construction cost. This cost considers removing the old pump and material and restoring the pumping station condition.

Regarding the mechanical, electrical, and structural costs, RIONED developed a formula to estimate these costs based on the basic price for constructing a pumping station with a capacity of 100 m^3/h. The basic price also considers the need for a backup or standby pump for each pumping station, pipeworks, electrical equipment, and data transmission system. Meanwhile, even though the wet set-up pumping station does not need a separate structure like the dry set-up, the pumping chamber needs to be adjusted for the pump operation and maintenance. These basic prices are € 25,000, € 11,000, € 19,000, and € 55,000 for mechanical, electrical, misc., and structural respectively. The basic price will be 20% higher for the mechanical, electrical, and misc for replacement. However, the basic price will be 20% of the basic price for the structural cost. The adjusted basic price will then be used to calculate the estimated cost for other pump capacities. The equations formulated by RIONED are:

$$C_{mech-elec} = 0.123\ x\ (basic\ price\ mech. + elec. + misc.)\ x\ capacity\ \left(\frac{m^3}{h}\right)^{0.46} \tag{C-4}$$

Capacity 10 – 50 m^3/h: $$C_{struc} = 0.0145\ x\ basic\ price\ structural\ x\ capacity\ \left(\frac{m^3}{h}\right) \tag{C-5}$$

Capacity 50-200 m^3/h: $$C_{struc} = 0.2\ x\ basic\ price\ structural\ x\ capacity\ \left(\frac{m^3}{h}\right)^{0.35} \tag{C-6}$$

Thus,

$$Cc = C_{mech-elec} + C_{structural} \tag{C-7}$$

The annual recurring cost consists of the required inspection and maintenance yearly with a flat rate for each pumping station of € 1170. Thus, the present value (PV) cost with a planning horizon of 30 years can be calculated using the PV analysis equation (Equation (3-2))

Increasing weir length

It is assumed that to lengthen the weirs, new CSO chambers will be constructed, replacing the older ones. These chambers already include the rectangular overflow weirs with the new length. RIONED [69] approximate another cost indicator to calculate the cost needed to replace CSO on the basic price of a CSO chamber with the size of 800 x 800 x 1400 mm. The basic price is € 2,700 per CSO chamber. In reality, the CSO weir length determines the size of the CSO chamber; meanwhile, the price calculation depends on the largest pipe diameter connected to the CSO chamber. In this thesis, each CSO chamber is only connected to one pipe. Thus, to ensure that the price calculated considers the assigned weir length, the incoming pipe diameter will be changed into the weir's length without making the changes in the model (see Equation (C-8)).

For diameter > 1,250 mm:

$$C_{CSO}(€)\ = 0.00012\ x\ Basic\ price_{800x800x1400}\ x\ weir\ length\ (mm)^{1.53} \tag{C-8}$$

Not only for the replacement, but the cost also calculated needs to approximate the maintenance cost of the CSO chambers. The inspection cost per chamber is approximated at € 23 per chamber. Meanwhile, the maintenance cost of the chambers, including cleaning of the weirs, depends highly on the pollution and is very site-specific. Thus, no cost indicator can be derived. However, in this thesis, it is assumed that the cleaning cost will be the same as the cleaning cost for a pumping station with a dry setup, which is € 270 per chamber under the assumption that cleaning will be performed twice a year under a normal situation, along with the inspection.

Appendix D – Design parameters of the selected Green-Blue measures

Infiltration Trench

Infiltration trench (IT) generally consists of two layers, the surface layer and the storage layer. The implemented IT will be IT overlaid by a topsoil and grass cover and equipped with an underdrain system. The underdrain is a safety measure because, during the wet season, the groundwater can reach 80 cm below ground level. Based on the several literature reviews [49, 54, 84] of the design reference of IT, the following parameters were chosen as the IT design that will be used in the optimisation.

Table D-1 Design parameters of IT

System component	Parameter	Value
Surface layer	Berm height (mm)	300
	Vegetatio volume fraction	0.2
	Manning surface roughness	0.02
	Surface slope	1%
Storage layer	Thickness (mm)	1000
	Void ratio	0.3
	Seepage rate (mm/hr)	10
	Clogging factor	0
Drain	Drain coefficient	0.7
	Drain exponent	0.5
	Offset (mm)	160
Other	Width (m)	2
	Impv. area coverage	45%
	Impv. area coverage when combined with PP	30%

Pervious/ Permeable Pavement

Pervious pavement (PP) consists of four important layers, the surface, the pavement, the soil, and the storage. In relation to discharge of stored water, PP is divided into three types, Type A – Total Infiltration, Type B – Partial Infiltration, and Type C – No Infiltration. Meanwhile, based on the material used as the surface layer, PP can use either a porous pavement (*e.g.* porous concrete or asphalt) or permeable pavements (*e.g.* concrete block paving). For this thesis, the selected PP is a Type-B PP with permeable pavement. The design parameters of the pervious pavement (PP) that will be implemented also refer to some literature sources [49, 85, 54, 86].

Table D-2 Design parameters of PP

System component	Parameter	Value
Surface layer	Berm height (mm)	1.5
	Vegetation volume fraction	0
	Manning surface roughness	0.015
	Surface slope	1%
Pavement layer	Thickness (mm)	150
	Void ratio	0.4
	Impervious surface fraction	0
	Permeability (mm/hr)	150
Soil layer	Thickness (mm)	150

System component	Parameter	Value
	Void ratio	0.5
	Suction head (mm)	45
Storage layer	Thickness (mm)	275
	Void ratio	0.4
	Seepage rate (mm/hr)	10
Drain	Drain coefficient	0.7
	Drain exponent	0.5
	Offset (mm)	250
Other	Coefficient of permeability (m/s)	$5 \times 10^{-6} – 10^{-4}$
	CBR	10 - 40 %
	Axle loads (kg)	2600
	Impv. area coverage	75%
	Impv. area coverage when combined with IT	55%

Rain Barrel

Rain barrels (RB) will release the stored water through either a drain, surface overflow, or throttle overflow when the storage is full. Rain barrels are manufactured in many sizes and can be found quite easily in stores. The design parameters of RB used in this thesis are based on a manufactured RB specification from one manufacturer (regenton.nu) and listed below.

Table D-3 Design parameters of RB

System component	Parameter	Value
Storage layer	Barrel height (mm)	960
Drain	Drain coefficient	58.5
	Drain exponent	0.5
	Offset (mm)	6
	Drain delay (hr)	6
Other	Volume per barrel (m3)	0.227
	Area per barrel (m2)	0.24
	Diameter (m)	0.6
	Spigot drain opening (cm)	2
	Impv. area coverage	10%

Appendix E - Nodes Properties

No.	Node ID	Elevation (m NAP)	Max Depth (m)
1	Jun_202001	22.83	1.45
2	Jun_202002	21.71	2.17
3	Jun_202003	22.82	0.76
4	Jun_202004	21.71	2.12
5	Jun_202005	22.63	1.97
6	Jun_202006	22.4	1.98
7	Jun_202007	22.3	2.22
8	Jun_202008	22.28	1.82
9	Jun_202009	20.12	4.09
10	Jun_202011	20.91	3.9
11	Jun_202012	20.84	3.33
12	Jun_202013	20.83	3.28
13	Jun_202014	20.95	3.46
14	Jun_202015	21.02	3.34
15	Jun_202016	20.95	3.25
16	Jun_202017	21.01	3.07
17	Jun_202018	21.09	2.69
18	Jun_202019	21.22	2.56
19	Jun_202020	21.54	2.27
20	Jun_202021	21.39	1.75
21	Jun_202022	21.47	1.84
22	Jun_202023	21.46	2.13
23	Jun_202024	21.47	2.05
24	Jun_202025	21.54	1.98
25	Jun_202026	21.52	2.09
26	Jun_204001	24.31	1.2
27	Jun_204002	24.32	1.33
28	Jun_204003	24.29	1.35
29	Jun_204004	24.21	1.49
30	Jun_204005	24.11	1.67
31	Jun_204006	24.03	1.91
32	Jun_204007	23.91	2.1
33	Jun_204008	22.9	3.04
34	Jun_204009	21.36	4.61
35	Jun_204010	22.96	2.85
36	Jun_204011	23.2	2.51
37	Jun_204012	23.36	2.31
38	Jun_204013	23.53	2.36
39	Jun_204014	23.58	2.75
40	Jun_204015	24.35	2.08
41	Jun_204016	24.5	2
42	Jun_204017	24.44	2.06
43	Jun_204018	24.47	1.98
44	Jun_204019	24.87	1.59
45	Jun_204020	24.98	1.46
46	Jun_204021	25.21	1.34
47	Jun_204022	25.16	1.42
48	Jun_204024	23.73	2.41
49	Jun_204025	24	1.9
50	Jun_204026	24.02	1.74
51	Jun_204027	23.97	1.73
52	Jun_204028	24	1.69
53	Jun_204029	24.09	1.52
54	Jun_204030	24.29	1.29
55	Jun_205001	24.7	1.42
56	Jun_205002	24.66	1.53
57	Jun_205003	24.6	1.63
58	Jun_205004	24.61	1.63
59	Jun_205005	24.59	1.76
60	Jun_205006	24.61	1.79
61	Jun_205007	24.5	1.87
62	Jun_205008	24.49	1.86
63	Jun_205009	24.48	1.87
64	Jun_205010	24.45	1.94
65	Jun_205011	24.39	2.1
66	Jun_205012	24.4	2.47
67	Jun_205013	24.54	2.3
68	Jun_205014	24.26	2.66
69	Jun_205015	24.18	2.82
70	Jun_205016	24.17	2.86
71	Jun_205017	24.15	3
72	Jun_205018	23.97	2.7
73	Jun_205019	22.82	4.08
74	Jun_205020	25.75	1.18
75	Jun_205021	25.82	1.48
76	Jun_205022	24.43	3.12
77	Jun_205023	24.5	3
78	Jun_205024	24.52	3.23
79	Jun_205025	25.75	2.1
80	Jun_205026	25.77	2.4
81	Jun_205027	25.9	2.27
82	Jun_205028	26.15	1.97
83	Jun_205029	26.18	1.87
84	Jun_205030	26.84	1.19
85	Jun_205031	26.76	1.36
86	Jun_205032	26.5	1.46
87	Jun_205033	26.75	1.25
88	Jun_205033A	26.76	1.24
89	Jun_205034	26.75	1.24
90	Jun_205035	26.53	1.57
91	Jun_205036	26.28	1.82
92	Jun_205037	26.28	1.97
93	Jun_205038	26.14	2.18
94	Jun_205039	25	3.54
95	Jun_205041	24.68	3.35
96	Jun_205042	24.72	3.6
97	Jun_205042X	24.74	3.50756
98	Jun_205043	24.77	3.31
99	Jun_205044	24.85	3.45
100	Jun_205046	24.94	3.57
101	Jun_205048	24.43	3.04
102	Jun_205061	26.6	1.7
103	Jun_205062	26.45	1.92
104	Jun_205063	26.38	1.97
105	Jun_205066	27.31	1.22
106	Jun_205067	25.12	1.67
107	Jun_205068	25.13	1.67
108	Jun_205069	25.17	1.68
109	Jun_205070	25.15	1.72
110	Jun_205071	26.22	0.95
111	Jun_205072	25.76	1.2
112	Jun_205073	25.29	1.69
113	Jun_205074	25.37	1.73
114	Jun_205075	25.47	1.66

No.	Node ID	Elevation (m NAP)	Max Depth (m)
115	Jun_205088	26.77	1.7
116	Jun_205098	26.61	1.19
117	Jun_205099	25.5	2.07
118	Jun_205100	25.13	3.32
119	Jun_205101	25.14	3.15
120	Jun_205102	25.16	3.11
121	Jun_205103	25.23	2.78
122	Jun_205104	25.25	2.51
123	Jun_205105	25.33	2.47
124	Jun_205105X	25.41	2.34
125	Jun_205106	25.46	2.09
126	Jun_205107	25.54	2.06
127	Jun_205108	25.69	2.05
128	Jun_205109	25.6	2.11
129	Jun_205110	25.57	2.15
130	Jun_205111	25.75	2.11
131	Jun_205112	26.04	1.95
132	Jun_205113	26.24	2
133	Jun_205114	26.52	1.73
134	Jun_205115	26.79	1.26
135	Jun_205116	26.34	1.66
136	Jun_205117	26.26	1.83
137	Jun_205118	26.37	1.79
138	Jun_205118A	26.37	1.79
139	Jun_205119	26.36	1.77
140	Jun_205120	26.01	2.1
141	Jun_205121	27.04	1.2
142	Jun_205122	25.98	1.96
143	Jun_205123	26.06	1.93
144	Jun_205124	25.86	1.88
145	Jun_205125	25.72	1.94
146	Jun_205126	25.72	2.1
147	Jun_205127	24.57	2.36
148	Jun_205128	24.67	2.17
149	Jun_205129	24.78	2.07
150	Jun_205130	24.7	2.25
151	Jun_205131	24.84	2.14
152	Jun_205132	24.94	2.12
153	Jun_205133	25	2.19
154	Jun_205134	25.09	2.22
155	Jun_205135	25.9	1.36
156	Jun_205136	26.27	1.47
157	Jun_205137	26.27	1.5
158	Jun_205138	26.36	1.36
159	Jun_205139	25.55	1.79
160	Jun_205140	25.68	1.62
161	Jun_205141	25.77	1.55
162	Jun_205142	25.82	1.49
163	Jun_205143	25.89	1.52
164	Jun_205144	25.87	1.65
165	Jun_205145	25.91	1.74
166	Jun_205146	26.05	1.73
167	Jun_205147	26.16	1.7
168	Jun_205148	26.76	1.5
169	Jun_205149	26.77	1.34
170	Jun_205150	26.65	1.61
171	Jun_205151	26.85	1.3
172	Jun_205153	26.76	1.5
173	Jun_205154	26.75	1.38
174	Jun_205155	26.77	1.33
175	Jun_205156	27.1	1.08
176	Jun_205157	24.19	2.85
177	Jun_205158	24.61	2.11
178	Jun_205159	25.35	1.45
179	Jun_205160	25.59	1.73
180	Jun_205161	25.59	1.43
181	Jun_205162	25.77	2.05
182	Jun_205163	25.82	1.92
183	Jun_205164	25.84	1.99
184	Jun_205165	25.87	1.95
185	Jun_205166	26.12	1.62
186	Jun_205167	26.33	1.54
187	Jun_205168	25.95	1.85
188	Jun_205169	25.91	1.91
189	Jun_205170	26	1.8
190	Jun_205171	26.09	1.69
191	Jun_205172	26	1.75
192	Jun_205173	25.89	1.98
193	Jun_205174	25.87	2
194	Jun_205175	25.77	2.05
195	Jun_205176	25.75	2.12
196	Jun_205177	25.85	2.12
197	Jun_205178	26.15	1.87
198	Jun_205179	25.93	2.13
199	Jun_205180	25.95	2.26
200	Jun_205181	25.89	2.31
201	Jun_205182	26.73	1.69
202	Jun_205183	26.79	1.5
203	Jun_205184	25.97	1.74
204	Jun_205185	26.38	1.62
205	Jun_205186	26.44	1.67
206	Jun_205187	26.27	1.85
207	Jun_205188	26.52	1.64
208	Jun_205189	26.93	1.24
209	Jun_205190	27.04	1.26
210	Jun_205191	26.5	1.72
211	Jun_205192	26.5	1.78
212	Jun_205193	26.25	2.12
213	Jun_205194	26.38	1.9
214	Jun_205195	26.15	2.22
215	Jun_205196	25.93	2.44
216	Jun_205197	25.97	2.6
217	Jun_205198	26.47	1.97
218	Jun_205199	26.04	2.45
219	Jun_205200	26.17	2.18
220	Jun_205201	26.19	2.32
221	Jun_205202	26.73	1.64
222	Jun_205203	26.86	1.68
223	Jun_205204	26.79	1.82
224	Jun_205205	26.4	1.79
225	Jun_205206	26.3	2.04
226	Jun_205207	26.18	2.09
227	Jun_205209	26.24	2.08
228	Jun_205210	26.21	2.03
229	Jun_205216	27.13	0.75
230	Jun_205217	27.21	1.08
231	Jun_205218	27.34	1.22
232	Jun_205219	27.72	1.04
233	Jun_205220	25.49	2.2
234	Jun_205221	25.66	2.05

No.	Node ID	Elevation (m NAP)	Max Depth (m)
235	Jun_205222	25.83	2.05
236	Jun_205223	25.76	2.05
237	Jun_205224	26.05	2.06
238	Jun_205225	26.15	2.02
239	Jun_205226	26.23	1.81
240	Jun_205227	26.28	1.55
241	Jun_205228	25.99	1.84
242	Jun_205229	26.01	1.85
243	Jun_205230	26.09	1.82
244	Jun_205231E	24.3	2.16
245	Jun_205231EA	24.7	1.76
246	Jun_205300	24.235995	2.764005
247	Jun_205300F	24.236	2.764
248	Jun_205300INF	25.7	1.3
249	Jun_205301	24.87	2.13
250	Jun_205301INF	25.7	1.3
251	Jun_205302	25.1	1.9
252	Jun_205302INF	25.7	1.3
253	Jun_205303	25.28	1.72
254	Jun_205303INF	25.7	1.3
255	Jun_205304	24.97	2.03
256	Jun_205305	25.19	1.81
257	Jun_205305INF	25.7	1.3
258	Jun_205306	25.33	1.67
259	Jun_205306INF	25.7	1.3
260	Jun_205307	25.22	1.78
261	Jun_205307INF	25.7	1.3
262	Jun_205308	25.3	1.7
263	Jun_205308INF	25.7	1.3
264	Jun_205309	25.36	1.64
265	Jun_205309INF	25.6	1.4
266	Jun_205310	25.54	1.46
267	Jun_205310INF	25.6	1.4
268	Jun_205312INF	25.6	1
269	Jun_206001	25.08	2.22
270	Jun_206002	24.81	2.14
271	Jun_206003	24.68	2.1
272	Jun_206004	24.43	2.21
273	Jun_206005	24.29	2.34
274	Jun_206006	24.21	2.11
275	Jun_206007	24.12	1.79
276	Jun_206007A	24.15	1.624805
277	Jun_206008	24.11	1.63
278	Jun_206009	23.99	1.68
279	Jun_206010	23.87	1.59
280	Jun_206011	23.85	1.44
281	Jun_206012	22.79	2.53
282	Jun_206013	22.74	2.58
283	Jun_206014	22.36	2.94
284	Jun_206015	22.52	2.58
285	Jun_206016	22.51	2.61
286	Jun_206017	22.61	2.57
287	Jun_206018	22.71	2.81
288	Jun_206019	22.74	2.58
289	Jun_206020	22.77	2.63
290	Jun_206021	22.89	2.31
291	Jun_206022	22.93	2.09
292	Jun_206023	22.91	1.82
293	Jun_206024	22.84	1.82
294	Jun_206025	22.94	1.78
295	Jun_206026	23.17	1.54
296	Jun_206027	23.22	1.29
297	Jun_206028	22.82	2.73
298	Jun_206029	22.76	2.77
299	Jun_206030	22.88	2.09
300	Jun_206031	22.99	1.95
301	Jun_206032	23.22	1.6
302	Jun_206033	23.21	1.58
303	Jun_206034	23.04	1.73
304	Jun_206035E	22.6	1.96
305	Jun_206035EA	23.3	1.26
306	Jun_206035I	23.07	1.88
307	Jun_206036	23.35	1.44
308	Jun_206037	23.43	1.47
309	Jun_206038	23.45	1.48
310	Jun_206039	23.45	1.67
311	Jun_206040	23.8	1.39
312	Jun_206041	23.65	1.5
313	Jun_206042	23.55	1.61
314	Jun_206043	23.54	1.73
315	Jun_206044	23.58	1.38
316	Jun_206045	23.62	1.37
317	Jun_206046	23.78	1.45
318	Jun_206047	23.82	1.33
319	Jun_206048	23.9	2.26
320	Jun_206049	24	1.44
321	Jun_206050	24.02	1.73
322	Jun_206051	24.14	2.14
323	Jun_206052	24.9	1.33
324	Jun_206053	25.25	1.22
325	Jun_206054	25.51	1.1
326	Jun_206055	24.23	1.9
327	Jun_206056	24.48	1.92
328	Jun_206057	24.57	1.91
329	Jun_206058	24.48	1.83
330	Jun_206059	24.7	1.74
331	Jun_206060	24.77	1.82
332	Jun_206061	25.81	1.13
333	Jun_206062	25.53	1.32
334	Jun_206063	26.21	0.97
335	Jun_206064	26.39	0.83
336	Jun_206065	26.17	1.32
337	Jun_206066	24.72	1.86
338	Jun_206067	24.88	1.64
339	Jun_206068	24.97	1.54
340	Jun_206069	25.04	1.42
341	Jun_206070	24.95	1.45
342	Jun_206071	25.07	1.35
343	Jun_206072	24.86	1.75
344	Jun_206073	25.37	1.23
345	Jun_206074	25.51	1.11
346	Jun_206075	25.6	1.42
347	Jun_206076	25.68	1.58
348	Jun_206077	25.79	1.54
349	Jun_206078	25.65	1.16
350	Jun_206079	25.8	1.3
351	Jun_206080	24.58	1.8
352	Jun_206081	24.72	1.58
353	Jun_206082	24.77	1.63
354	Jun_206083	24.96	1.62

No.	Node ID	Elevation (m NAP)	Max Depth (m)
355	Jun_206084	25.93	1.09
356	Jun_206084A	26.01	1.037666
357	Jun_206085	25.76	1.29
358	Jun_206086	25.53	1.56
359	Jun_206087	25.94	1.21
360	Jun_206088	26.19	1.08
361	Jun_206089	25.44	1.52
362	Jun_206090	25.11	1.86
363	Jun_206091	26.06	1.31
364	Jun_206092	25.86	1.72
365	Jun_206093	25.21	2.38
366	Jun_206094	25.28	2.44
367	Jun_206095	26.49	1.09
368	Jun_206096	26.62	1.15
369	Jun_206097	26.79	1.24
370	Jun_206097A	26.88	1.15
371	Jun_206098	25.32	2.07
372	Jun_206099	25.43	1.78
373	Jun_206100	25.7	1.65
374	Jun_206101	25.51	1.23
375	Jun_206102	25.56	1.5
376	Jun_206103	25.54	1.24
377	Jun_206104	25.42	1.79
378	Jun_206105	25.51	1.53
379	Jun_206106	26.12	1.27
380	Jun_206107	26.26	1.25
381	Jun_206108	25.55	1.45
382	Jun_206109	25.59	1.43
383	Jun_206110	25.99	1.17
384	Jun_206111	25.88	1.27
385	Jun_206112	26	1.16
386	Jun_206113	25.33	2.49
387	Jun_206114	25.41	2.81
388	Jun_206115	25.47	2.56
389	Jun_206116	25.5	2.7
390	Jun_206117	25.61	3.1
391	Jun_206118	25.53	3.24
392	Jun_206119	25.87	2.7
393	Jun_206120	25.99	2.35
394	Jun_206121	26.59	1.61
395	Jun_206122	26.74	1.49
396	Jun_206123	26.85	1.28
397	Jun_206124	26.93	1.12
398	Jun_206125	26.06	2.04
399	Jun_206126	26.27	1.74
400	Jun_206127	26.33	1.68
401	Jun_206128	26.41	1.55
402	Jun_206129	26.49	1.58
403	Jun_206130	26.22	2.04
404	Jun_206131	26.37	1.98
405	Jun_206132	26.47	1.68
406	Jun_206133	26.63	1.14
407	Jun_206134	25.79	2.63
408	Jun_206135	26	2.48
409	Jun_206136	26.2	2.33
410	Jun_206137	26.27	2.22
411	Jun_206138	27.25	1.55
412	Jun_206139	27.17	1.82
413	Jun_206140	26.36	2.29
414	Jun_206141	26.61	2
415	Jun_206142	27.41	1.35
416	Jun_206143	27.43	1.22
417	Jun_206144	27.2	1.18
418	Jun_206145	27.48	0.83
419	Jun_206146	23.94	1.51
420	Jun_206147	24.44	1.25
421	Jun_206148	24.47	1.53
422	Jun_206149	24.01	1.47
423	Jun_206150	24.12	1.29
424	Jun_206151	24.23	1.23
425	Jun_206152	24.37	1.17
426	Jun_206153	24.61	0.93
427	Jun_207001	27.78	1.38
428	Jun_207002	27.24	1.98
429	Jun_207003	27.59	1.7
430	Jun_207004	27.76	1.21
431	Jun_207005	26.95	1.87
432	Jun_207006	26.18	2.18
433	Jun_207007	26.33	1.8
434	Jun_207008	26.5	1.45
435	Jun_207009	26.68	1.16
436	Jun_207010	26.87	0.84
437	Jun_207011	25.98	2.2
438	Jun_209003	24.94	3.59
439	Jun_209005	25.05	3.54
440	Jun_209009	26.42	1.57
441	Jun_209009X	26.48	1.51
442	Jun_209009Y	26.54	1.45
443	Jun_209015	26.3	1.55
444	Jun_209016	26.36	1.55
445	Jun_209017	26.26	1.67
446	Jun_209018	26.51	1.38
447	Jun_209019	26.17	1.72
448	Jun_209020	26.12	1.77
449	Jun_209021	26.29	1.61
450	Jun_209023	26.29	1.57
451	Jun_209024	26.17	1.71
452	Jun_209026	23.86	3.61
453	Jun_209026E	24.6	2.36
454	Jun_209026EA	25.7	1.25
455	Jun_215229	26.05	1.85
456	Jun_219003	24.94	3.57
457	Jun_219021	26.34	1.58
458	Jun_290000	25.32	2.44
459	Jun_290004	25.27	2.74
460	Jun_290008	25.25	3.02
461	Jun_290012	25.16	3.13
462	Jun_290016	25.1	3.35
463	Jun_290018	25.5	2.1
464	Jun_295121	27.17	1.21
465	Jun_295205	26.08	2.39
466	Jun_295224	26.31	1.37
467	Jun_296083	24.93	1.55
468	Jun_296131	26.66	1.35
469	Jun_296132	26.63	1.35
470	Jun_296135	26.05	2.5
471	Jun_G01	24.85	3.7
472	Jun_G02	24.87	3.62
473	Jun_G03	24.93	3.38
474	Jun_G04	24.98	2.95

No.	Node ID	Elevation (m NAP)	Max Depth (m)
475	Jun_G05	26.68	1.8
476	Jun_G06	25.3	2.32
477	Jun_G07	25.62	1.65
478	Jun_G08	25.82	1.61
479	Jun_G08a	25.92	1.51
480	Jun_G09	25.05	2.8
481	Jun_G10	25.1	2.58
482	Jun_G10_f	25.1	2.75
483	Jun_G11	25.18	2.17
484	Jun_G12	25.3	2.03
485	Jun_G13	25.4	1.88
486	Jun_G14	25.65	1.73
487	Jun_G15	25.9	1.55
488	Jun_G16	25.96	1.58
489	Jun_G17	25.99	1.81
490	Jun_RCplan1	25	3.49
491	Jun_RCplan10	25	2.68
492	Jun_RCplan11	25	2.85

No.	Node ID	Elevation (m NAP)	Max Depth (m)
493	Jun_RCplan12	25	2.93
494	Jun_RCplan13	25	3.48
495	Jun_RCplan14	25	2.45
496	Jun_RCplan16	25	2.38
497	Jun_RCplan17	25	3.31
498	Jun_RCplan2	25	2.27
499	Jun_RCplan20	25	2.45
500	Jun_RCplan21	25	2.27
501	Jun_RCplan3	25	2.43
502	Jun_RCplan4	25	2.48
503	Jun_RCplan5	25	2.62
504	Jun_RCplan6	25	2.38
505	Jun_RCplan7	25	2.28
506	Jun_RCplan8	25	2.33
507	Jun_RCplan9	25	2.35
508	Jun_TGVARC1	25.2	1.8
509	Jun_205231I	24.7	2.13

Appendix F – Conduits Properties and value ranges of decision variables

No.	Conduit_ID	Length (m)	Current Diameter (m)	Inner Diameter (m)	
				Min	Max
1	Con_202001.1	81.59657	0.151	0.151	1.5
2	Con_202002.1	70.77429	0.151	0.151	1.5
3	Con_202002.2	22.47221	0.151	0.151	1.5
4	Con_202004.1	81.59657	0.188	0.188	1.5
5	Con_202005.1	80.99383	0.188	0.188	1.5
6	Con_202006.1	81.59657	0.188	0.188	1.5
7	Con_202007.1	61.09828	0.188	0.188	1.5
8	Con_202008.1	4.992314	0.188	0.188	1.5
9	Con_202009.1	73.87722	0.188	0.188	1.5
10	Con_202011.1	100.7025	0.188	0.188	1.5
11	Con_202012.1	100.6479	0.188	0.188	1.5
12	Con_202013.1	32.64966	0.188	0.188	1.5
13	Con_202014.1	70.71068	0.188	0.188	1.5
14	Con_202015.1	41.10961	0.188	0.188	1.5
15	Con_202016.1	80.61017	0.188	0.188	1.5
16	Con_202017.1	81.84131	0.188	0.188	1.5
17	Con_202018.1	13	0.188	0.188	1.5
18	Con_202019.1	35.1141	0.188	0.188	1.5
19	Con_202020.1	81.60882	0.188	0.188	1.5
20	Con_202021.1	80.23092	0.188	0.188	1.5
21	Con_202022.1	78.74643	0.188	0.188	1.5
22	Con_202023.1	15.23155	0.188	0.188	1.5
23	Con_202024.1	42.5441	0.151	0.151	1.5
24	Con_202024.2	34.0147	0.188	0.188	1.5
25	Con_204001.1	50.32892	0.188	0.188	1.5
26	Con_204002.1	55.9017	0.188	0.188	1.5
27	Con_204003.1	46.09772	0.300	0.300	1.5
28	Con_204004.1	49.0408	0.300	0.300	1.5
29	Con_204005.1	50.77401	0.300	0.300	1.5
30	Con_204006.1	27.78489	0.300	0.300	1.5
31	Con_204007.1	12.16553	0.300	0.300	1.5
32	Con_204008.1	3.122371	0.300	0.300	1.5
33	Con_204008.2	10.29563	0.300	0.300	1.5
34	Con_204010.1	99.00505	0.188	0.188	1.5
35	Con_204011.1	48.79549	0.188	0.188	1.5
36	Con_204012.1	71.80529	0.188	0.188	1.5
37	Con_204013.1	63.60031	0.188	0.188	1.5
38	Con_204014.1	58.18075	0.300	0.300	1.5
39	Con_204014.2	50.92151	0.300	0.300	1.5
40	Con_204015.1	56.85948	0.300	0.300	1.5
41	Con_204016.1	30.41381	0.300	0.300	1.5
42	Con_204017.1	76.23647	0.300	0.300	1.5
43	Con_204018.1	47.53946	0.300	0.300	1.5
44	Con_204019.1	47.42362	0.300	0.300	1.5
45	Con_204020.1	53.31041	0.300	0.300	1.5
46	Con_204021.1	57.00877	0.300	0.300	1.5
47	Con_204024.1	59.61543	0.300	0.300	1.5
48	Con_204025.1	50.15975	0.300	0.300	1.5
49	Con_204026.1	51.31277	0.300	0.300	1.5
50	Con_204027.1	41.6173	0.300	0.300	1.5
51	Con_204028.1	51.47815	0.300	0.300	1.5
52	Con_204029.1	52.83938	0.300	0.300	1.5
53	Con_205001.1	43.01163	0.300	0.300	1.5
54	Con_205002.1	46.17359	0.300	0.300	1.5
55	Con_205003.1	35.1141	0.300	0.300	1.5
56	Con_205004.1	44.10215	0.300	0.300	1.5
57	Con_205005.1	45.45327	0.300	0.300	1.5
58	Con_205006.1	36.24914	0.300	0.300	1.5
59	Con_205007.1	51.0098	0.300	0.300	1.5
60	Con_205008.1	17.72005	0.300	0.300	1.5
61	Con_205009.1	53.2635	0.300	0.300	1.5
62	Con_205010.1	48.41487	0.300	0.300	1.5
63	Con_205011.1	56.20754	0.300	0.300	1.5
64	Con_205012.1	43.71711	0.600	0.600	1.5
65	Con_205012.2	42.10867	0.400	0.400	1.5
66	Con_205012.3	5.685068	0.700	0.700	1.5
67	Con_205013.1	46.05391	0.600	0.600	1.5
68	Con_205014.1	21.57506	0.600	0.600	1.5

No.	Conduit_ID	Length (m)	Current Diameter (m)	Inner Diameter (m)	
				Min	Max
69	Con_205015.1	46.75866	0.600	0.600	1.5
70	Con_205016.1	29.24978	0.600	0.600	1.5
71	Con_205017.1	31.62278	0.400	0.400	1.5
72	Con_205017.2	61.40033	0.600	0.600	1.5
73	Con_205018.1	25.53984	0.400	0.400	1.5
74	Con_205018.2	20.12461	0.300	0.300	1.5
75	Con_205020.1	21.93171	0.300	0.300	1.5
76	Con_205021.1	55.9017	0.300	0.300	1.5
77	Con_205022.1	48.60041	0.600	0.600	1.5
78	Con_205022.2	10.81665	0.600	0.600	1.5
79	Con_205023.1	53.33854	0.600	0.600	1.5
80	Con_205024.1	44.65423	0.300	0.300	1.5
81	Con_205025.1	52.27549	0.300	0.300	1.5
82	Con_205026.1	48.3719	0.300	0.300	1.5
83	Con_205027.1	48.79549	0.300	0.300	1.5
84	Con_205028.1	53.74012	0.300	0.300	1.5
85	Con_205029.1	43.26662	0.300	0.300	1.5
86	Con_205030.1	67.77905	0.300	0.300	1.5
87	Con_205031.1	70.71068	0.300	0.300	1.5
88	Con_205032.1	47.65874	0.300	0.300	1.5
89	Con_205033.1	33.03967	0.300	0.300	1.5
90	Con_205033.2	16.88062	0.188	0.188	1.5
91	Con_205033.3	78.28778	0.400	0.400	1.5
92	Con_205034.1	61.28069	0.300	0.300	1.5
93	Con_205035.1	42.57934	0.300	0.300	1.5
94	Con_205036.1	49.24429	0.300	0.300	1.5
95	Con_205037.1	39.81206	0.300	0.300	1.5
96	Con_205038.1	47.07441	0.300	0.300	1.5
97	Con_205039.1	29.43677	0.600	0.600	1.5
98	Con_205039.2	5.385165	0.600	0.600	1.5
99	Con_205041.1	60.29925	0.600	0.600	1.5
100	Con_205041.2	53.03772	0.600	0.600	1.5
101	Con_205042X.1	40.01801	0.600	0.600	1.5
102	Con_205043.1	54.45181	0.600	0.600	1.5
103	Con_205043.2	80.20262	0.600	0.600	1.5
104	Con_205046.1	40.65736	0.600	0.600	1.5
105	Con_205061.1	32.01562	0.300	0.300	1.5
106	Con_205062.1	36.13862	0.300	0.300	1.5
107	Con_205063.1	38.04948	0.300	0.300	1.5
108	Con_205066.1	41.23106	0.300	0.300	1.5
109	Con_205067.1	40.73823	0.400	0.400	1.5
110	Con_205068.1	41.37345	0.400	0.400	1.5
111	Con_205069.1	37.87141	0.400	0.400	1.5
112	Con_205070.1	35.57062	0.300	0.300	1.5
113	Con_205070.2	54.19829	0.300	0.300	1.5
114	Con_205071.1	41.51432	0.300	0.300	1.5
115	Con_205073.1	47.53946	0.300	0.300	1.5
116	Con_205074.1	47.16991	0.300	0.300	1.5
117	Con_205075.1	55.90931	0.300	0.300	1.5
118	Con_205098.1	61.05877	0.300	0.300	1.5
119	Con_205099.1	5.941077	0.400	0.400	1.5
120	Con_205099.2	28.28427	0.300	0.300	1.5
121	Con_205101.1	61.18762	0.600	0.600	1.5
122	Con_205102.1	49.00274	0.600	0.600	1.5
123	Con_205103.1	60.86686	0.600	0.600	1.5
124	Con_205103.2	13.77982	0.297	0.297	1.5
125	Con_205104.1	51.50233	0.600	0.600	1.5
126	Con_205105.1	51.88709	0.600	0.600	1.5
127	Con_205105.2	41.87081	0.600	0.600	1.5
128	Con_205105X.1	5.8544	0.297	0.297	1.5
129	Con_205105X.2	59.85904	0.400	0.400	1.5
130	Con_205107.1	21.09502	0.300	0.300	1.5
131	Con_205108.1	41.4367	0.300	0.300	1.5
132	Con_205109.1	39.45884	0.300	0.300	1.5
133	Con_205110.1	36.40055	0.300	0.300	1.5
134	Con_205110.2	52.20153	0.300	0.300	1.5
135	Con_205111.1	29.41088	0.300	0.300	1.5
136	Con_205112.1	51.86521	0.188	0.188	1.5
137	Con_205112.2	44.55334	0.300	0.300	1.5
138	Con_205113.1	19.31321	0.188	0.188	1.5
139	Con_205115.1	53.75872	0.188	0.188	1.5
140	Con_205115.2	13.92839	0.300	0.300	1.5

No.	Conduit_ID	Length (m)	Current Diameter (m)	Inner Diameter (m)	
				Min	Max
141	Con_205116.1	54.08327	0.188	0.188	1.5
142	Con_205117.1	49.06774	0.300	0.300	1.5
143	Con_205118A.1	41.95001	0.300	0.300	1.5
144	Con_205119.1	69.2315	0.300	0.300	1.5
145	Con_205120.1	35.73514	0.300	0.300	1.5
146	Con_205120.2	23.53721	0.300	0.300	1.5
147	Con_205121.1	49.98	0.188	0.188	1.5
148	Con_205121.2	21.47091	0.188	0.188	1.5
149	Con_205122.1	39.21734	0.300	0.300	1.5
150	Con_205123.1	50.69517	0.300	0.300	1.5
151	Con_205124.1	37.01351	0.300	0.300	1.5
152	Con_205126.1	30.08322	0.300	0.300	1.5
153	Con_205126.2	19.92486	0.300	0.300	1.5
154	Con_205127.1	47.88528	0.300	0.300	1.5
155	Con_205127.2	28.17801	0.300	0.300	1.5
156	Con_205128.1	47.01064	0.300	0.300	1.5
157	Con_205129.1	50.11986	0.300	0.300	1.5
158	Con_205130.1	43.04649	0.300	0.300	1.5
159	Con_205131.1	54.20332	0.300	0.300	1.5
160	Con_205132.1	45.79301	0.300	0.300	1.5
161	Con_205133.1	49.39636	0.300	0.300	1.5
162	Con_205134.1	42.48529	0.300	0.300	1.5
163	Con_205134.2	37.85499	0.300	0.300	1.5
164	Con_205135.1	72.01389	0.300	0.300	1.5
165	Con_205136.1	21.63331	0.300	0.300	1.5
166	Con_205137.1	51.89412	0.300	0.300	1.5
167	Con_205139.1	54.03702	0.300	0.300	1.5
168	Con_205140.1	51.0098	0.300	0.300	1.5
169	Con_205141.1	50.01	0.300	0.300	1.5
170	Con_205142.1	50.03998	0.300	0.300	1.5
171	Con_205143.1	44.10215	0.300	0.300	1.5
172	Con_205144.1	49.09175	0.300	0.300	1.5
173	Con_205145.1	31.01613	0.300	0.300	1.5
174	Con_205146.1	52.03845	0.300	0.300	1.5
175	Con_205147.1	58.5235	0.300	0.300	1.5
176	Con_205148.1	58.5235	0.300	0.300	1.5

No.	Conduit_ID	Length (m)	Current Diameter (m)	Inner Diameter (m)	
				Min	Max
177	Con_205149.1	57.68882	0.300	0.300	1.5
178	Con_205150.1	36.89173	0.188	0.188	1.5
179	Con_205150.2	49.65884	0.300	0.300	1.5
180	Con_205153.1	39.39543	0.300	0.300	1.5
181	Con_205154.1	10.81665	0.188	0.188	1.5
182	Con_205155.1	59.61543	0.188	0.188	1.5
183	Con_205157.1	40.31129	0.188	0.188	1.5
184	Con_205158.1	29.06888	0.188	0.188	1.5
185	Con_205159.1	59.9333	0.151	0.151	1.5
186	Con_205159.2	46.06517	0.188	0.188	1.5
187	Con_205162.1	26.92582	0.300	0.300	1.5
188	Con_205163.1	25.70992	0.300	0.300	1.5
189	Con_205163.2	18.68154	0.300	0.300	1.5
190	Con_205165.1	33.52611	0.300	0.300	1.5
191	Con_205165.2	46.57252	0.300	0.300	1.5
192	Con_205166.1	17.11724	0.188	0.188	1.5
193	Con_205168.1	30.06659	0.300	0.300	1.5
194	Con_205169.1	30.14963	0.300	0.300	1.5
195	Con_205170.1	36.01389	0.300	0.300	1.5
196	Con_205170.2	31.57531	0.300	0.300	1.5
197	Con_205172.1	33.54102	0.300	0.300	1.5
198	Con_205173.1	31.40064	0.300	0.300	1.5
199	Con_205173.2	54.91812	0.300	0.300	1.5
200	Con_205174.1	38.60052	0.700	0.700	1.5
201	Con_205175.1	37.85499	0.300	0.300	1.5
202	Con_205176.1	16.97056	0.300	0.300	1.5
203	Con_205177.1	18.68154	0.300	0.300	1.5
204	Con_205177.2	23.08679	0.300	0.300	1.5
205	Con_205179.1	24.69818	0.300	0.300	1.5
206	Con_205181.1	25.63201	0.188	0.188	1.5
207	Con_205181.2	23.32381	0.400	0.400	1.5
208	Con_205181.3	40.36087	0.700	0.700	1.5
209	Con_205182.1	29.73214	0.188	0.188	1.5
210	Con_205184.1	39.62323	0.400	0.400	1.5
211	Con_205185.1	50.69517	0.300	0.300	1.5
212	Con_205186.1	29.42788	0.300	0.300	1.5

No.	Conduit_ID	Length (m)	Current Diameter (m)	Inner Diameter (m)	
				Min	Max
213	Con_205186.2	31.57531	0.300	0.300	1.5
214	Con_205187.1	34.52535	0.300	0.300	1.5
215	Con_205188.1	17	0.188	0.188	1.5
216	Con_205188.2	29.42788	0.300	0.300	1.5
217	Con_205189.1	13.34166	0.188	0.188	1.5
218	Con_205191.1	30.26549	0.300	0.300	1.5
219	Con_205193.1	3.605551	0.700	0.700	1.5
220	Con_205194.1	33.73426	0.300	0.300	1.5
221	Con_205195.1	23.34524	0.300	0.300	1.5
222	Con_205196.1	36.12478	0.700	0.700	1.5
223	Con_205197.1	41.4367	0.300	0.300	1.5
224	Con_205197.2	39.66106	0.700	0.700	1.5
225	Con_205198.1	40.31129	0.300	0.300	1.5
226	Con_205199.1	52.08647	0.300	0.300	1.5
227	Con_205200.1	48.27007	0.700	0.700	1.5
228	Con_205200.2	42.95346	0.700	0.700	1.5
229	Con_205201.1	27.07397	0.500	0.500	1.5
230	Con_205201.2	32.98485	0.700	0.700	1.5
231	Con_205202.1	41.23106	0.500	0.500	1.5
232	Con_205203.1	39.31921	0.300	0.300	1.5
233	Con_205203.2	28.01785	0.500	0.500	1.5
234	Con_205205.1	30.80584	0.300	0.300	1.5
235	Con_205206.1	32.98485	0.300	0.300	1.5
236	Con_205209.1	33.52611	0.700	0.700	1.5
237	Con_205210.1	64.26487	0.700	0.700	1.5
238	Con_205216.1	50.60632	0.188	0.188	1.5
239	Con_205217.1	51.61395	0.188	0.188	1.5
240	Con_205218.1	43.86342	0.188	0.188	1.5
241	Con_205220.1	61.18823	0.300	0.300	1.5
242	Con_205220.2	60.12769	0.300	0.300	1.5
243	Con_205221.1	60.16644	0.300	0.300	1.5
244	Con_205222.1	22.13594	0.300	0.300	1.5
245	Con_205222.2	47.07441	0.300	0.300	1.5
246	Con_205223.1	65.9242	0.300	0.300	1.5
247	Con_205223.2	46.06517	0.300	0.300	1.5
248	Con_205224.1	51.89412	0.300	0.300	1.5
249	Con_205224.2	41.14608	0.300	0.300	1.5
250	Con_205225.1	52.37795	0.300	0.300	1.5
251	Con_205226.1	60.09385	0.300	0.300	1.5
252	Con_205227.1	41.97618	0.300	0.300	1.5
253	Con_205228.1	43.38202	0.300	0.300	1.5
254	Con_205229.1	41.9161	0.300	0.300	1.5
255	Con_205230.1	13.68422	0.300	0.300	1.5
256	Con_205230.2	16.14514	0.300	0.300	1.5
257	Con_205230.3	33.43414	0.300	0.300	1.5
258	Con_206001.1	66.61081	0.300	0.300	1.5
259	Con_206002.1	39.20459	0.300	0.300	1.5
260	Con_206003.1	65.06919	0.300	0.300	1.5
261	Con_206004.1	50.03998	0.300	0.300	1.5
262	Con_206005.1	47.04253	0.300	0.300	1.5
263	Con_206006.1	50	0.300	0.300	1.5
264	Con_206007.1	31	0.300	0.300	1.5
265	Con_206007A.1	72.65737	0.151	0.151	1.5
266	Con_206008.1	29.15476	0.300	0.300	1.5
267	Con_206009.1	42.05948	0.300	0.300	1.5
268	Con_206010.1	33.28663	0.300	0.300	1.5
269	Con_206011.1	49.23609	0.300	0.300	1.5
270	Con_206012.1	8.843783	0.400	0.400	1.5
271	Con_206012.2	38.59757	0.400	0.400	1.5
272	Con_206013.1	65.0686	0.400	0.400	1.5
273	Con_206014.1	45.75198	0.300	0.300	1.5
274	Con_206015.1	50.80354	0.300	0.300	1.5
275	Con_206016.1	35.12834	0.300	0.300	1.5
276	Con_206017.1	61.0082	0.300	0.300	1.5
277	Con_206018.1	16	0.300	0.300	1.5
278	Con_206018.2	25.01999	0.188	0.188	1.5
279	Con_206019.1	10.29563	0.300	0.300	1.5
280	Con_206020.1	40.11234	0.300	0.300	1.5
281	Con_206021.1	37.21559	0.300	0.300	1.5
282	Con_206022.1	61.40033	0.300	0.300	1.5
283	Con_206023.1	24	0.300	0.300	1.5
284	Con_206024.1	38.32754	0.300	0.300	1.5

No.	Conduit_ID	Length (m)	Current Diameter (m)	Inner Diameter (m)	
				Min	Max
285	Con_206025.1	55.02727	0.300	0.300	1.5
286	Con_206026.1	37.43305	0.300	0.300	1.5
287	Con_206028.1	15	0.400	0.400	1.5
288	Con_206029.1	82.28001	0.400	0.400	1.5
289	Con_206030.1	78.44744	0.400	0.400	1.5
290	Con_206031.1	67.6757	0.400	0.400	1.5
291	Con_206032.1	46.40043	0.400	0.400	1.5
292	Con_206033.1	45.58019	0.400	0.400	1.5
293	Con_206034.1	18.14921	0.300	0.300	1.5
294	Con_206036.1	37.33631	0.300	0.300	1.5
295	Con_206037.1	38.32754	0.300	0.300	1.5
296	Con_206038.1	45.88028	0.300	0.300	1.5
297	Con_206039.1	50.15975	0.188	0.188	1.5
298	Con_206039.2	53.36666	0.300	0.300	1.5
299	Con_206040.1	51.47815	0.188	0.188	1.5
300	Con_206041.1	51.62364	0.188	0.188	1.5
301	Con_206043.1	56.46238	0.300	0.300	1.5
302	Con_206044.1	40.81666	0.300	0.300	1.5
303	Con_206045.1	58.82177	0.300	0.300	1.5
304	Con_206046.1	14.21267	0.300	0.300	1.5
305	Con_206047.1	56.63921	0.300	0.300	1.5
306	Con_206048.1	17.02939	0.300	0.300	1.5
307	Con_206049.1	66.61081	0.300	0.300	1.5
308	Con_206050.1	57.80138	0.300	0.300	1.5
309	Con_206051.1	40.71855	0.188	0.188	1.5
310	Con_206051.2	80.43009	0.300	0.300	1.5
311	Con_206052.1	80.50466	0.188	0.188	1.5
312	Con_206053.1	49.25444	0.188	0.188	1.5
313	Con_206055.1	56.85068	0.300	0.300	1.5
314	Con_206056.1	56.58622	0.300	0.300	1.5
315	Con_206057.1	57.38467	0.300	0.300	1.5
316	Con_206058.1	32.55764	0.188	0.188	1.5
317	Con_206058.2	49.57822	0.300	0.300	1.5
318	Con_206059.1	38.20995	0.188	0.188	1.5
319	Con_206060.1	31.1127	0.188	0.188	1.5
320	Con_206060.2	10.29563	0.188	0.188	1.5
321	Con_206061.1	15.13275	0.151	0.151	1.5
322	Con_206061.2	14.14214	0.151	0.151	1.5
323	Con_206062.1	31.14482	0.151	0.151	1.5
324	Con_206064.1	33.24154	0.151	0.151	1.5
325	Con_206066.1	34.65545	0.188	0.188	1.5
326	Con_206066.2	19.72308	0.188	0.188	1.5
327	Con_206067.1	17.02939	0.151	0.151	1.5
328	Con_206067.2	15.29706	0.151	0.151	1.5
329	Con_206068.1	28.31961	0.151	0.151	1.5
330	Con_206070.1	33.30165	0.151	0.151	1.5
331	Con_206072.1	80.95678	0.188	0.188	1.5
332	Con_206073.1	49.72927	0.188	0.188	1.5
333	Con_206074.1	29.06888	0.188	0.188	1.5
334	Con_206075.1	16.27882	0.151	0.151	1.5
335	Con_206075.2	15.13275	0.151	0.151	1.5
336	Con_206076.1	29	0.151	0.151	1.5
337	Con_206078.1	29	0.151	0.151	1.5
338	Con_206080.1	51.73973	0.300	0.300	1.5
339	Con_206081.1	43.41659	0.300	0.300	1.5
340	Con_206082.1	60.10824	0.300	0.300	1.5
341	Con_206083.1	51.61395	0.188	0.188	1.5
342	Con_206083.2	13.60147	0.300	0.300	1.5
343	Con_206084.1	58	0.188	0.188	1.5
344	Con_206084A.1	26.79935	0.151	0.151	1.5
345	Con_206085.1	53.03772	0.188	0.188	1.5
346	Con_206086.1	54.45181	0.188	0.188	1.5
347	Con_206086.2	55.17246	0.188	0.188	1.5
348	Con_206087.1	53.74012	0.188	0.188	1.5
349	Con_206090.1	60.44005	0.300	0.300	1.5
350	Con_206090.2	73.57309	0.300	0.300	1.5
351	Con_206092.1	52.3259	0.188	0.188	1.5
352	Con_206092.2	50.24938	0.188	0.188	1.5
353	Con_206093.1	38.60052	0.188	0.188	1.5
354	Con_206093.2	54.81788	0.235	0.235	1.5
355	Con_206094.1	36.06938	0.188	0.188	1.5
356	Con_206094.2	33.30165	0.188	0.188	1.5

No.	Conduit_ID	Length (m)	Current Diameter (m)	Inner Diameter (m)	
				Min	Max
357	Con_206095.1	42.44997	0.188	0.188	1.5
358	Con_206097.1	40.66903	0.151	0.151	1.5
359	Con_206097A.1	15.34829	0.151	0.151	1.5
360	Con_206098.1	34.66987	0.188	0.188	1.5
361	Con_206099.1	31.24932	0.188	0.188	1.5
362	Con_206100.1	23.97749	0.151	0.151	1.5
363	Con_206100.2	22.18829	0.151	0.151	1.5
364	Con_206102.1	28.28427	0.151	0.151	1.5
365	Con_206104.1	42.42641	0.188	0.188	1.5
366	Con_206105.1	41.01219	0.188	0.188	1.5
367	Con_206105.2	50.24938	0.151	0.151	1.5
368	Con_206105.3	30.41381	0.188	0.188	1.5
369	Con_206106.1	48.9183	0.151	0.151	1.5
370	Con_206108.1	48.25971	0.188	0.188	1.5
371	Con_206109.1	29	0.151	0.151	1.5
372	Con_206109.2	20.51829	0.188	0.188	1.5
373	Con_206111.1	29	0.151	0.151	1.5
374	Con_206113.1	55.31727	0.235	0.235	1.5
375	Con_206114.1	53.07542	0.235	0.235	1.5
376	Con_206115.1	51.85557	0.235	0.235	1.5
377	Con_206116.1	55.22681	0.235	0.235	1.5
378	Con_206117.1	55.9464	0.235	0.235	1.5
379	Con_206118.1	16.12452	0.235	0.235	1.5
380	Con_206118.2	54.12947	0.235	0.235	1.5
381	Con_206119.1	44.55334	0.188	0.188	1.5
382	Con_206120.1	41.01219	0.188	0.188	1.5
383	Con_206120.2	40.31129	0.188	0.188	1.5
384	Con_206121.1	38.18377	0.188	0.188	1.5
385	Con_206122.1	28.31961	0.151	0.151	1.5
386	Con_206123.1	17.80449	0.151	0.151	1.5
387	Con_206125.1	57.28001	0.188	0.188	1.5
388	Con_206125.2	46.09772	0.188	0.188	1.5
389	Con_206126.1	20.51829	0.151	0.151	1.5
390	Con_206126.2	30.4795	0.151	0.151	1.5
391	Con_206127.1	31.241	0.151	0.151	1.5
392	Con_206128.1	21.26029	0.151	0.151	1.5
393	Con_206130.1	47.01064	0.188	0.188	1.5
394	Con_206131.1	34.20526	0.188	0.188	1.5
395	Con_206132.1	24.75884	0.151	0.151	1.5
396	Con_206132.2	26.17251	0.151	0.151	1.5
397	Con_206133.1	25.45584	0.151	0.151	1.5
398	Con_206134.1	53.66563	0.235	0.235	1.5
399	Con_206135.1	24.75884	0.235	0.235	1.5
400	Con_206136.1	30.8707	0.235	0.235	1.5
401	Con_206136.2	42.15448	0.235	0.235	1.5
402	Con_206137.1	24.75884	0.235	0.235	1.5
403	Con_206138.1	35.12834	0.188	0.188	1.5
404	Con_206139.1	20.12461	0.188	0.188	1.5
405	Con_206140.1	27.65863	0.188	0.188	1.5
406	Con_206141.1	32.64966	0.188	0.188	1.5
407	Con_206142.1	45.27693	0.188	0.188	1.5
408	Con_206143.1	63.60031	0.188	0.188	1.5
409	Con_206144.1	65.25335	0.188	0.188	1.5
410	Con_206146.1	41.03657	0.188	0.188	1.5
411	Con_206146.2	50.35871	0.188	0.188	1.5
412	Con_206147.1	30.52868	0.188	0.188	1.5
413	Con_206149.1	51.1957	0.188	0.188	1.5
414	Con_206150.1	53.36666	0.188	0.188	1.5
415	Con_206151.1	64.28841	0.188	0.188	1.5
416	Con_206152.1	48.76474	0.188	0.188	1.5
417	Con_207001.1	76.00658	0.151	0.151	1.5
418	Con_207002.1	10.04988	0.151	0.151	1.5
419	Con_207002.2	57.31492	0.188	0.188	1.5
420	Con_207003.1	41.88078	0.151	0.151	1.5
421	Con_207005.1	59.03389	0.188	0.188	1.5
422	Con_207006.1	64.28841	0.151	0.151	1.5
423	Con_207006.2	10.16677	0.151	0.151	1.5
424	Con_207007.1	70.88018	0.151	0.151	1.5
425	Con_207008.1	67.44628	0.151	0.151	1.5
426	Con_207009.1	73.4983	0.151	0.151	1.5
427	Con_209005.1	60.42168	0.600	0.600	1.5
428	Con_209009X.1	52.74605	0.297	0.297	1.5

No.	Conduit_ID	Length (m)	Current Diameter (m)	Inner Diameter (m)	
				Min	Max
429	Con_209009X.2	51.27617	0.297	0.297	1.5
430	Con_209015.1	9.493008	0.300	0.300	1.5
431	Con_209016.1	40.30115	0.300	0.300	1.5
432	Con_209016.2	69.45936	0.300	0.300	1.5
433	Con_209017.1	38.01097	0.300	0.300	1.5
434	Con_209018.1	43.55893	0.300	0.300	1.5
435	Con_209020.1	31.33223	0.300	0.300	1.5
436	Con_209021.1	42.50655	0.300	0.300	1.5
437	Con_209021.2	12.179	0.300	0.300	1.5
438	Con_209023.1	27.71224	0.300	0.300	1.5
439	Con_219003.1	14.44855	0.600	0.600	1.5
440	Con_290000.1	48.77285	0.400	0.400	1.5
441	Con_290004.1	62.96227	0.400	0.400	1.5
442	Con_290008.1	50.44676	0.400	0.400	1.5
443	Con_290012.1	62.76135	0.400	0.400	1.5
444	Con_290016.1	50.73717	0.400	0.400	1.5
445	Con_290018.1	44.47281	0.400	0.400	1.5
446	Con_295205.1	50.69517	0.700	0.700	1.5
447	Con_G01.1	54.78944	0.600	0.600	1.5
448	Con_G01.2	11.18034	0.300	0.300	1.5
449	Con_G02.1	39.29377	0.300	0.300	1.5
450	Con_G02.2	41.24379	0.300	0.300	1.5
451	Con_G04.1	55.47585	0.300	0.300	1.5
452	Con_G04.2	41.78134	0.300	0.300	1.5
453	Con_G05.1	69.31294	0.300	0.300	1.5
454	Con_G06.1	59.92562	0.300	0.300	1.5
455	Con_G07.1	44.83972	0.300	0.300	1.5
456	Con_G07.2	56.98886	0.300	0.300	1.5
457	Con_G08a.1	41.52602	0.300	0.300	1.5
458	Con_G09.3	35.64506	0.300	0.300	1.5
459	Con_G10.2	57.35053	0.300	0.300	1.5
460	Con_G10_f.1	32.34621	0.300	0.300	1.5
461	Con_G11.1	38.16504	0.600	0.600	1.5
462	Con_G11.2	67.1	0.600	0.600	1.5
463	Con_G12.1	60.06164	0.600	0.600	1.5
464	Con_G13.1	59.95282	0.600	0.600	1.5
465	Con_G14.2	48.99324	0.600	0.600	1.5
466	Con_G15.1	17.96379	0.600	0.600	1.5
467	Con_G16_f.2	6.637017	0.400	0.400	1.5
468	Con_RCplan1.2	28.46565	0.300	0.300	1.5
469	Con_RCplan10.1	32.77462	0.600	0.600	1.5
470	Con_RCplan11.1	38.76183	0.600	0.600	1.5
471	Con_RCplan12.1	50.89597	0.600	0.600	1.5
472	Con_RCplan12.2	36.47119	0.300	0.300	1.5
473	Con_RCplan14.2	14.5165	0.600	0.600	1.5
474	Con_RCplan2.1	14.62566	0.300	0.300	1.5
475	Con_RCplan2.2	34.25442	0.300	0.300	1.5
476	Con_RCplan20.2	34.84612	0.600	0.600	1.5
477	Con_RCplan21.1	39.89628	0.300	0.300	1.5
478	Con_RCplan3.1	54.75885	0.300	0.300	1.5
479	Con_RCplan4.1	39.20308	0.300	0.300	1.5
480	Con_RCplan5.1	41.66183	0.300	0.300	1.5
481	Con_RCplan6.1	55.87918	0.600	0.600	1.5
482	Con_RCplan6.2	46.6832	0.600	0.600	1.5
483	Con_RCplan7.1	48.91627	0.600	0.600	1.5
484	Con_RCplan8.1	59.78931	0.600	0.600	1.5
485	Con_RCplan9.1	40.30208	0.600	0.600	1.5
486	Con_205300.2	22.4548	0.600	0.600	1.5

Appendix G – Sub-catchments properties and value ranges of decision variables

SC_ID	Outlet	Area (ha)	Impv.%	Impv. Area (m^2)	IT (m^2)		PP (m^2)		Total area RB (m^2)		Population	House(s)
					Min	Max	Min	Max	Min	Max		
Sub_202001	Jun_202001	0.046	94.78261	434.597	0	0	0	380	0	0.48	2	1
Sub_202002	Jun_202002	0.049924	25	124.81	0	0	0	100	0	0.48	3	1
Sub_202003	Jun_202003	0.023833	94.58333	225.4204504	0	0	0	190	0	0.48	1	1
Sub_202004	Jun_202004	0	0	0	0	0	0	0	0	0	0	0
Sub_202005	Jun_202005	0.024441	68.75	168.031875	0	0	0	0	0	0.48	1	1
Sub_202006	Jun_202006	0.052919	25	132.2975	0	0	0	0	0	0.48	3	1
Sub_202007	Jun_202007	0	0	0	0	0	0	0	0	0	0	0
Sub_202008	Jun_202008	0	0	0	0	0	0	0	0	0	0	0
Sub_202009	Jun_202009	0	0	0	0	0	0	0	0	0	0	0
Sub_202011	Jun_202011	0	0	0	0	0	0	0	0	0	0	0
Sub_202012	Jun_202012	0.002637	25	6.5925	0	0	0	0	0	0	0	0
Sub_202013	Jun_202013	0	0	0	0	0	0	0	0	0	0	0
Sub_202014	Jun_202014	0	0	0	0	0	0	0	0	0	0	0
Sub_202015	Jun_202015	0	0	0	0	0	0	0	0	0	0	0
Sub_202016	Jun_202016	0	0	0	0	0	0	0	0	0	0	0
Sub_202017	Jun_202017	0.062243	85.32258	531.0733347	0	0	0	0	0	0.48	1	1
Sub_202018	Jun_202018	0	0	0	0	0	0	0	0	0	0	0
Sub_202019	Jun_202019	0.019689	78.5	154.55865	0	0	0	0	0	0.48	1	1
Sub_202020	Jun_202020	0.031847	34.84375	110.9668906	0	0	0	50	0	0.48	1	1
Sub_202021	Jun_202021	0.129787	65.45802	849.5600042	0	0	0	250	0	0.96	4	2
Sub_202022	Jun_202022	0.020505	25	51.2625	0	0	0	40	0	0.48	1	1
Sub_202023	Jun_202023	0.045592	25	113.98	0	0	0	106	0	0.48	2	1
Sub_202024	Jun_202024	0.033069	25	82.6725	0	0	0	70	0	0.48	2	1
Sub_202025	Jun_202025	0.114281	64.29825	734.8068308	0	0	0	200	0	1.44	6	3
Sub_202026	Jun_202026	0.039548	25	98.87	0	0	0	85	0	0.48	2	1
Sub_204001	Jun_204001	0.002649	93.33333	24.72399912	0	0	0	0	0	0	0	0
Sub_204002	Jun_204002	0.031329	93.54839	293.077751	0	0	0	0	0	0.96	5	2
Sub_204003	Jun_204003	0.004373	90	39.357	0	0	0	0	0	0	0	0
Sub_204004	Jun_204004	0.004521	90	40.689	0	0	0	0	0	0	0	0
Sub_204005	Jun_204005	0.028208	95	267.976	0	0	0	0	0	1.44	6	3
Sub_204006	Jun_204006	0.006581	95	62.5195	0	0	0	0	0	0.48	1	1
Sub_204007	Jun_204007	0	0	0	0	0	0	0	0	0	0	0

SC_ID	Outlet	Area (ha)	Impv.%	Impv. Area (m^2)	IT (m^2)		PP (m^2)		Total area RB (m^2)		Population	House(s)
					Min	Max	Min	Max	Min	Max		
Sub_204008	Jun_204008	0	0	0	0	0	0	0	0	0	0	0
Sub_204009	Jun_204009	0	0	0	0	0	0	0	0	0	0	0
Sub_204010	Jun_204010	0	0	0	0	0	0	0	0	0	0	0
Sub_204011	Jun_204011	0	0	0	0	0	0	0	0	0	0	0
Sub_204012	Jun_204012	0	0	0	0	0	0	0	0	0	0	0
Sub_204013	Jun_204013	0	0	0	0	0	0	0	0	0	0	0
Sub_204014	Jun_204014	0.02484	93.2	231.5088	0	0	0	0	0	0.48	3	1
Sub_204015	Jun_204015	0.045595	93.44444	426.0599242	0	0	0	0	0	1.44	7	3
Sub_204016	Jun_204016	0	0	0	0	0	0	0	0	0	0	0
Sub_204017	Jun_204017	0.016413	92.1875	151.3073438	0	0	0	0	0	0.48	2	1
Sub_204018	Jun_204018	0.000876	90	7.884	0	0	0	0	0	0	0	0
Sub_204019	Jun_204019	0	0	0	0	0	0	0	0	0	0	0
Sub_204020	Jun_204020	0.032949	89.69697	295.5425465	0	0	0	0	0	1.44	6	3
Sub_204021	Jun_204021	0.08986	94.44444	848.6777378	0	0	0	0	0	3.84	17	8
Sub_204022	Jun_204022	0.021187	95	201.2765	0	0	0	0	0	0.96	5	2
Sub_204024	Jun_204024	0.013332	93.07692	124.0901497	0	0	0	0	0	0.48	2	1
Sub_204025	Jun_204025	0.02671	91.2963	243.8524173	0	0	0	0	0	0.48	1	1
Sub_204026	Jun_204026	0.033276	93.18182	310.0718242	0	0	0	0	0	0.96	4	2
Sub_204027	Jun_204027	0.001925	90	17.325	0	0	0	0	0	0	0	0
Sub_204028	Jun_204028	0	0	0	0	0	0	0	0	0	0	0
Sub_204029	Jun_204029	0	0	0	0	0	0	0	0	0	0	0
Sub_204030	Jun_204030	0.018868	90	169.812	0	0	0	0	0	0	0	0
Sub_205001	Jun_205001	0.019152	93.68421	179.423999	0	0	0	0	0	0.48	1	1
Sub_205002	Jun_205002	0.010296	90	92.664	0	0	0	0	0	0	0	0
Sub_205003	Jun_205003	0.009732	90	87.588	0	0	0	0	0	0	0	0
Sub_205004	Jun_205004	0.00672	90	60.48	0	0	0	0	0	0	0	0
Sub_205005	Jun_205005	0.02369	93.75	222.09375	0	0	0	0	0	0.48	2	1
Sub_205006	Jun_205006	0.038621	93.94737	362.8341377	0	0	0	0	0	0.48	3	1
Sub_205007	Jun_205007	0.004991	95	47.4145	0	0	0	0	0	0.48	1	1
Sub_205008	Jun_205008	0.02578	95	244.91	0	0	0	0	0	0.48	3	1
Sub_205009	Jun_205009	0.004604	95	43.738	0	0	0	0	0	0	0	0
Sub_205010	Jun_205010	0	0	0	0	0	0	0	0	0	0	0
Sub_205011	Jun_205011	0.025229	93.6	236.14344	0	0	0	0	0	0.48	2	1
Sub_205012	Jun_205012	0.049079	90.7	445.14653	0	0	0	0	0	0.48	1	1
Sub_205013	Jun_205013	0.112815	86.91964	980.5839187	0	0	0	0	0	0.96	5	2
Sub_205014	Jun_205014	0.066232	92.95455	615.6565756	0	0	0	0	0	0.96	4	2

SC_ID	Outlet	Area (ha)	Impv.%	Impv. Area (m^2)	IT (m^2)		PP (m^2)		Total area RB (m^2)		Population	House(s)
					Min	Max	Min	Max	Min	Max		
Sub_205015	Jun_205015	0.0659	92.12121	607.0787739	0	0	0	0	0	0.48	3	1
Sub_205016	Jun_205016	0.053114	88.30189	469.0066585	0	0	0	0	0	0.48	3	1
Sub_205017	Jun_205017	0.031598	91.77419	289.9880856	0	0	0	0	0	0.48	1	1
Sub_205018	Jun_205018	0.016897	91.25	154.185125	0	0	0	0	0	0	0	0
Sub_205020	Jun_205020	0.01283	90.76923	116.4569221	0	0	0	0	0	0	0	0
Sub_205021	Jun_205021	0.055217	92.18182	509.0003555	0	0	0	0	0	0.48	3	1
Sub_205022	Jun_205022	0.095121	83.36842	793.0087479	0	0	0	0	0	1.92	8	4
Sub_205023	Jun_205023	0.146387	82.34694	1205.452151	0	0	0	0	0	2.88	12	6
Sub_205024	Jun_205024	0.140264	87.76596	1231.040461	0	52	0	306	0	1.44	7	3
Sub_205025	Jun_205025	0.096265	85.30928	821.2297839	0	0	0	0	0	1.44	7	3
Sub_205026	Jun_205026	0.105883	91.17925	965.4332528	0	0	0	0	0	1.44	7	3
Sub_205027	Jun_205027	0.104407	85.86538	896.494673	0	0	0	0	0	1.44	7	3
Sub_205028	Jun_205028	0.148531	89.42568	1328.248568	0	0	0	0	0	2.88	12	6
Sub_205029	Jun_205029	0.114451	83.11404	951.2484992	0	0	0	0	0	1.92	9	4
Sub_205030	Jun_205030	0.126469	87.93651	1112.124248	0	0	0	0	0	1.92	9	4
Sub_205031	Jun_205031	0.189572	85.39683	1618.884786	0	0	0	0	0	3.36	14	7
Sub_205032	Jun_205032	0.094515	81.52632	770.5460135	0	0	0	0	0	0.96	5	2
Sub_205033	Jun_205033	0.054135	89.53704	484.708766	0	60	0	0	0	0.48	2	1
Sub_205034	Jun_205034	0.09742	84.08163	819.1232395	0	0	0	0	0	1.92	9	4
Sub_205035	Jun_205035	0.11142	89.36937	995.7535205	0	0	0	0	0	2.88	12	6
Sub_205036	Jun_205036	0.123274	88.86179	1095.43483	0	0	0	0	0	1.92	8	4
Sub_205037	Jun_205037	0.126749	83.77953	1061.897165	0	0	0	0	0	3.36	14	7
Sub_205038	Jun_205038	0.109923	85.45455	939.34205	0	0	0	0	0	3.36	14	7
Sub_205039	Jun_205039	0.020123	90	181.107	0	30	0	70	0	0	0	0
Sub_205041	Jun_205041	0.094167	88.24468	830.9736782	0	0	0	90	0	0.96	5	2
Sub_205042	Jun_205042	0.157194	79.4586	1249.041517	0	0	0	132	0	1.44	7	3
Sub_205042X	Jun_205042X	0.208556	86.05263	1794.67923	0	0	0	160	0	2.88	12	6
Sub_205043	Jun_205043	0.090621	88.68132	803.63899	0	0	0	130	0	0.96	4	2
Sub_205044	Jun_205044	0.110616	65.45045	723.9866977	0	0	0	50	0	1.92	9	4
Sub_205045	Jun_G01	0.092584	85.21815	788.98372	0	0	0	85	0	1.44	7	3
Sub_205046	Jun_205046	0.023139	93.04348	215.2933084	0	0	0	85	0	0.48	2	1
Sub_205048	Jun_205048	0.053511	92.07547	492.7050475	0	0	0	0	0	0.48	3	1
Sub_205061	Jun_205061	0.086467	91.39535	790.2681728	0	0	0	0	0	1.92	8	4
Sub_205062	Jun_205062	0.05762	92.93103	535.4685949	0	0	0	55	0	0.96	4	2
Sub_205063	Jun_205063	0.076237	84.40789	643.500431	0	0	0	70	0	0.48	3	1
Sub_205064	Jun_G02	0.044696	46.04102	205.784943	0	0	0	30	0	0.96	4	2

SC_ID	**Outlet**	**Area (ha)**	**Impv.%**	**Impv. Area (m^2)**	**IT (m^2)**		**PP (m^2)**		**Total area RB (m^2)**		**Population**	**House(s)**
					Min	**Max**	**Min**	**Max**	**Min**	**Max**		
Sub_205066	Jun_205066	0.008181	90	73.629	0	0	0	0	0	0.48	2	1
Sub_205067	Jun_205067	0.069233	93.4058	646.6763751	0	0	0	0	0	0.96	5	2
Sub_205068	Jun_205068	0.073233	90.34247	661.6050106	0	0	0	0	0	0.96	5	2
Sub_205069	Jun_205069	0.084771	86.17647	730.5265538	0	0	0	0	0	1.44	6	3
Sub_205070	Jun_205070	0.091674	86.92308	796.8586436	0	0	0	40	0	1.44	6	3
Sub_205071	Jun_205071	0.076466	74.61039	570.5158082	0	0	0	70	0	1.44	6	3
Sub_205072	Jun_205072	0.090471	79.61538	720.2883044	0	0	0	144	0	1.44	7	3
Sub_205073	Jun_205073	0.136645	81.69118	1116.269129	0	0	0	0	0	2.4	10	5
Sub_205074	Jun_205074	0.153423	77.20779	1184.545077	0	0	0	0	0	2.88	13	6
Sub_205075	Jun_205075	0.16935	83.38235	1412.080097	0	0	0	0	0	2.4	10	5
Sub_205076	Jun_G07	0.130922	89.58335	1172.843135	0	0	0	150	0	1.92	9	4
Sub_205077	Jun_G08	0.026526	89.06271	236.2477445	0	50	0	0	0	0	5	2
Sub_205078	Jun_G06	0.019167	100	191.67	0	0	0	0	0	0	4	2
Sub_205079	Jun_G06	0.008914	50.4032	44.92941248	0	0	0	0	0	0	2	1
Sub_205080	Jun_G14	0.008029	95.56848	76.73193259	0	0	0	0	0	0.48	1	1
Sub_205081	Jun_G13	0.085969	99.67301	856.8788997	0	0	0	0	0	0	9	4
Sub_205082	Jun_G12	0.097862	74.08805	725.0404749	0	0	0	0	0	0	12	6
Sub_205083	Jun_G11	0.062068	77.17699	479.0221415	0	0	0	0	0	0	9	4
Sub_205084	Jun_G10	0.041237	77.49375	319.5609769	0	0	0	0	0	0	5	2
Sub_205085	Jun_G09	0.035579	54.1286	192.5841459	0	0	0	0	0	0	4	2
Sub_205086	Jun_G04	0.05353	100	535.3	0	0	0	0	0	0	4	2
Sub_205087	Jun_G05	0.033342	65.22512	217.4735951	0	0	0	0	0	0	5	2
Sub_205088	Jun_205088	0.109632	76.31818	836.691471	0	0	0	50	0	1.44	6	3
Sub_205098	Jun_205098	0.072202	90.20833	651.3221843	0	0	0	40	0	1.92	8	4
Sub_205099	Jun_205099	0.050756	86.47059	438.8901266	0	15	0	0	0	0	0	0
Sub_205100	Jun_205100	0.110119	68.51351	754.4639208	0	0	0	50	0	1.92	9	4
Sub_205101	Jun_205101	0.136083	68.01471	925.5645781	0	0	0	80	0	4.32	18	9
Sub_205102	Jun_205102	0.181985	74.72527	1359.887826	0	0	0	100	0	3.36	15	7
Sub_205103	Jun_205103	0.112285	85.53571	960.4377197	0	0	0	110	0	1.44	7	3
Sub_205104	Jun_205104	0.076603	80.77922	618.793059	0	0	0	40	0	1.92	9	4
Sub_205105	Jun_205105	0.033776	91.02941	307.4609352	0	0	0	40	0	0.48	1	1
Sub_205105X	Jun_205105X	0.061521	88.46774	544.2623833	0	0	0	70	0	1.44	6	3
Sub_205106	Jun_205106	0.021594	90	194.346	0	0	0	0	0	0	0	0
Sub_205107	Jun_205107	0.090966	85.71429	779.7086104	0	20	0	30	0	2.4	11	5
Sub_205108	Jun_205108	0.106806	87.00935	929.3120636	0	0	0	0	0	2.88	13	6
Sub_205109	Jun_205109	0.134188	74.25373	996.3959521	0	0	0	0	0	3.84	17	8

SC_ID	Outlet	Area (ha)	Impv.%	Impv. Area (m^2)	IT (m^2)		PP (m^2)		Total area RB (m^2)		Population	House(s)
					Min	Max	Min	Max	Min	Max		
Sub_205110	Jun_205110	0.1087	87.20183	947.8838921	0	0	0	0	0	1.92	9	4
Sub_205111	Jun_205111	0.090592	74.66667	676.4202969	0	0	0	150	0	2.4	11	5
Sub_205112	Jun_205112	0.076082	83.75	637.18675	0	0	0	200	0	1.44	6	3
Sub_205113	Jun_205113	0.077249	86.75325	670.1601809	0	0	0	85	0	2.4	11	5
Sub_205114	Jun_205114	0.056225	94.03509	528.7122935	0	25	0	0	0	1.92	8	4
Sub_205115	Jun_205115	0.085498	89.29412	763.4468672	0	0	0	150	0	2.4	10	5
Sub_205116	Jun_205116	0.098654	87.47475	862.9733987	0	0	0	150	0	2.88	13	6
Sub_205117	Jun_205117	0.077242	90.97403	702.7016025	0	0	0	380	0	0.48	3	1
Sub_205118	Jun_205118	0.136822	85.21898	1165.983128	0	0	0	200	0	4.32	19	9
Sub_205118A	Jun_205118A	0.068426	80.28986	549.391396	0	0	0	100	0	0.96	5	2
Sub_205119	Jun_205119	0.18228	89.91758	1639.017648	0	0	0	300	0	2.88	13	6
Sub_205120	Jun_205120	0.183974	70.46196	1296.316863	0	0	0	355	0	1.92	8	4
Sub_205121	Jun_205121	0.084604	44.11765	373.2529661	0	0	0	300	0	1.44	6	3
Sub_205122	Jun_205122	0.231239	67.09052	1551.394475	0	0	0	250	0	3.36	15	7
Sub_205123	Jun_205123	0.178855	78.25843	1399.69115	0	0	0	150	0	1.92	9	4
Sub_205124	Jun_205124	0.096321	90.92784	875.8260477	0	0	0	75	0	0.48	2	1
Sub_205125	Jun_205125	0.087311	90.45977	789.8132978	0	0	0	50	0	0.96	5	2
Sub_205126	Jun_205126	0.065697	87.92308	577.6282587	0	0	0	0	0	0.48	3	1
Sub_205127	Jun_205127	0.003682	95	34.979	0	0	0	0	0	0	0	0
Sub_205128	Jun_205128	0.077153	82.27273	634.7587938	0	0	0	0	0	1.44	6	3
Sub_205129	Jun_205129	0.019017	93.42105	177.6588108	0	0	0	0	0	0.48	2	1
Sub_205130	Jun_205130	0.032307	88.4375	285.7150313	0	0	0	0	0	0.48	1	1
Sub_205131	Jun_205131	0.052675	89.90385	473.5685299	0	0	0	0	0	0.96	4	2
Sub_205132	Jun_205132	0.027118	86.66667	235.0226757	0	0	0	0	0	0.48	1	1
Sub_205133	Jun_205133	0.022011	85.22727	187.593744	0	0	0	0	0	0.48	1	1
Sub_205134	Jun_205134	0.048101	83.85417	403.3469431	0	0	0	0	0	0.96	4	2
Sub_205135	Jun_205135	0	0	0	0	0	0	0	0	0	0	0
Sub_205136	Jun_205136	0.007743	83.75	64.847625	0	0	0	0	0	0	0	0
Sub_205137	Jun_205137	0.060468	87.04918	526.3689816	0	0	0	311	0	0	0	0
Sub_205138	Jun_205138	0.109353	61.14679	668.6584927	0	0	0	311	0	0.96	5	2
Sub_205139	Jun_205139	0.025663	87.8	225.32114	0	0	0	0	0	0.48	1	1
Sub_205140	Jun_205140	0.04212	88.33333	372.059986	0	0	0	0	0	0.48	1	1
Sub_205141	Jun_205141	0.026421	95	250.9995	0	0	0	0	0	0.48	3	1
Sub_205142	Jun_205142	0.037778	90.39474	341.4932488	0	0	0	0	0	0.48	2	1
Sub_205143	Jun_205143	0.191572	91.04167	1744.103481	0	0	0	0	0	1.44	7	3
Sub_205144	Jun_205144	0.024023	85.41667	205.1964663	0	0	0	0	0	0	0	0

SC_ID	**Outlet**	**Area (ha)**	**Impv.%**	**Impv. Area (m^2)**	**IT (m^2)**		**PP (m^2)**		**Total area RB (m^2)**		**Population**	**House(s)**
					Min	**Max**	**Min**	**Max**	**Min**	**Max**		
Sub_205145	Jun_205145	0.037042	94.18919	348.8955976	0	0	0	0	0	0.96	4	2
Sub_205146	Jun_205146	0	0	0	0	0	0	0	0	0	0	0
Sub_205147	Jun_205147	0.025115	91.15385	228.9328943	0	0	0	0	0	0.48	1	1
Sub_205148	Jun_205148	0.099319	91.66667	910.4241998	0	0	0	0	0	1.44	6	3
Sub_205149	Jun_205149	0.063504	90.78125	576.49725	0	0	0	0	0	0.96	5	2
Sub_205150	Jun_205150	0.074006	89.18919	660.0535195	0	0	0	0	0	0.48	3	1
Sub_205151	Jun_205151	0.270591	94.35424	2553.140816	0	0	0	0	0	5.76	25	12
Sub_205153	Jun_205153	0.013332	84.28571	112.3697086	0	0	0	0	0	0	0	0
Sub_205154	Jun_205154	0.02067	90	186.03	0	0	0	0	0	0.48	1	1
Sub_205155	Jun_205155	0.025603	88.8	227.35464	0	0	0	0	0	0.48	2	1
Sub_205156	Jun_205156	0.229697	94.02174	2159.651161	0	0	0	0	0	5.28	23	11
Sub_205157	Jun_205157	0.016345	90	147.105	0	0	0	0	0	0	0	0
Sub_205158	Jun_205158	0.014445	90	130.005	0	0	0	0	0	0	0	0
Sub_205159	Jun_205159	0.002823	90	25.407	0	0	0	0	0	0	0	0
Sub_205160	Jun_205160	0.028457	95	270.3415	0	0	0	0	0	0.48	3	1
Sub_205161	Jun_205161	0.064977	93.23077	605.7855742	0	0	0	0	0	0.96	4	2
Sub_205162	Jun_205162	0.058702	79.23729	465.1387398	0	0	0	150	0	1.44	7	3
Sub_205163	Jun_205163	0.049936	83.5	416.9656	0	0	0	150	0	0.48	3	1
Sub_205164	Jun_205164	0.04829	84.375	407.446875	0	0	0	80	0	1.92	8	4
Sub_205165	Jun_205165	0.045182	92.77778	419.1885656	0	0	0	314	0	0.96	4	2
Sub_205166	Jun_205166	0.016649	64.41176	107.2391392	0	0	0	50	0	0.48	2	1
Sub_205167	Jun_205167	0	0	0	0	0	0	0	0	0	0	0
Sub_205168	Jun_205168	0.093275	73.3871	684.5181753	0	0	0	150	0	2.88	12	6
Sub_205169	Jun_205169	0.071884	85.76389	616.5051469	0	0	0	150	0	1.92	9	4
Sub_205170	Jun_205170	0.060685	92.08333	558.8076881	0	0	0	150	0	1.44	7	3
Sub_205171	Jun_205171	0.043982	89.4186	393.2808865	0	0	0	70	0	1.44	7	3
Sub_205172	Jun_205172	0.05637	75.98214	428.3113232	0	0	0	180	0	1.44	7	3
Sub_205173	Jun_205173	0.090046	84.7191	762.8616079	0	0	0	0	0	1.92	8	4
Sub_205174	Jun_205174	0.044953	92.22222	414.5665456	0	0	0	0	0	0.96	4	2
Sub_205175	Jun_205175	0.077321	85.12987	658.2326678	0	0	0	30	0	1.44	6	3
Sub_205176	Jun_205176	0.060667	77.21311	468.4287744	0	0	0	60	0	1.44	7	3
Sub_205177	Jun_205177	0.023502	91.52174	215.0943933	0	0	0	40	0	0.48	1	1
Sub_205178	Jun_205178	0.03388	93.08824	315.3829571	0	0	0	40	0	0.96	4	2
Sub_205179	Jun_205179	0.045851	93.47826	428.6071699	0	0	0	50	0	1.44	6	3
Sub_205180	Jun_205180	0.028798	87.5	251.9825	0	30	0	40	0	0.48	3	1
Sub_205181	Jun_205181	0.054056	87.68519	473.9910631	0	0	0	0	0	0.48	3	1

SC_ID	Outlet	Area (ha)	Impv.%	Impv. Area (m^2)	IT (m^2)		PP (m^2)		Total area RB (m^2)		Population	House(s)
					Min	Max	Min	Max	Min	Max		
Sub_205182	Jun_205182	0.065523	44.61538	292.3333544	0	25	0	45	0	1.92	9	4
Sub_205183	Jun_205183	0.04224	91.30952	385.6914125	0	25	0	45	0	0.96	4	2
Sub_205184	Jun_205184	0.083977	92.14286	773.7880954	0	0	0	190	0	1.92	9	4
Sub_205185	Jun_205185	0.085772	80.29412	688.6987261	0	0	0	100	0	2.4	10	5
Sub_205186	Jun_205186	0.077154	90.12987	695.387999	0	0	0	190	0	1.92	8	4
Sub_205187	Jun_205187	0.085285	83.89535	715.5014925	0	0	0	150	0	2.4	11	5
Sub_205188	Jun_205188	0.043617	83.06818	362.3184807	0	0	0	100	0	0.96	4	2
Sub_205189	Jun_205189	0.03118	78.22581	243.9080756	0	0	0	50	0	0.96	4	2
Sub_205190	Jun_205190	0.043074	81.74419	352.104924	0	0	0	20	0	1.44	7	3
Sub_205191	Jun_205191	0.07891	75.06329	592.3244214	0	0	0	150	0	2.4	10	5
Sub_205192	Jun_205192	0.103366	91.35922	944.3437135	0	0	0	250	0	2.88	12	6
Sub_205193	Jun_205193	0.116132	92.4569	1073.720471	0	0	0	0	0	2.4	10	5
Sub_205194	Jun_205194	0.074738	93.33333	697.5546418	0	0	0	200	0	1.92	9	4
Sub_205195	Jun_205195	0.051679	85.96154	444.2406426	0	0	0	130	0	0.96	5	2
Sub_205196	Jun_205196	0.057671	92.63158	534.215585	0	40	0	0	0	0.96	5	2
Sub_205197	Jun_205197	0.053656	61.2963	328.8914273	0	30	0	0	0	0.96	4	2
Sub_205198	Jun_205198	0.172216	40.49419	697.3747425	0	0	0	240	0	5.28	23	11
Sub_205199	Jun_205199	0.061866	91.93548	568.7680406	0	0	0	60	0	0.96	4	2
Sub_205200	Jun_205200	0.200422	83.2	1667.51104	0	0	0	180	0	6.24	26	13
Sub_205201	Jun_205201	0.049045	91.32653	447.9109664	0	0	0	0	0	0.48	2	1
Sub_205202	Jun_205202	0.077518	65.97403	511.4174858	0	0	0	0	0	1.92	9	4
Sub_205203	Jun_205203	0.073356	75.13699	551.1749038	0	0	0	0	0	1.44	6	3
Sub_205204	Jun_205204	0.141652	48.1338	681.8249038	0	0	0	165	0	3.84	17	8
Sub_205205	Jun_205205	0.169195	40.76923	689.794987	0	0	0	0	0	2.88	13	6
Sub_205206	Jun_205206	0.394193	37.3731	1473.221441	0	0	0	0	0	8.16	34	17
Sub_205207	Jun_205207	0.299716	42.13333	1262.803313	0	0	0	305	0	5.28	23	11
Sub_205209	Jun_205209	0.041586	91.42857	380.2148512	0	0	0	0	0	0.48	2	1
Sub_205210	Jun_205210	0.043439	91.59091	397.8617539	0	0	0	0	0	0.48	2	1
Sub_205211I	Jun_G17	0.021023	77.2034	162.3047078	0	0	0	0	0	0	0	0
Sub_205212	Jun_G14	0	0	0	0	0	0	0	0	0	0	0
Sub_205213	Jun_G15	0	0	0	0	0	0	0	0	0	0	0
Sub_205213A	Jun_G17	0.003054	76.75989	23.44247041	0	0	0	0	0	0	0	0
Sub_205214	Jun_G14	0.028397	70.9215	201.3957836	0	0	0	0	0	0.48	3	1
Sub_205216	Jun_205216	0.009942	83.5	83.0157	0	0	0	60	0	0	0	0
Sub_205217	Jun_205217	0.017848	95	169.556	0	0	0	150	0	0.48	3	1
Sub_205218	Jun_205218	0.024653	95	234.2035	0	0	0	183	0	0.96	4	2

SC_ID	Outlet	Area (ha)	Impv.%	Impv. Area (m^2)	IT (m^2)		PP (m^2)		Total area RB (m^2)		Population	House(s)
					Min	Max	Min	Max	Min	Max		
Sub_205219	Jun_205219	0.050819	95	482.7805	0	0	0	183	0	1.92	9	4
Sub_205220	Jun_205220	0.164862	86.0303	1418.312732	0	0	0	250	0	4.32	19	9
Sub_205221	Jun_205221	0.166497	84.82036	1412.233548	0	0	0	250	0	4.32	19	9
Sub_205222	Jun_205222	0.094244	89.94737	847.6999938	0	0	0	280	0	1.44	7	3
Sub_205223	Jun_205223	0.066367	81.49254	540.8415402	0	0	0	250	0	0.96	4	2
Sub_205224	Jun_205224	0.117978	91.77966	1082.798073	0	35	0	200	0	2.4	10	5
Sub_205225	Jun_205225	0.138618	85.07194	1179.250218	0	0	0	350	0	4.32	18	9
Sub_205226	Jun_205226	0.113256	87.38938	989.7371621	0	58	0	110	0	2.88	12	6
Sub_205227	Jun_205227	0.076005	92.89474	706.0464714	0	0	0	0	0	1.92	8	4
Sub_205228	Jun_205228	0.074596	72.46667	540.5723715	0	0	0	250	0	1.92	8	4
Sub_205229	Jun_205229	0.101196	88.86139	899.2417222	0	0	0	0	0	2.88	13	6
Sub_205230	Jun_205230	0.025202	86	216.7372	0	0	0	0	0	0.48	1	1
Sub_205231I	Jun_205231	0.001942	90	17.478	0	0	0	0	0	0	0	0
Sub_205300	Jun_205300	0.022013	92.72727	204.1205395	0	0	0	0	0	0.48	1	1
Sub_205300F	Jun_205300F	0.004567	90	41.103	0	0	0	0	0	0	0	0
Sub_205300INF	Jun_205300INF	0	0	0	0	0	0	0	0	0	0	0
Sub_205301INF	Jun_205301INF	0	0	0	0	0	0	0	0	0	0	0
Sub_205302INF	Jun_205302INF	0	0	0	0	0	0	0	0	0	0	0
Sub_205303INF	Jun_205303INF	0	0	0	0	0	0	0	0	0	0	0
Sub_205305INF	Jun_205305INF	0	0	0	0	0	0	0	0	0	0	0
Sub_205306INF	Jun_205306INF	0	0	0	0	0	0	0	0	0	0	0
Sub_205307INF	Jun_205307INF	0	0	0	0	0	0	0	0	0	0	0
Sub_205308INF	Jun_205308INF	0	0	0	0	0	0	0	0	0	0	0
Sub_205309INF	Jun_205309INF	0	0	0	0	0	0	0	0	0	0	0
Sub_205310INF	Jun_205310INF	0	0	0	0	0	0	0	0	0	0	0
Sub_205312INF	Jun_205312INF	0	0	0	0	0	0	0	0	0	0	0
Sub_206001	Jun_206001	0.113554	83.07018	943.295122	0	0	0	85	0	3.36	14	7
Sub_206002	Jun_206002	0.040283	79.5	320.24985	0	0	0	0	0	1.44	6	3
Sub_206003	Jun_206003	0.03125	90.48387	282.7620938	0	0	0	0	0	1.44	6	3
Sub_206004	Jun_206004	0.022083	95	209.7885	0	0	0	0	0	0.96	4	2
Sub_206005	Jun_206005	0.060728	89.2623	542.0720954	0	0	0	0	0	2.88	12	6
Sub_206006	Jun_206006	0	0	0	0	0	0	0	0	0	0	0
Sub_206007	Jun_206007	0.000328	58.66611	1.924248408	0	0	0	0	0	0	0	0
Sub_206007A	Jun_206007A	0.038232	95	363.204	0	0	0	0	0	1.44	7	3
Sub_206008	Jun_206008	0	0	0	0	0	0	0	0	0	0	0
Sub_206009	Jun_206009	0	0	0	0	0	0	0	0	0	0	0

SC_ID	Outlet	Area (ha)	Impv.%	Impv. Area (m^2)	IT (m^2)		PP (m^2)		Total area RB (m^2)		Population	House(s)
					Min	Max	Min	Max	Min	Max		
Sub_206010	Jun_206010	0.001802	95	17.119	0	0	0	0	0	0	0	0
Sub_206011	Jun_206011	0	0	0	0	0	0	0	0	0	0	0
Sub_206012	Jun_206012	0	0	0	0	0	0	0	0	0	0	0
Sub_206013	Jun_206013	0	0	0	0	0	0	0	0	0	0	0
Sub_206014	Jun_206014	0.004191	95	39.8145	0	0	0	0	0	0.48	1	1
Sub_206015	Jun_206015	0.091798	93.40659	857.4538149	0	0	0	0	0	3.36	15	7
Sub_206016	Jun_206016	0.105455	91.83962	968.4947127	0	0	0	0	0	1.92	8	4
Sub_206017	Jun_206017	0.072106	92.22222	664.9775395	0	0	0	0	0	1.44	6	3
Sub_206018	Jun_206018	0	0	0	0	0	0	0	0	0	0	0
Sub_206019	Jun_206019	0.002519	80	20.152	0	0	0	0	0	0	0	0
Sub_206020	Jun_206020	0.010004	80	80.032	0	0	0	0	0	0	0	0
Sub_206021	Jun_206021	0.016536	80.58824	133.2607137	0	0	0	0	0	0	0	0
Sub_206022	Jun_206022	0.079372	85.5	678.6306	0	0	0	0	0	2.4	10	5
Sub_206023	Jun_206023	0.039883	88.125	351.4689375	0	0	0	0	0	0.96	4	2
Sub_206024	Jun_206024	0.016444	81.25	133.6075	0	0	0	0	0	0	0	0
Sub_206025	Jun_206025	0.048766	89.08163	434.4154769	0	0	0	0	0	1.44	6	3
Sub_206026	Jun_206026	0.061516	89.91803	553.1397533	0	0	0	0	0	1.44	7	3
Sub_206027	Jun_206027	0.219111	90.68493	1987.00657	0	0	0	0	0	6.24	27	13
Sub_206028	Jun_206028	0	0	0	0	0	0	0	0	0	0	0
Sub_206029	Jun_206029	0	0	0	0	0	0	0	0	0	0	0
Sub_206030	Jun_206030	0.016629	95	157.9755	0	0	0	0	0	0.48	3	1
Sub_206031	Jun_206031	0.097038	93.45361	906.8551407	0	0	0	0	0	2.88	13	6
Sub_206032	Jun_206032	0.041871	81.34146	340.5848272	0	0	0	0	0	1.92	8	4
Sub_206033	Jun_206033	0.016914	95	160.683	0	0	0	0	0	0.48	3	1
Sub_206034	Jun_206034	0	0	0	0	0	0	0	0	0	0	0
Sub_206036	Jun_206036	0	0	0	0	0	0	0	0	0	0	0
Sub_206037	Jun_206037	0	0	0	0	0	0	0	0	0	0	0
Sub_206038	Jun_206038	0.000056	60.35764	0.338002784	0	0	0	0	0	0	0	0
Sub_206039	Jun_206039	0.010985	95	104.3575	0	0	0	0	0	0.48	2	1
Sub_206040	Jun_206040	0.179335	93.88889	1683.756409	0	0	0	0	0	6.24	27	13
Sub_206041	Jun_206041	0.006375	95	60.5625	0	0	0	0	0	0.48	1	1
Sub_206042	Jun_206042	0.026552	95	252.244	0	0	0	0	0	0.96	5	2
Sub_206043	Jun_206043	0.046567	95	442.3865	0	0	0	0	0	1.92	9	4
Sub_206044	Jun_206044	0.010178	90	91.602	0	0	0	0	0	0	0	0
Sub_206045	Jun_206045	0	0	0	0	0	0	0	0	0	0	0
Sub_206046	Jun_206046	0.025649	84.03846	215.5502461	0	0	0	0	0	0.48	1	1

SC_ID	Outlet	Area (ha)	Impv.%	Impv. Area (m^2)	IT (m^2)		PP (m^2)		Total area RB (m^2)		Population	House(s)
					Min	Max	Min	Max	Min	Max		
Sub_206047	Jun_206047	0.001447	80	11.576	0	0	0	0	0	0	0	0
Sub_206048	Jun_206048	0.002614	95	24.833	0	0	0	0	0	0.48	1	1
Sub_206049	Jun_206049	0.026959	82.22222	221.6628829	0	0	0	0	0	0	0	0
Sub_206050	Jun_206050	0.117764	91.65254	1079.336972	0	0	0	0	0	1.92	8	4
Sub_206051	Jun_206051	0.031988	95	303.886	0	0	0	0	0	1.44	6	3
Sub_206052	Jun_206052	0.045639	90.86957	414.7196305	0	0	0	240	0	0.48	2	1
Sub_206053	Jun_206053	0.026367	95	250.4865	0	0	0	180	0	0.96	5	2
Sub_206054	Jun_206054	0.030598	95	290.681	0	0	0	210	0	1.44	6	3
Sub_206055	Jun_206055	0.102655	95	975.2225	0	0	0	0	0	4.8	20	10
Sub_206056	Jun_206056	0.033989	95	322.8955	0	0	0	0	0	1.44	7	3
Sub_206057	Jun_206057	0.002515	95	23.8925	0	0	0	0	0	0	0	0
Sub_206058	Jun_206058	0.016685	90	150.165	0	0	0	0	0	0	0	0
Sub_206059	Jun_206059	0	0	0	0	0	0	0	0	0	0	0
Sub_206060	Jun_206060	0	0	0	0	0	0	0	0	0	0	0
Sub_206061	Jun_206061	0	0	0	0	0	0	0	0	0	0	0
Sub_206062	Jun_206062	0	0	0	0	0	0	0	0	0	0	0
Sub_206063	Jun_206063	0	0	0	0	0	0	0	0	0	0	0
Sub_206064	Jun_206064	0	0	0	0	0	0	0	0	0	0	0
Sub_206065	Jun_206065	0.009964	95	94.658	0	0	0	65	0	0.48	2	1
Sub_206066	Jun_206066	0	0	0	0	0	0	0	0	0	0	0
Sub_206067	Jun_206067	0	0	0	0	0	0	0	0	0	0	0
Sub_206068	Jun_206068	0	0	0	0	0	0	0	0	0	0	0
Sub_206069	Jun_206069	0.003718	95	35.321	0	0	0	25	0	0.48	1	1
Sub_206070	Jun_206070	0.027847	95	264.5465	0	0	0	195	0	0.96	5	2
Sub_206071	Jun_206071	0.032419	95	307.9805	0	0	0	225	0	1.44	6	3
Sub_206072	Jun_206072	0.003987	95	37.8765	0	0	0	25	0	0.48	1	1
Sub_206073	Jun_206073	0.03706	95	352.07	0	0	0	260	0	1.44	7	3
Sub_206074	Jun_206074	0.003389	95	32.1955	0	0	0	25	0	0.48	1	1
Sub_206075	Jun_206075	0	0	0	0	0	0	0	0	0	0	0
Sub_206076	Jun_206076	0.008305	95	78.8975	0	0	0	55	0	0.48	2	1
Sub_206077	Jun_206077	0.025544	95	242.668	0	0	0	170	0	0.96	5	2
Sub_206078	Jun_206078	0.010786	95	102.467	0	0	0	75	0	0.48	2	1
Sub_206079	Jun_206079	0.030554	95	290.263	0	0	0	210	0	1.44	6	3
Sub_206080	Jun_206080	0.015223	95	144.6185	0	0	0	0	0	0.48	3	1
Sub_206081	Jun_206081	0.016407	95	155.8665	0	0	0	0	0	0.48	3	1
Sub_206082	Jun_206082	0.065108	88.30769	574.9537081	0	0	0	0	0	1.44	6	3

SC_ID	Outlet	Area (ha)	Impv.%	Impv. Area (m^2)	IT (m^2)		PP (m^2)		Total area RB (m^2)		Population	House(s)
					Min	Max	Min	Max	Min	Max		
Sub_206083	Jun_206083	0.042939	91.16279	391.443904	0	0	0	0	0	0.96	4	2
Sub_206084	Jun_206084	0.010396	95	98.762	0	0	0	70	0	0.48	2	1
Sub_206084A	Jun_206084A	0.012372	95	117.534	0	0	0	85	0	0.48	2	1
Sub_206085	Jun_206085	0.021087	95	200.3265	0	0	0	145	0	0.96	4	2
Sub_206086	Jun_206086	0.041219	95	391.5805	0	0	0	285	0	1.92	8	4
Sub_206087	Jun_206087	0.064541	95	613.1395	0	0	0	450	0	2.88	13	6
Sub_206088	Jun_206088	0.042477	95	403.5315	0	0	0	295	0	1.92	8	4
Sub_206089	Jun_206089	0.010824	95	102.828	0	0	0	75	0	0.48	2	1
Sub_206090	Jun_206090	0.012019	95	114.1805	0	0	0	0	0	0.48	2	1
Sub_206091	Jun_206091	0.021065	95	200.1175	0	0	0	145	0	0.96	4	2
Sub_206092	Jun_206092	0.02583	95	245.385	0	0	0	180	0	0.96	5	2
Sub_206093	Jun_206093	0.025691	90	231.219	0	0	0	0	0	0	0	0
Sub_206094	Jun_206094	0.000925	95	8.7875	0	0	0	0	0	0	0	0
Sub_206095	Jun_206095	0.01373	95	130.435	0	0	0	96	0	0.48	3	1
Sub_206096	Jun_206096	0.004277	95	40.6315	0	0	0	30	0	0.48	1	1
Sub_206097	Jun_206097	0.027649	95	262.6655	0	0	0	190	0	0.96	5	2
Sub_206097A	Jun_206097A	0.010321	95	98.0495	0	0	0	72	0	0.48	2	1
Sub_206098	Jun_206098	0.000875	95	8.3125	0	0	0	0	0	0	0	0
Sub_206099	Jun_206099	0.025553	95	242.7535	0	0	0	175	0	0.96	5	2
Sub_206100	Jun_206100	0.011077	95	105.2315	0	0	0	75	0	0.48	2	1
Sub_206101	Jun_206101	0.015712	95	149.264	0	0	0	105	0	0.48	3	1
Sub_206102	Jun_206102	0.041047	95	389.9465	0	0	0	285	0	1.92	8	4
Sub_206103	Jun_206103	0.040525	95	384.9875	0	0	0	280	0	1.92	8	4
Sub_206104	Jun_206104	0.021668	95	205.846	0	0	0	150	0	0.96	4	2
Sub_206105	Jun_206105	0.005806	95	55.157	0	0	0	40	0	0.48	1	1
Sub_206106	Jun_206106	0.009991	95	94.9145	0	0	0	65	0	0.48	2	1
Sub_206107	Jun_206107	0.077373	95	735.0435	0	0	0	540	0	3.36	15	7
Sub_206108	Jun_206108	0.030751	95	292.1345	0	0	0	215	0	1.44	6	3
Sub_206109	Jun_206109	0.003617	95	34.3615	0	0	0	25	0	0.48	1	1
Sub_206110	Jun_206110	0.034417	95	326.9615	0	0	0	240	0	1.44	7	3
Sub_206111	Jun_206111	0.028602	95	271.719	0	0	0	200	0	1.44	6	3
Sub_206112	Jun_206112	0	0	0	0	0	0	0	0	0	0	0
Sub_206113	Jun_206113	0.029318	95	278.521	0	0	0	0	0	1.44	6	3
Sub_206114	Jun_206114	0.035861	95	340.6795	0	0	0	0	0	1.44	7	3
Sub_206115	Jun_206115	0.055694	95	529.093	0	0	0	0	0	2.4	11	5
Sub_206116	Jun_206116	0.028738	95	273.011	0	0	0	0	0	1.44	6	3

SC_ID	Outlet	Area (ha)	Impv.%	Impv. Area (m^2)	IT (m^2)		PP (m^2)		Total area RB (m^2)		Population	House(s)
					Min	Max	Min	Max	Min	Max		
Sub_206117	Jun_206117	0.022424	95	213.028	0	0	0	0	0	0.96	4	2
Sub_206118	Jun_206118	0.011457	90	103.113	0	0	0	0	0	0	0	0
Sub_206119	Jun_206119	0.02377	94.16667	223.8341746	0	0	0	150	0	0.96	4	2
Sub_206120	Jun_206120	0.009611	95	91.3045	0	0	0	67	0	0.48	2	1
Sub_206121	Jun_206121	0.002193	95	20.8335	0	0	0	15	0	0	0	0
Sub_206122	Jun_206122	0.007504	95	71.288	0	0	0	52	0	0.48	1	1
Sub_206123	Jun_206123	0.015732	95	149.454	0	0	0	110	0	0.48	3	1
Sub_206124	Jun_206124	0	0	0	0	0	0	0	0	0	0	0
Sub_206125	Jun_206125	0	0	0	0	0	0	0	0	0	0	0
Sub_206126	Jun_206126	0	0	0	0	0	0	0	0	0	0	0
Sub_206127	Jun_206127	0.018079	95	171.7505	0	0	0	125	0	0.96	4	2
Sub_206128	Jun_206128	0.004302	95	40.869	0	0	0	30	0	0.48	1	1
Sub_206129	Jun_206129	0.063854	95	606.613	0	0	0	300	0	2.88	12	6
Sub_206130	Jun_206130	0	0	0	0	0	0	0	0	0	0	0
Sub_206131	Jun_206131	0	0	0	0	0	0	0	0	0	0	0
Sub_206132	Jun_206132	0	0	0	0	0	0	0	0	0	0	0
Sub_206133	Jun_206133	0.007694	95	73.093	0	0	0	60	0	0.48	1	1
Sub_206134	Jun_206134	0	0	0	0	0	0	0	0	0	0	0
Sub_206135	Jun_206135	0	0	0	0	0	0	0	0	0	0	0
Sub_206136	Jun_206136	0.008789	95	83.4955	0	0	0	0	0	0.48	2	1
Sub_206137	Jun_206137	0.007985	95	75.8575	0	0	0	0	0	0.48	2	1
Sub_206138	Jun_206138	0.044767	94.33333	422.3020184	0	0	0	0	0	1.92	8	4
Sub_206139	Jun_206139	0.020186	92.25	186.21585	0	20	0	0	0	0.48	2	1
Sub_206140	Jun_206140	0.00518	95	49.21	0	15	0	0	0	0.48	1	1
Sub_206141	Jun_206141	0.015483	90	139.347	0	30	0	0	0	0	0	0
Sub_206142	Jun_206142	0.097606	93.26531	910.3253848	0	0	0	0	0	2.88	12	6
Sub_206143	Jun_206143	0.029525	90.66667	267.6933432	0	0	0	0	0	0.48	1	1
Sub_206144	Jun_206144	0	0	0	0	0	0	0	0	0	0	0
Sub_206145	Jun_206145	0.09241	91.23656	843.117051	0	0	0	0	0	0.96	4	2
Sub_206146	Jun_206146	0	0	0	0	0	0	0	0	0	0	0
Sub_206147	Jun_206147	0	0	0	0	0	0	0	0	0	0	0
Sub_206148	Jun_206148	0.012835	95	121.9325	0	0	0	0	0	0.48	2	1
Sub_206149	Jun_206149	0	0	0	0	0	0	0	0	0	0	0
Sub_206150	Jun_206150	0.013842	95	131.499	0	0	0	0	0	0.48	3	1
Sub_206151	Jun_206151	0.012558	95	119.301	0	0	0	0	0	0.48	2	1
Sub_206152	Jun_206152	0.050814	95	482.733	0	0	0	0	0	2.4	10	5

SC_ID	Outlet	Area (ha)	Impv.%	Impv. Area (m^2)	IT (m^2)		PP (m^2)		Total area RB (m^2)		Population	House(s)
					Min	Max	Min	Max	Min	Max		
Sub_206153	Jun_206153	0.02735	95	259.825	0	0	0	0	0	0.96	5	2
Sub_207001	Jun_207001	0.078154	95	742.463	0	0	0	0	0	2.88	13	6
Sub_207002	Jun_207002	0.038777	94.87179	367.8843401	0	0	0	0	0	1.44	7	3
Sub_207003	Jun_207003	0.057742	88.27586	509.7224708	0	0	0	0	0	0.96	5	2
Sub_207004	Jun_207004	0.057016	81.92982	467.1310617	0	0	0	0	0	0	0	0
Sub_207005	Jun_207005	0.181685	89.61326	1628.138514	0	0	0	0	0	3.36	14	7
Sub_207006	Jun_207006	0.044327	91.59091	405.9950268	0	0	0	270	0	0.48	2	1
Sub_207007	Jun_207007	0.01064	90	95.76	0	0	0	90	0	0	0	0
Sub_207008	Jun_207008	0	0	0	0	0	0	0	0	0	0	0
Sub_207009	Jun_207009	0.007345	95	69.7775	0	0	0	50	0	0.48	1	1
Sub_207010	Jun_207010	0.016917	95	160.7115	0	0	0	160	0	0.48	3	1
Sub_207011	Jun_207011	0.004019	90	36.171	0	0	0	35	0	0	0	0
Sub_209002	Jun_G03	0.018823	57.66237	108.5378791	0	0	0	0	0	0	6	3
Sub_209003	Jun_209003	0.009418	90	84.762	0	13	0	27	0	0	0	0
Sub_209005	Jun_209005	0.025325	90	227.925	0	0	0	0	0	0	0	0
Sub_209009	Jun_209009	0.067655	92.86765	628.2960861	0	0	0	0	0	1.44	7	3
Sub_209009X	Jun_209009X	0.308266	83.53896	2575.222104	0	0	0	235	0	5.28	23	11
Sub_209009Y	Jun_209009Y	0.122699	86.35246	1059.536049	0	0	0	235	0	3.36	14	7
Sub_209015	Jun_209015	0.024944	90	224.496	0	53	0	0	0	0	0	0
Sub_209016	Jun_209016	0.058676	88.72881	520.6251656	0	0	0	120	0	0.96	5	2
Sub_209017	Jun_209017	0.051987	78.07692	405.898484	0	76	0	100	0	0.96	5	2
Sub_209018	Jun_209018	0.090122	90.72222	817.6067911	0	0	0	250	0	1.44	7	3
Sub_209019	Jun_209019	0.049446	79.5	393.0957	0	50	0	80	0	0.48	3	1
Sub_209020	Jun_209020	0.049704	83.9	417.01656	0	0	0	170	0	1.44	6	3
Sub_209021	Jun_209021	0.067598	88.16176	595.9558652	0	0	0	150	0	1.92	8	4
Sub_209023	Jun_209023	0.133728	79.02256	1056.75289	0	0	0	200	0	3.36	15	7
Sub_209024	Jun_209024	0.089576	83.31461	746.2989505	0	0	0	200	0	2.4	11	5
Sub_215229	Jun_215229	0.068684	86.98529	597.4497658	0	0	0	0	0	1.92	8	4
Sub_219003	Jun_219003	0.003885	90	34.965	0	0	0	0	0	0	0	0
Sub_219021	Jun_219021	0.070128	87.64286	614.6218486	0	0	0	70	0	1.92	9	4
Sub_290000	Jun_290000	0.047582	91.04167	433.1944742	0	0	0	50	0	0.96	4	2
Sub_290004	Jun_290004	0.060325	90.5	545.94125	0	0	0	70	0	0.48	1	1
Sub_290008	Jun_290008	0.288187	87.39583	2518.634206	0	0	0	105	0	3.36	15	7
Sub_290012	Jun_290012	0.153057	87.72727	1342.727276	0	0	0	70	0	3.36	15	7
Sub_290016	Jun_290016	0.043203	92.38636	399.1367911	0	30	0	50	0	0.96	4	2
Sub_290018	Jun_290018	0.10201	92.2549	941.0922349	0	0	0	85	0	3.36	14	7

SC_ID	Outlet	Area (ha)	Impv.%	Impv. Area (m^2)	IT (m^2)		PP (m^2)		Total area RB (m^2)		Population	House(s)
					Min	Max	Min	Max	Min	Max		
Sub_295121	Jun_295121	0.162766	65.39877	1064.46962	0	0	0	450	0	1.44	7	3
Sub_295205	Jun_295205	0.099654	59.79798	595.9107899	0	0	0	0	0	2.4	11	5
Sub_295224	Jun_295224	0	0	0	0	0	0	0	0	0	0	0
Sub_296083	Jun_296083	0.033944	95	322.468	0	0	0	0	0	1.44	7	3
Sub_296131	Jun_296131	0.013394	95	127.243	0	0	0	93	0	0.48	3	1
Sub_296132	Jun_296132	0.016799	95	159.5905	0	0	0	120	0	0.48	3	1
Sub_296135	Jun_296135	0	0	0	0	0	0	0	0	0	0	0
Sub_RCplan1	Jun_RCplan1	0.0263	78.84615	207.3653745	0	0	0	60	0	0	0	0
Sub_RCplan10	Jun_RCplan10	0.0655	54.38907	356.2484085	0	0	0	60	0	0.96	0	0
Sub_RCplan10_toe	Jun_RCplan10	1.244	51.00849	6345.456156	0	0	0	0	0	0	0	0
Sub_RCplan11	Jun_RCplan11	0.0389	90	350.1	0	50	0	50	0	0.96	0	0
Sub_RCplan12	Jun_RCplan12	0.1195	90.12605	1077.006298	0	0	0	300	0	0.96	0	0
Sub_RCplan13	Jun_RCplan13	0.117	81.53846	953.999982	0	0	0	100	0	0.96	0	0
Sub_RCplan14	Jun_RCplan14	0.0187	90	168.3	0	0	0	0	0	0	0	0
Sub_RCplan16	Jun_RCplan16	0.0369	90	332.1	0	0	0	0	0	0	0	0
Sub_RCplan17	Jun_RCplan17	0.0374	84.60526	316.4236724	0	0	0	100	0	1.44	0	0
Sub_RCplan2	Jun_RCplan2	0.0299	88	263.12	0	0	0	100	0	0	0	0
Sub_RCplan20_toe	Jun_RCplan20	1.244	53.9002	6705.18488	0	30	0	0	0	0	0	0
Sub_RCplan3	Jun_RCplan3	0.0435	87.55814	380.877909	0	50	0	90	0	0.96	0	0
Sub_RCplan4	Jun_RCplan4	0.0608	81.22951	493.8754208	0	0	0	150	0	0	0	0
Sub_RCplan5	Jun_RCplan5	0.0529	85.66038	453.1434102	0	50	0	100	0	1.44	0	0
Sub_RCplan6	Jun_RCplan6	0.03	90	270	0	0	0	0	0	0.96	0	0
Sub_RCplan7	Jun_RCplan7	0.0352	90	316.8	0	0	0	60	0	1.92	0	0
Sub_RCplan8	Jun_RCplan8	0.0597	90.91667	542.7725199	0	0	0	120	0	2.88	0	0
Sub_RCplan9	Jun_RCplan9	0.0807	90.49383	730.2852081	0	0	0	110	0	1.92	0	0

Appendix H - Model Validation

A calibrated SWMM model of the case study location is used to simulate the optimisation process in the case study location. Before starting the optimisation process in this thesis, validation of the model using the monitoring data from the case study location in Riethoven is needed to see whether the available model is accurate enough to model the rainfall-runoff process. The validation was done using the monitoring data from water level sensors located in all combined sewer overflow (CSO) chambers and the main pumping station in 2018. There is no available flooding-related data from the case study location; thus, the validation process checks the model's accuracy in modelling the rainfall/runoff process based on the water level at the pumping station and predicting CSO events. It is assumed that the model is generally satisfactory in predicting flooding events when it is accurate enough to generate runoff and route the flow in the network.

To assess the accuracy of the model compared to the monitoring data, a hydrology evaluator parameter called Nash–Sutcliffe efficiency index (NSE) is used along with the ratio of the root mean square error (RMSE) to the standard deviation of the monitoring data (RSR) developed by Moriasi *et al.* (2017) [87]. NSE is one of the widely known assessment criteria for the fitness of hydrologic models [88, 89]. NSE calculated the absolute difference between the monitoring and model prediction data, normalized by the variance of the monitoring data. The NSE value can range between 1 to -infinity, with 1 being the perfect fittest value, 0.0 – 1.0 being the acceptable value, and ≤ 0.0 means that the model is unacceptable as the monitoring data give a better prediction than the model [87]. Despite its wide usage, assessment of accuracy using only NSE has its downside. NSE is a dimensionless evaluation index, which indicates how well the plot of monitoring data vs simulation fits the 1:1 linear line. It is calculated based on the normalized value of the ratio between the residual variance to monitoring data variance (Equation (H-1)). Due to this squared value of variances, NSE is sensitive to high extreme values, leading to overestimating and negating the lower values. Thefore, Moriasi *et al.* (2017) [87] suggested coupling NSE evaluation with RSR as the error-index evaluator.

$$NSE = 1 - \frac{\sum_{i=1}^{n}\left(X_i^{obs} - X_i^{sim}\right)^2}{\sum_{i=1}^{n}(X_i^{obs} - X^{mean})^2} \tag{H-1}$$

In general, RSR is a modified version of RMSE. It standardized the RMSE value using the monitoring data's standar deviation (Equation (H-2)).

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\sqrt{\sum_{i=1}^{n}\left(X_i^{obs} - X_i^{sim}\right)^2}}{\sqrt{\sum_{i=1}^{n}(X_i^{obs} - X^{mean})^2}} \tag{H-2}$$

The performance indicator of both NSE and RSR in Table D. 1 is used for the validation process. The thesis assumes that as long as the model reaches the level of 'Satisfactory' for both NSE and RSR, it is accurate enough to model the UDS rehabilitation measures.

Table H-1 Performance indicator for NSE and RSR

(Source: [87])

Performance Rating	Evaluator	
	RSR	NSE
Very good	0.0 ≤ RSR ≤ 0.5	0.75 < NSE ≤ 1.00
Good	0.5 < RSR ≤ 0.6	0.65 < NSE ≤ 0.75
Satisfactory	0.6 < RSR ≤ 0.7	0.50 < NSE ≤ 0.65
Unsatisfactory	RSR > 0.7	NSE ≤ 0.50

Based on the highest recorded rainfall analysis in 2018, three validation periods are chosen: 28 – 30 April, 9 – 11 August, and 7 – 11 December. It is assumed that these three validation periods can be representative enough to evaluate the model's performance. The monitoring data fluctuates a lot; thus, both the monitoring and simulation data are filtered further to only look at the interest value: during the increase of water level (> 23.8 m NAP). The results can be seen from the graphs below using the monitoring data of water level in the main pumping station and the simulation data from Jun_205019.

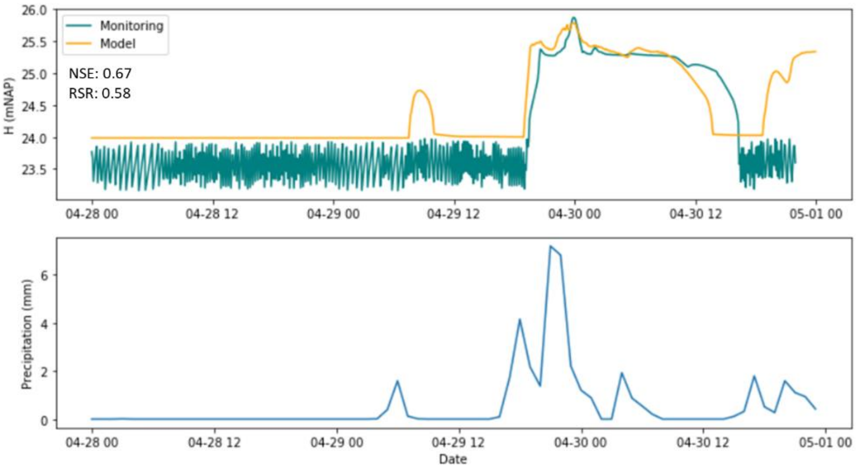


Figure H-1 Comparison between monitoring and simulation of pumping station from 28 - 30 April 2018

The validation resulted in NSE = 0.67 and RSR = 0.58 (Good model result)

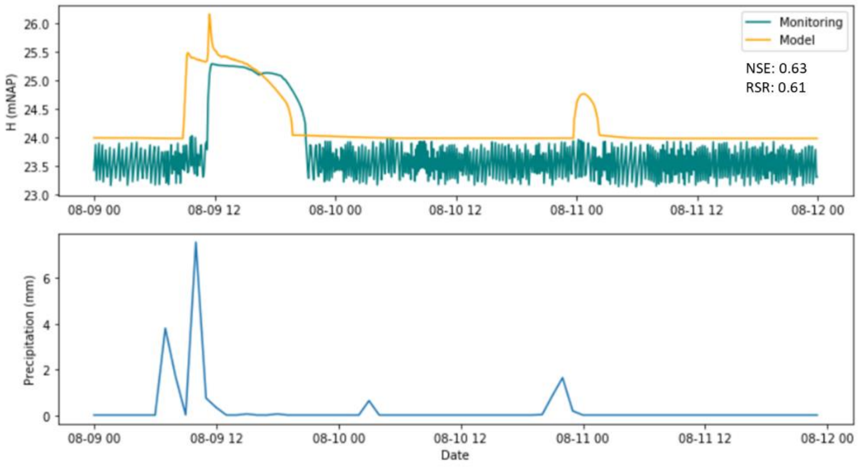


Figure H-2 Comparison between monitoring and simulation of pumping station from 9 - 11 August 2018

The validation resulted in NSE = 0.63 and RSR = 0.61 (Satisfactory model result)

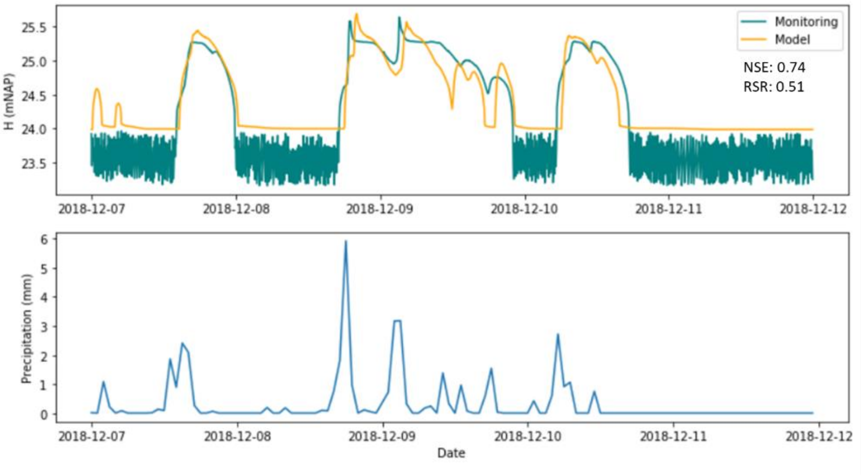


Figure H-3 Comparison between monitoring and simulation of pumping station from 7 - 11 December 2018

The validation resulted in NSE = 0.74 and RSR = 0.51 (Good model result)

Based on the model validation results from the pumping station, the model is good enough to be used directly for the thesis. The water level at the pumping station can be used to assume that the rainfall/runoff and flow routing of the model works decent enough as it is the most downstream point of the network. Generally, the model works better in colder months (April, December) compared to hot months (*e.g.* August). From Figure H-2, the timing of the water level increase comes early for the model. It means that in reality, the water attenuation is higher. This can be caused by several factors that are not incorporated in the model: Evaporation Rate and dynamic values of D-Store Imperviousness. During hot months, more water will evaporate from the surface and the soil can retain more water. The evaporation will also affect the surface capability to retain water in depression storage in impervious areas. As more water evaporated, the depression storage can withhold more water, thus, attenuate the flow.

The next validation is done to look at the model's ability to predict CSO events. Although CSO events are not the main interest process for this thesis, it can give a clearer view of the model's ability to simulate this event during heavy rainfall periods. However, there is a constant bias from the monitoring data values due to a shift in the sensor from CSO 1 and CSO 2. Therefore, the validation of CSO did not use the NSE and RSR values. The validation of occurrence can be calculated by using an accuracy score whether there is a CSO event from that particular rainfall event or not. CSO event happens when the water is overflowing from the CSO weirs. Based on that analysis, the precision of the model based on the number of True Positive, True Negative, False Positive, and False Negative values can also be calculated. The result shows that the model can accurately predict the CSO occurrences. However, it fails to estimate the water level peaks in each CSO chamber that the inaccurate monitoring data values can cause.

- Accuracy of CSO occurrence from CSO 1: 0.99
- Accuracy of CSO occurrence from CSO 2: 0.96
- Accuracy of CSO occurrence from CSO 3: 0.95

Table H-2 Matrix of model precision to predict CSO occurrences

	Model Output		
Sensor Output		CSO	No CSO
	CSO	28	4
	No CSO	12	454

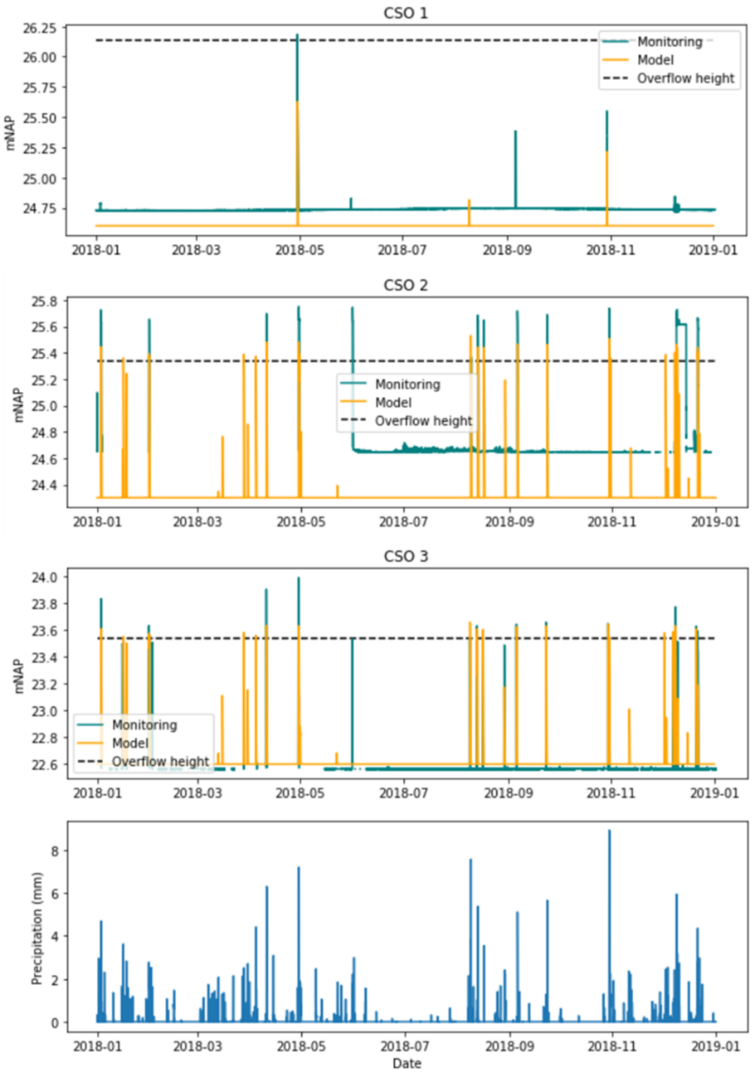


Figure H-4 Combined sewer overflow events occurrences (monitoring data vs simulation) for 2018

Appendix I – List of Decision Variables for the Optimisation

No. of decision variable	Sub-catchment/ Conduit ID	Minimum value of DV	Maximum value of DV	Intervention type
1	Sub_207001	0	2.88	RB
1	Sub_207002	0	1.44	RB
1	Sub_207003	0	0.96	RB
1	Sub_207005	0	3.36	RB
1	Sub_207009	0	0.48	RB
1	Sub_207010	0	0.48	RB
1	Sub_207006	0	0.48	RB
1	Sub_296131	0	0.48	RB
1	Sub_296132	0	0.48	RB
1	Sub_206133	0	0.48	RB
1	Sub_206122	0	0.48	RB
1	Sub_206123	0	0.48	RB
1	Sub_206127	0	0.96	RB
1	Sub_206128	0	0.48	RB
1	Sub_206129	0	2.88	RB
1	Sub_206119	0	0.96	RB
1	Sub_206120	0	0.48	RB
1	Sub_206138	0	1.92	RB
1	Sub_206139	0	0.48	RB
1	Sub_206140	0	0.48	RB
1	Sub_206142	0	2.88	RB
1	Sub_206143	0	0.48	RB
1	Sub_206145	0	0.96	RB
2	Sub_206108	0	1.44	RB
2	Sub_206109	0	0.48	RB
2	Sub_206110	0	1.44	RB
2	Sub_206111	0	1.44	RB
2	Sub_206104	0	0.96	RB
2	Sub_206105	0	0.48	RB
2	Sub_206106	0	0.48	RB
2	Sub_206107	0	3.36	RB
2	Sub_206099	0	0.96	RB
2	Sub_206100	0	0.48	RB
2	Sub_206101	0	0.48	RB
2	Sub_206102	0	1.92	RB
2	Sub_206103	0	1.92	RB
2	Sub_206095	0	0.48	RB
2	Sub_206096	0	0.48	RB
2	Sub_206097	0	0.96	RB
2	Sub_206097A	0	0.48	RB
2	Sub_206091	0	0.96	RB
2	Sub_206092	0	0.96	RB
3	Sub_206084	0	0.48	RB
3	Sub_206084A	0	0.48	RB
3	Sub_206085	0	0.96	RB
3	Sub_206086	0	1.92	RB
3	Sub_206087	0	2.88	RB
3	Sub_206088	0	1.92	RB
3	Sub_206089	0	0.48	RB
3	Sub_206072	0	0.48	RB
3	Sub_206073	0	1.44	RB
3	Sub_206074	0	0.48	RB
3	Sub_206076	0	0.48	RB
3	Sub_206077	0	0.96	RB
3	Sub_206078	0	0.48	RB
3	Sub_206079	0	1.44	RB
3	Sub_206065	0	0.48	RB
3	Sub_206069	0	0.48	RB
3	Sub_206070	0	0.96	RB
3	Sub_206071	0	1.44	RB
4	Sub_206051	0	1.44	RB
4	Sub_206055	0	4.8	RB
4	Sub_206056	0	1.44	RB
4	Sub_206052	0	0.48	RB
4	Sub_206053	0	0.96	RB
4	Sub_206054	0	1.44	RB

No. of decision variable	Sub-catchment/ Conduit ID	Minimum value of DV	Maximum value of DV	Intervention type
4	Sub_206039	0	0.48	RB
4	Sub_206043	0	1.92	RB
4	Sub_206046	0	0.48	RB
4	Sub_206048	0	0.48	RB
4	Sub_206040	0	6.24	RB
4	Sub_206041	0	0.48	RB
4	Sub_206042	0	0.96	RB
5	Sub_202021	0	0.96	RB
5	Sub_202022	0	0.48	RB
5	Sub_202023	0	0.48	RB
5	Sub_202024	0	0.48	RB
5	Sub_202025	0	1.44	RB
5	Sub_202026	0	0.48	RB
5	Sub_202001	0	0.48	RB
5	Sub_202002	0	0.48	RB
5	Sub_202003	0	0.48	RB
5	Sub_202005	0	0.48	RB
5	Sub_202006	0	0.48	RB
6	Sub_206022	0	2.4	RB
6	Sub_206023	0	0.96	RB
6	Sub_206148	0	0.48	RB
6	Sub_206150	0	0.48	RB
6	Sub_206151	0	0.48	RB
6	Sub_206152	0	2.4	RB
6	Sub_206153	0	0.96	RB
7	Sub_290018	0	3.36	RB
7	Sub_209009	0	1.44	RB
7	Sub_209009X	0	5.28	RB
7	Sub_209009Y	0	3.36	RB
7	Sub_205103	0	1.44	RB
7	Sub_205104	0	1.92	RB
7	Sub_205105	0	0.48	RB
7	Sub_205098	0	1.92	RB
7	Sub_290000	0	0.96	RB
7	Sub_205101	0	4.32	RB
7	Sub_205102	0	3.36	RB

No. of decision variable	Sub-catchment/ Conduit ID	Minimum value of DV	Maximum value of DV	Intervention type
7	Sub_290004	0	0.48	RB
7	Sub_290012	0	3.36	RB
7	Sub_290016	0	0.96	RB
7	Sub_205033	0	0.48	RB
7	Sub_205034	0	1.92	RB
7	Sub_205035	0	2.88	RB
7	Sub_205036	0	1.92	RB
7	Sub_205037	0	3.36	RB
7	Sub_205038	0	3.36	RB
8	Sub_205224	0	2.4	RB
8	Sub_205225	0	4.32	RB
8	Sub_205226	0	2.88	RB
8	Sub_205220	0	4.32	RB
8	Sub_205221	0	4.32	RB
8	Sub_205222	0	1.44	RB
8	Sub_205223	0	0.96	RB
8	Sub_205227	0	1.92	RB
8	Sub_205228	0	1.92	RB
8	Sub_205229	0	2.88	RB
8	Sub_215229	0	1.92	RB
8	Sub_205230	0	0.48	RB
8	Sub_205105X	0	1.44	RB
8	Sub_209016	0	0.96	RB
8	Sub_209017	0	0.96	RB
8	Sub_209018	0	1.44	RB
8	Sub_209019	0	0.48	RB
8	Sub_209020	0	1.44	RB
8	Sub_209021	0	1.92	RB
8	Sub_209023	0	3.36	RB
8	Sub_209024	0	2.4	RB
8	Sub_219021	0	1.92	RB
9	Sub_205217	0	0.48	RB
9	Sub_205218	0	0.96	RB
9	Sub_205219	0	1.92	RB
9	Sub_205025	0	1.44	RB
9	Sub_205026	0	1.44	RB

No. of decision variable	Sub-catchment/ Conduit ID	Minimum value of DV	Maximum value of DV	Intervention type
9	Sub_205027	0	1.44	RB
9	Sub_205028	0	2.88	RB
9	Sub_205029	0	1.92	RB
9	Sub_205030	0	1.92	RB
9	Sub_205031	0	3.36	RB
9	Sub_205032	0	0.96	RB
10	Sub_RCplan17	0	1.44	RB
10	Sub_205061	0	1.92	RB
10	Sub_205062	0	0.96	RB
10	Sub_205063	0	0.48	RB
10	Sub_205064	0	0.96	RB
10	Sub_205066	0	0.48	RB
10	Sub_205041	0	0.96	RB
10	Sub_205042	0	1.44	RB
10	Sub_205042X	0	2.88	RB
10	Sub_205043	0	0.96	RB
10	Sub_205044	0	1.92	RB
10	Sub_205045	0	1.44	RB
10	Sub_205046	0	0.48	RB
11	Sub_205162	0	1.44	RB
11	Sub_205163	0	0.48	RB
11	Sub_205164	0	1.92	RB
11	Sub_205165	0	0.96	RB
11	Sub_205166	0	0.48	RB
11	Sub_205168	0	2.88	RB
11	Sub_205169	0	1.92	RB
11	Sub_205170	0	1.44	RB
11	Sub_205171	0	1.44	RB
11	Sub_205172	0	1.44	RB
11	Sub_205173	0	1.92	RB
11	Sub_205107	0	2.4	RB
11	Sub_205108	0	2.88	RB
11	Sub_205109	0	3.84	RB
11	Sub_205110	0	1.92	RB
11	Sub_205174	0	0.96	RB
11	Sub_205175	0	1.44	RB
11	Sub_205176	0	1.44	RB
11	Sub_205177	0	0.48	RB
11	Sub_205178	0	0.96	RB
11	Sub_205179	0	1.44	RB
11	Sub_205180	0	0.48	RB
11	Sub_205115	0	2.4	RB
11	Sub_205116	0	2.88	RB
11	Sub_205126	0	0.48	RB
11	Sub_205111	0	2.4	RB
11	Sub_205112	0	1.44	RB
11	Sub_205113	0	2.4	RB
11	Sub_205114	0	1.92	RB
11	Sub_205117	0	0.48	RB
12	Sub_205181	0	0.48	RB
12	Sub_205182	0	1.92	RB
12	Sub_205184	0	1.92	RB
12	Sub_205185	0	2.4	RB
12	Sub_205186	0	1.92	RB
12	Sub_205194	0	1.92	RB
12	Sub_205195	0	0.96	RB
12	Sub_205197	0	0.96	RB
12	Sub_205187	0	2.4	RB
12	Sub_205188	0	0.96	RB
12	Sub_205189	0	0.96	RB
12	Sub_205190	0	1.44	RB
12	Sub_205191	0	2.4	RB
12	Sub_205192	0	2.88	RB
12	Sub_205199	0	0.96	RB
12	Sub_205193	0	2.4	RB
12	Sub_205200	0	6.24	RB
12	Sub_205201	0	0.48	RB
12	Sub_205209	0	0.48	RB
12	Sub_205210	0	0.48	RB
13	Sub_205118	0	4.32	RB
13	Sub_205118A	0	0.96	RB
13	Sub_205119	0	2.88	RB

No. of decision variable	Sub-catchment/ Conduit ID	Minimum value of DV	Maximum value of DV	Intervention type
13	Sub_205124	0	0.48	RB
13	Sub_205125	0	0.96	RB
13	Sub_RCplan10	0	0.96	RB
13	Sub_RCplan6	0	0.96	RB
13	Sub_RCplan7	0	2.88	RB
13	Sub_RCplan8	0	1.92	RB
13	Sub_RCplan9	0	0.96	RB
13	Sub_205214	0	0.48	RB
13	Sub_205080	0	0.48	RB
14	Sub_205067	0	0.96	RB
14	Sub_205068	0	0.96	RB
14	Sub_205069	0	1.44	RB
14	Sub_205070	0	1.44	RB
14	Sub_205071	0	1.44	RB
14	Sub_205072	0	1.44	RB
14	Sub_205076	0	1.92	RB
14	Sub_RCplan3	0	0.96	RB
14	Sub_RCplan5	0	1.44	RB
14	Sub_205073	0	2.4	RB
14	Sub_205074	0	2.88	RB
14	Sub_205075	0	2.4	RB
14	Sub_205013	0	0.96	RB
14	Sub_205014	0	0.96	RB
14	Sub_205015	0	0.48	RB
14	Sub_205016	0	0.48	RB
14	Sub_205017	0	0.48	RB
14	Sub_205300	0	0.48	RB
15	Sub_205160	0	0.48	RB
15	Sub_205161	0	0.96	RB
15	Sub_205021	0	0.48	RB
15	Sub_205022	0	1.92	RB
15	Sub_205023	0	2.88	RB
15	Sub_205048	0	0.48	RB
15	Sub_205150	0	0.48	RB
15	Sub_205151	0	5.76	RB
15	Sub_205154	0	0.48	RB
15	Sub_205155	0	0.48	RB
15	Sub_205156	0	5.28	RB
15	Sub_205139	0	0.48	RB
15	Sub_205140	0	0.48	RB
15	Sub_205141	0	0.48	RB
15	Sub_205142	0	0.48	RB
15	Sub_205143	0	1.44	RB
15	Sub_205145	0	0.96	RB
15	Sub_205147	0	0.48	RB
15	Sub_205148	0	1.44	RB
15	Sub_205149	0	0.96	RB
15	Sub_205128	0	1.44	RB
15	Sub_205129	0	0.48	RB
15	Sub_205130	0	0.48	RB
15	Sub_205131	0	0.96	RB
15	Sub_205132	0	0.48	RB
15	Sub_205133	0	0.48	RB
15	Sub_205134	0	0.96	RB
16	Sub_206139	0	20	IT
16	Sub_206140	0	15	IT
16	Sub_206141	0	30	IT
17	Sub_290016	0	30	IT
17	Sub_205039	0	30	IT
17	Sub_209003	0	13	IT
17	Sub_205024	0	52	IT
17	Sub_205033	0	60	IT
17	Sub_205224	0	35	IT
17	Sub_205226	0	58	IT
17	Sub_209015	0	53	IT
17	Sub_209017	0	76	IT
17	Sub_209019	0	50	IT
17	Sub_205099	0	15	IT
17	Sub_205107	0	20	IT
18	Sub_205114	0	25	IT
18	Sub_RCplan11	0	50	IT
18	Sub_RCplan20_toe	0	30	IT

No. of decision variable	Sub-catchment/ Conduit ID	Minimum value of DV	Maximum value of DV	Intervention type
18	Sub_RCplan3	0	50	IT
18	Sub_205077	0	50	IT
18	Sub_RCplan5	0	50	IT
18	Sub_205180	0	30	IT
18	Sub_205182	0	25	IT
18	Sub_205183	0	25	IT
18	Sub_205196	0	40	IT
18	Sub_205197	0	30	IT
19	Sub_202001	0	380	PP
19	Sub_202002	0	100	PP
19	Sub_202003	0	190	PP
20	Sub_202020	0	50	PP
20	Sub_202021	0	250	PP
20	Sub_202022	0	40	PP
20	Sub_202023	0	106	PP
20	Sub_202024	0	70	PP
20	Sub_202025	0	200	PP
20	Sub_202026	0	85	PP
21	Sub_205024	0	306	PP
21	Sub_205041	0	90	PP
21	Sub_205042	0	132	PP
21	Sub_205042X	0	160	PP
21	Sub_205043	0	130	PP
21	Sub_205044	0	50	PP
21	Sub_205045	0	85	PP
21	Sub_205046	0	85	PP
21	Sub_209003	0	27	PP
21	Sub_205039	0	70	PP
21	Sub_205062	0	55	PP
21	Sub_205063	0	70	PP
21	Sub_205064	0	30	PP
22	Sub_205076	0	100	PP
22	Sub_RCplan7	0	60	PP
22	Sub_RCplan8	0	120	PP
22	Sub_RCplan9	0	110	PP
22	Sub_RCplan10	0	60	PP
22	Sub_RCplan11	0	50	PP
22	Sub_RCplan12	0	300	PP
22	Sub_RCplan13	0	100	PP
22	Sub_RCplan1	0	60	PP
22	Sub_RCplan17	0	100	PP
22	Sub_RCplan2	0	150	PP
22	Sub_RCplan3	0	90	PP
22	Sub_RCplan4	0	150	PP
22	Sub_RCplan5	0	100	PP
23	Sub_205100	0	50	PP
23	Sub_205101	0	80	PP
23	Sub_205102	0	100	PP
23	Sub_205103	0	110	PP
23	Sub_205104	0	40	PP
23	Sub_205105	0	40	PP
23	Sub_205105X	0	70	PP
23	Sub_205107	0	30	PP
23	Sub_290000	0	50	PP
23	Sub_290004	0	70	PP
23	Sub_290008	0	105	PP
23	Sub_290012	0	70	PP
23	Sub_290016	0	50	PP
23	Sub_290018	0	85	PP
23	Sub_209009X	0	235	PP
23	Sub_209009Y	0	235	PP
24	Sub_205111	0	150	PP
24	Sub_205112	0	200	PP
24	Sub_205113	0	85	PP
24	Sub_205115	0	150	PP
24	Sub_205116	0	200	PP
24	Sub_205117	0	380	PP
24	Sub_205162	0	150	PP
24	Sub_205163	0	150	PP
24	Sub_205164	0	80	PP
24	Sub_205165	0	314	PP
24	Sub_205166	0	50	PP

No. of decision variable	Sub-catchment/ Conduit ID	Minimum value of DV	Maximum value of DV	Intervention type
24	Sub_205168	0	150	PP
24	Sub_205169	0	150	PP
24	Sub_205170	0	150	PP
24	Sub_205171	0	70	PP
24	Sub_205172	0	180	PP
24	Sub_205175	0	30	PP
24	Sub_205176	0	60	PP
24	Sub_205177	0	40	PP
24	Sub_205178	0	40	PP
24	Sub_205179	0	50	PP
24	Sub_205180	0	40	PP
24	Sub_205184	0	190	PP
24	Sub_205185	0	100	PP
24	Sub_205186	0	190	PP
24	Sub_205187	0	150	PP
25	Sub_205118	0	200	PP
25	Sub_205118A	0	100	PP
25	Sub_205119	0	300	PP
25	Sub_205121	0	300	PP
25	Sub_205122	0	250	PP
25	Sub_205123	0	150	PP
25	Sub_205124	0	75	PP
25	Sub_205125	0	50	PP
25	Sub_205120	0	355	PP
25	Sub_295121	0	450	PP
26	Sub_205216	0	60	PP
26	Sub_205217	0	150	PP
26	Sub_205218	0	183	PP
26	Sub_205219	0	183	PP
27	Sub_205220	0	250	PP
27	Sub_205221	0	250	PP
27	Sub_205222	0	280	PP
27	Sub_205223	0	250	PP
27	Sub_205228	0	250	PP
27	Sub_205224	0	200	PP
27	Sub_205225	0	350	PP
27	Sub_205226	0	110	PP
27	Sub_209020	0	170	PP
27	Sub_209021	0	150	PP
27	Sub_209023	0	200	PP
27	Sub_209024	0	200	PP
27	Sub_219021	0	70	PP
27	Sub_209016	0	120	PP
27	Sub_209017	0	100	PP
27	Sub_209018	0	250	PP
27	Sub_209019	0	80	PP
28	Sub_206069	0	25	PP
28	Sub_206070	0	195	PP
28	Sub_206071	0	225	PP
28	Sub_206072	0	25	PP
28	Sub_206073	0	260	PP
28	Sub_206074	0	25	PP
28	Sub_206076	0	55	PP
28	Sub_206077	0	170	PP
28	Sub_206078	0	75	PP
28	Sub_206079	0	210	PP
29	Sub_206084	0	70	PP
29	Sub_206084A	0	85	PP
29	Sub_206085	0	145	PP
29	Sub_206086	0	285	PP
29	Sub_206089	0	75	PP
29	Sub_206087	0	450	PP
29	Sub_206088	0	295	PP
30	Sub_206099	0	175	PP
30	Sub_206100	0	75	PP
30	Sub_206101	0	105	PP
30	Sub_206102	0	285	PP
30	Sub_206103	0	280	PP
30	Sub_206104	0	150	PP
30	Sub_206105	0	40	PP
30	Sub_206108	0	215	PP
30	Sub_206106	0	65	PP

No. of decision variable	Sub-catchment/ Conduit ID	Minimum value of DV	Maximum value of DV	Intervention type
30	Sub_206107	0	540	PP
30	Sub_206109	0	25	PP
30	Sub_206110	0	240	PP
30	Sub_206111	0	200	PP
31	Sub_207006	0	270	PP
31	Sub_207007	0	90	PP
31	Sub_207009	0	50	PP
31	Sub_207010	0	160	PP
31	Sub_207011	0	35	PP
32	Con_202009.2	Curve_202009.2	Curve_202009.2	Pump
33	Con_206014.2	Curve_206014.2	Curve_206014.2	Pump
34	Con_207011.1	Curve_207011.1	Curve_207011.1	Pump
35	Con_202002.2	0.1506	1.5	Pipe
35	Con_202004.1	0.1882	1.5	Pipe
35	Con_202005.1	0.1882	1.5	Pipe
35	Con_202006.1	0.1882	1.5	Pipe
35	Con_202007.1	0.1882	1.5	Pipe
35	Con_202008.1	0.1882	1.5	Pipe
36	Con_202023.1	0.1882	1.5	Pipe
36	Con_202021.1	0.1882	1.5	Pipe
36	Con_202022.1	0.1882	1.5	Pipe
36	Con_202018.1	0.1882	1.5	Pipe
36	Con_202019.1	0.1882	1.5	Pipe
36	Con_202020.1	0.1882	1.5	Pipe
37	Con_202012.1	0.1882	1.5	Pipe
37	Con_202013.1	0.1882	1.5	Pipe
37	Con_202014.1	0.1882	1.5	Pipe
37	Con_202009.1	0.1882	1.5	Pipe
37	Con_202011.1	0.1882	1.5	Pipe
37	Con_202015.1	0.1882	1.5	Pipe
37	Con_202016.1	0.1882	1.5	Pipe
37	Con_202017.1	0.1882	1.5	Pipe
38	Con_206023.1	0.3	1.5	Pipe
38	Con_206024.1	0.3	1.5	Pipe
38	Con_206025.1	0.3	1.5	Pipe
38	Con_206026.1	0.3	1.5	Pipe
38	Con_206018.1	0.3	1.5	Pipe
38	Con_206019.1	0.3	1.5	Pipe
38	Con_206020.1	0.3	1.5	Pipe
38	Con_206021.1	0.3	1.5	Pipe
38	Con_206022.1	0.3	1.5	Pipe
38	Con_206014.1	0.3	1.5	Pipe
38	Con_206015.1	0.3	1.5	Pipe
38	Con_206016.1	0.3	1.5	Pipe
38	Con_206017.1	0.3	1.5	Pipe
39	Con_206150.1	0.1882	1.5	Pipe
39	Con_206151.1	0.1882	1.5	Pipe
39	Con_206152.1	0.1882	1.5	Pipe
39	Con_206146.2	0.1882	1.5	Pipe
39	Con_206149.1	0.1882	1.5	Pipe
39	Con_206018.2	0.1882	1.5	Pipe
40	Con_206012.1	0.4	1.5	Pipe
40	Con_206012.2	0.4	1.5	Pipe
40	Con_206013.1	0.4	1.5	Pipe
40	Con_206028.1	0.4	1.5	Pipe
40	Con_206029.1	0.4	1.5	Pipe
40	Con_206030.1	0.4	1.5	Pipe
40	Con_206031.1	0.4	1.5	Pipe
40	Con_206032.1	0.4	1.5	Pipe
40	Con_206033.1	0.4	1.5	Pipe
41	Con_206040.1	0.1882	1.5	Pipe
41	Con_206041.1	0.1882	1.5	Pipe
41	Con_206039.1	0.1882	1.5	Pipe
41	Con_206034.1	0.3	1.5	Pipe
41	Con_206036.1	0.3	1.5	Pipe
41	Con_206037.1	0.3	1.5	Pipe
41	Con_206038.1	0.3	1.5	Pipe
41	Con_206039.2	0.3	1.5	Pipe
41	Con_206043.1	0.3	1.5	Pipe
41	Con_206044.1	0.3	1.5	Pipe
41	Con_206045.1	0.3	1.5	Pipe
41	Con_206046.1	0.3	1.5	Pipe

No. of decision variable	Sub-catchment/ Conduit ID	Minimum value of DV	Maximum value of DV	Intervention type
41	Con_206047.1	0.3	1.5	Pipe
41	Con_206048.1	0.3	1.5	Pipe
41	Con_206049.1	0.3	1.5	Pipe
41	Con_206050.1	0.3	1.5	Pipe
41	Con_206051.2	0.3	1.5	Pipe
41	Con_206055.1	0.3	1.5	Pipe
41	Con_206056.1	0.3	1.5	Pipe
41	Con_206057.1	0.3	1.5	Pipe
41	Con_206058.2	0.3	1.5	Pipe
41	Con_206080.1	0.3	1.5	Pipe
41	Con_206081.1	0.3	1.5	Pipe
41	Con_206082.1	0.3	1.5	Pipe
41	Con_206083.2	0.3	1.5	Pipe
41	Con_206090.1	0.3	1.5	Pipe
41	Con_206090.2	0.3	1.5	Pipe
42	Con_206067.1	0.1506	1.5	Pipe
42	Con_206067.2	0.1506	1.5	Pipe
42	Con_206068.1	0.1506	1.5	Pipe
42	Con_206070.1	0.1506	1.5	Pipe
42	Con_206066.1	0.1882	1.5	Pipe
42	Con_206060.2	0.1882	1.5	Pipe
42	Con_206058.1	0.1882	1.5	Pipe
42	Con_206059.1	0.1882	1.5	Pipe
43	Con_206066.2	0.1882	1.5	Pipe
43	Con_206072.1	0.1882	1.5	Pipe
43	Con_206073.1	0.1882	1.5	Pipe
43	Con_206074.1	0.1882	1.5	Pipe
43	Con_206075.1	0.1506	1.5	Pipe
43	Con_206075.2	0.1506	1.5	Pipe
43	Con_206076.1	0.1506	1.5	Pipe
43	Con_206078.1	0.1506	1.5	Pipe
44	Con_206083.1	0.1882	1.5	Pipe
44	Con_206086.2	0.1882	1.5	Pipe
45	Con_206093.1	0.1882	1.5	Pipe
45	Con_206094.2	0.1882	1.5	Pipe
45	Con_206098.1	0.1882	1.5	Pipe
45	Con_206099.1	0.1882	1.5	Pipe
45	Con_206100.1	0.1506	1.5	Pipe
45	Con_206100.2	0.1506	1.5	Pipe
45	Con_206102.1	0.1506	1.5	Pipe
45	Con_206104.1	0.1882	1.5	Pipe
45	Con_206105.1	0.1882	1.5	Pipe
45	Con_206105.3	0.1882	1.5	Pipe
45	Con_206108.1	0.1882	1.5	Pipe
45	Con_206109.1	0.1506	1.5	Pipe
45	Con_206109.2	0.1882	1.5	Pipe
45	Con_206111.1	0.1506	1.5	Pipe
46	Con_206093.2	0.2353	1.5	Pipe
46	Con_206113.1	0.2353	1.5	Pipe
46	Con_206114.1	0.2353	1.5	Pipe
46	Con_206115.1	0.2353	1.5	Pipe
46	Con_206116.1	0.2353	1.5	Pipe
46	Con_206117.1	0.2353	1.5	Pipe
46	Con_206118.2	0.2353	1.5	Pipe
46	Con_206134.1	0.2353	1.5	Pipe
46	Con_206135.1	0.2353	1.5	Pipe
46	Con_206136.1	0.2353	1.5	Pipe
46	Con_206136.2	0.2353	1.5	Pipe
46	Con_206137.1	0.2353	1.5	Pipe
47	Con_207007.1	0.1506	1.5	Pipe
47	Con_207006.1	0.1506	1.5	Pipe
47	Con_207006.2	0.1506	1.5	Pipe
48	Con_207002.2	0.1882	1.5	Pipe
48	Con_207005.1	0.1882	1.5	Pipe
49	Con_205154.1	0.1882	1.5	Pipe
49	Con_205155.1	0.1882	1.5	Pipe
49	Con_205150.1	0.1882	1.5	Pipe
50	Con_205148.1	0.3	1.5	Pipe
50	Con_205149.1	0.3	1.5	Pipe
50	Con_205150.2	0.3	1.5	Pipe
50	Con_205153.1	0.3	1.5	Pipe
50	Con_205143.1	0.3	1.5	Pipe

No. of decision variable	Sub-catchment/ Conduit ID	Minimum value of DV	Maximum value of DV	Intervention type
50	Con_205144.1	0.3	1.5	Pipe
50	Con_205145.1	0.3	1.5	Pipe
50	Con_205146.1	0.3	1.5	Pipe
50	Con_205147.1	0.3	1.5	Pipe
50	Con_205134.2	0.3	1.5	Pipe
50	Con_205139.1	0.3	1.5	Pipe
50	Con_205140.1	0.3	1.5	Pipe
50	Con_205141.1	0.3	1.5	Pipe
50	Con_205142.1	0.3	1.5	Pipe
51	Con_205130.1	0.3	1.5	Pipe
51	Con_205131.1	0.3	1.5	Pipe
51	Con_205132.1	0.3	1.5	Pipe
51	Con_205133.1	0.3	1.5	Pipe
51	Con_205127.1	0.3	1.5	Pipe
51	Con_205127.2	0.3	1.5	Pipe
51	Con_205128.1	0.3	1.5	Pipe
51	Con_205129.1	0.3	1.5	Pipe
51	Con_205018.2	0.3	1.5	Pipe
52	Con_205223.1	0.3	1.5	Pipe
52	Con_205224.1	0.3	1.5	Pipe
52	Con_205224.2	0.3	1.5	Pipe
52	Con_205225.1	0.3	1.5	Pipe
52	Con_205226.1	0.3	1.5	Pipe
52	Con_209015.1	0.3	1.5	Pipe
53	Con_209018.1	0.3	1.5	Pipe
53	Con_209020.1	0.3	1.5	Pipe
53	Con_209021.1	0.3	1.5	Pipe
53	Con_209021.2	0.3	1.5	Pipe
53	Con_209023.1	0.3	1.5	Pipe
53	Con_205230.2	0.3	1.5	Pipe
53	Con_205033.3	0.4	1.5	Pipe
53	Con_209016.1	0.3	1.5	Pipe
53	Con_209016.2	0.3	1.5	Pipe
53	Con_209017.1	0.3	1.5	Pipe
53	Con_205230.1	0.3	1.5	Pipe
54	Con_205222.2	0.3	1.5	Pipe
54	Con_205223.2	0.3	1.5	Pipe
54	Con_205227.1	0.3	1.5	Pipe
54	Con_205228.1	0.3	1.5	Pipe
54	Con_205229.1	0.3	1.5	Pipe
54	Con_205230.3	0.3	1.5	Pipe
54	Con_205220.1	0.3	1.5	Pipe
54	Con_205220.2	0.3	1.5	Pipe
54	Con_205221.1	0.3	1.5	Pipe
54	Con_205222.1	0.3	1.5	Pipe
54	Con_205105X.1	0.2965	1.5	Pipe
55	Con_205033.2	0.1882	1.5	Pipe
55	Con_205216.1	0.1882	1.5	Pipe
55	Con_205217.1	0.1882	1.5	Pipe
55	Con_205218.1	0.1882	1.5	Pipe
56	Con_205033.1	0.3	1.5	Pipe
56	Con_205034.1	0.3	1.5	Pipe
56	Con_205035.1	0.3	1.5	Pipe
56	Con_205036.1	0.3	1.5	Pipe
56	Con_205037.1	0.3	1.5	Pipe
56	Con_205038.1	0.3	1.5	Pipe
57	Con_205029.1	0.3	1.5	Pipe
57	Con_205030.1	0.3	1.5	Pipe
57	Con_205031.1	0.3	1.5	Pipe
57	Con_205032.1	0.3	1.5	Pipe
57	Con_205024.1	0.3	1.5	Pipe
57	Con_205025.1	0.3	1.5	Pipe
57	Con_205026.1	0.3	1.5	Pipe
57	Con_205027.1	0.3	1.5	Pipe
57	Con_205028.1	0.3	1.5	Pipe
58	Con_205017.1	0.4	1.5	Pipe
58	Con_205018.1	0.4	1.5	Pipe
58	Con_205017.2	0.6	1.5	Pipe
58	Con_205022.1	0.6	1.5	Pipe
58	Con_205022.2	0.6	1.5	Pipe
58	Con_205023.1	0.6	1.5	Pipe
59	Con_205041.1	0.6	1.5	Pipe

No. of decision variable	Sub-catchment/ Conduit ID	Minimum value of DV	Maximum value of DV	Intervention type
59	Con_205041.2	0.6	1.5	Pipe
59	Con_205042X.1	0.6	1.5	Pipe
59	Con_205043.2	0.6	1.5	Pipe
59	Con_205043.1	0.6	1.5	Pipe
59	Con_G01.1	0.6	1.5	Pipe
59	Con_205046.1	0.6	1.5	Pipe
59	Con_219003.1	0.6	1.5	Pipe
59	Con_205039.1	0.6	1.5	Pipe
59	Con_205101.1	0.6	1.5	Pipe
59	Con_205102.1	0.6	1.5	Pipe
59	Con_205103.1	0.6	1.5	Pipe
59	Con_205104.1	0.6	1.5	Pipe
59	Con_205105.1	0.6	1.5	Pipe
59	Con_205105.2	0.6	1.5	Pipe
59	Con_209005.1	0.6	1.5	Pipe
59	Con_205039.2	0.6	1.5	Pipe
59	Con_205103.2	0.2965	1.5	Pipe
59	Con_209009X.1	0.2965	1.5	Pipe
59	Con_209009X.2	0.2965	1.5	Pipe
60	Con_290018.1	0.4	1.5	Pipe
60	Con_205105X.2	0.4	1.5	Pipe
60	Con_290000.1	0.4	1.5	Pipe
60	Con_290004.1	0.4	1.5	Pipe
60	Con_290008.1	0.4	1.5	Pipe
60	Con_290012.1	0.4	1.5	Pipe
60	Con_290016.1	0.4	1.5	Pipe
61	Con_205099.1	0.4	1.5	Pipe
61	Con_205099.2	0.3	1.5	Pipe
61	Con_205107.1	0.3	1.5	Pipe
61	Con_205108.1	0.3	1.5	Pipe
61	Con_205109.1	0.3	1.5	Pipe
61	Con_205173.1	0.3	1.5	Pipe
61	Con_205173.2	0.3	1.5	Pipe
61	Con_205126.2	0.3	1.5	Pipe
61	Con_205110.2	0.3	1.5	Pipe
62	Con_205126.1	0.3	1.5	Pipe

No. of decision variable	Sub-catchment/ Conduit ID	Minimum value of DV	Maximum value of DV	Intervention type
62	Con_205162.1	0.3	1.5	Pipe
62	Con_205163.1	0.3	1.5	Pipe
62	Con_205163.2	0.3	1.5	Pipe
62	Con_205165.1	0.3	1.5	Pipe
62	Con_205170.2	0.3	1.5	Pipe
62	Con_205172.1	0.3	1.5	Pipe
62	Con_205165.2	0.3	1.5	Pipe
62	Con_205168.1	0.3	1.5	Pipe
62	Con_205169.1	0.3	1.5	Pipe
62	Con_205170.1	0.3	1.5	Pipe
63	Con_205181.2	0.4	1.5	Pipe
63	Con_205184.1	0.4	1.5	Pipe
64	Con_205175.1	0.3	1.5	Pipe
64	Con_205176.1	0.3	1.5	Pipe
64	Con_205177.1	0.3	1.5	Pipe
64	Con_205177.2	0.3	1.5	Pipe
64	Con_205179.1	0.3	1.5	Pipe
64	Con_205115.2	0.3	1.5	Pipe
65	Con_205112.2	0.3	1.5	Pipe
65	Con_205111.1	0.3	1.5	Pipe
65	Con_205110.1	0.3	1.5	Pipe
66	Con_205120.1	0.3	1.5	Pipe
66	Con_205120.2	0.3	1.5	Pipe
66	Con_205121.1	0.1882	1.5	Pipe
66	Con_205121.2	0.1882	1.5	Pipe
66	Con_205122.1	0.3	1.5	Pipe
66	Con_205124.1	0.3	1.5	Pipe
66	Con_G10.2	0.3	1.5	Pipe
67	Con_G11.1	0.6	1.5	Pipe
67	Con_G11.2	0.6	1.5	Pipe
67	Con_G12.1	0.6	1.5	Pipe
67	Con_G13.1	0.6	1.5	Pipe
67	Con_G14.2	0.6	1.5	Pipe
67	Con_G15.1	0.6	1.5	Pipe
68	Con_G07.2	0.3	1.5	Pipe
68	Con_G06.1	0.3	1.5	Pipe

No. of decision variable	Sub-catchment/ Conduit ID	Minimum value of DV	Maximum value of DV	Intervention type
68	Con_G04.2	0.3	1.5	Pipe
68	Con_G02.2	0.3	1.5	Pipe
68	Con_G01.2	0.3	1.5	Pipe
69	Con_RCplan1.2	0.3	1.5	Pipe
69	Con_RCplan12.2	0.3	1.5	Pipe
69	Con_RCplan2.2	0.3	1.5	Pipe
69	Con_RCplan4.1	0.3	1.5	Pipe
69	Con_RCplan5.1	0.3	1.5	Pipe
69	Con_RCplan2.1	0.3	1.5	Pipe
69	Con_RCplan21.1	0.3	1.5	Pipe
69	Con_RCplan3.1	0.3	1.5	Pipe
70	Con_RCplan10.1	0.6	1.5	Pipe
70	Con_RCplan11.1	0.6	1.5	Pipe
70	Con_RCplan12.1	0.6	1.5	Pipe
70	Con_RCplan6.1	0.6	1.5	Pipe
70	Con_RCplan6.2	0.6	1.5	Pipe
70	Con_RCplan7.1	0.6	1.5	Pipe
70	Con_RCplan8.1	0.6	1.5	Pipe
70	Con_RCplan9.1	0.6	1.5	Pipe
70	Con_RCplan20.2	0.6	1.5	Pipe
70	Con_RCplan14.2	0.6	1.5	Pipe
71	Con_205012.3	0.7	1.5	Pipe
71	Con_205012.1	0.6	1.5	Pipe
71	Con_205013.1	0.6	1.5	Pipe
71	Con_205014.1	0.6	1.5	Pipe
71	Con_205300.2	0.6	1.5	Pipe
71	Con_205015.1	0.6	1.5	Pipe
71	Con_205016.1	0.6	1.5	Pipe
72	Con_206140.1	0.1882	1.5	Pipe
72	Con_206141.1	0.1882	1.5	Pipe
72	Con_206142.1	0.1882	1.5	Pipe
72	Con_206143.1	0.1882	1.5	Pipe
72	Con_206144.1	0.1882	1.5	Pipe

Appendix J – Data input for the simulation of the optimisation problem

This appendix elaborated on the used data for the formal optimisation simulation. All necessary lists for the simulation are described below. The scripts for the Genetic Algorithm python, PySWMM , and SWMMToolBox package used for this optimisation will not be included. More information on the ***geneticalgorithm*** python package can refer to [39], ***PySWMM*** can refer to [31], and ***SWMMToolBox*** can refer to [32]. For this thesis, the ***geneticalgoritm*** package has been adjusted to include the codes showing the average objective function values versus the iteration number after the simulation ended.

Data preparation

Before the start of the optimisation, several data are needed. These are:

- List of decision variables (DV); A *dataframe* consists of five columns:
  - Type of intervention, *i.e* RB, PP, IT, Pump, or Pipe – *Index column*
  - No. of decision variable from 1 – 72
  - Object ID, *e.g.* Sub_205124, Con_207001.1, Con_206014.2
  - Minimum value for intervention (current value of area of measures, pipe diameter, or pump curve) related to that intervention object (sub-catchment, pipe, or pump)
  - Maximum value of intervention
- List of unchanged objects; A *dataframe* consist of three columns:
  - Type of object, *i.e.* Pipe or Pump
  - Object ID
  - Original pipe diameter/ pump curve
- Price catalogue of measures; A *dataframe* that shows the price of implementing either pipe or pump according to the defined cost based on the diameter for pipes and pump capacity for pumps.
- Original adjusted SWMM input model (*.inp*)

Made lists

- Possible values of decision variables; A python *nested list* that includes the discretised values for each intervention in a particular area/ pipe/ pump (*e.g.* [[5, 10, 15,...], [2, 4, 6,…], …])
- Range bounds of decision variables; A python *nested list* that includes the range-bound of each decision variable values (*e.g.* [[0, 3], [0, 2], …]).
  [0, 3] means that there are three possible values of DV that the function can explore.

Appendix K - Manual Optimisation Result

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
1	Sub_207001	RB	0	0.48	1.44	m^2	-	€ 266.9	€ 800.6
1	Sub_207002	RB	0	0.48	1.44	m^2	-	€ 266.9	€ 800.6
1	Sub_207003	RB	0	0.48	0.96	m^2	-	€ 266.9	€ 533.8
1	Sub_207005	RB	0	0.48	1.44	m^2	-	€ 266.9	€ 800.6
1	Sub_207009	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
1	Sub_207010	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
1	Sub_207006	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
1	Sub_296131	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
1	Sub_296132	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
1	Sub_206133	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
1	Sub_206122	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
1	Sub_206123	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
1	Sub_206127	RB	0	0.48	0.96	m^2	-	€ 266.9	€ 533.8
1	Sub_206128	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
1	Sub_206129	RB	0	0.48	1.44	m^2	-	€ 266.9	€ 800.6
1	Sub_206119	RB	0	0.48	0.96	m^2	-	€ 266.9	€ 533.8
1	Sub_206120	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
1	Sub_206138	RB	0	0.48	1.44	m^2	-	€ 266.9	€ 800.6
1	Sub_206139	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
1	Sub_206140	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
1	Sub_206142	RB	0	0.48	1.44	m^2	-	€ 266.9	€ 800.6
1	Sub_206143	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
1	Sub_206145	RB	0	0.48	0.96	m^2	-	€ 266.9	€ 533.8
2	Sub_206108	RB	0	1.44	1.44	m^2	-	€ 800.6	€ 800.6
2	Sub_206109	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
2	Sub_206110	RB	0	1.44	1.44	m^2	-	€ 800.6	€ 800.6
2	Sub_206111	RB	0	1.44	1.44	m^2	-	€ 800.6	€ 800.6
2	Sub_206104	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.8
2	Sub_206105	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
2	Sub_206106	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
2	Sub_206107	RB	0	2.4	2.4	m^2	-	€ 1,334.4	€ 1,334.4
2	Sub_206099	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.8
2	Sub_206100	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
2	Sub_206101	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
2	Sub_206102	RB	0	1.92	1.92	m^2	-	€ 1,067.5	€ 1,067.5
2	Sub_206103	RB	0	1.92	1.92	m^2	-	€ 1,067.5	€ 1,067.5
2	Sub_206095	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
2	Sub_206096	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
2	Sub_206097	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.8
2	Sub_206097A	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
2	Sub_206091	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.8
2	Sub_206092	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.8
3	Sub_206084	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
3	Sub_206084A	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
3	Sub_206085	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.8
3	Sub_206086	RB	0	1.2	1.92	m^2	-	€ 667.2	€ 1,067.5
3	Sub_206087	RB	0	1.2	1.92	m^2	-	€ 667.2	€ 1,067.5
3	Sub_206088	RB	0	1.2	1.92	m^2	-	€ 667.2	€ 1,067.5
3	Sub_206089	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
3	Sub_206072	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
3	Sub_206073	RB	0	1.2	1.44	m^2	-	€ 667.2	€ 800.6
3	Sub_206074	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
3	Sub_206076	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
3	Sub_206077	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.8
3	Sub_206078	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
3	Sub_206079	RB	0	1.2	1.44	m^2	-	€ 667.2	€ 800.6
3	Sub_206065	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
3	Sub_206069	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
3	Sub_206070	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.8
3	Sub_206071	RB	0	1.2	1.44	m^2	-	€ 667.2	€ 800.6
4	Sub_206051	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
4	Sub_206055	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
4	Sub_206056	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
4	Sub_206052	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
4	Sub_206053	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
4	Sub_206054	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
4	Sub_206039	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
4	Sub_206043	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
4	Sub_206046	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
4	Sub_206048	RB	0	0	0	m^2	-	€ 0.0	€ 0.0

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
4	Sub_206040	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
4	Sub_206041	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
4	Sub_206042	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
5	Sub_202021	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.8
5	Sub_202022	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
5	Sub_202023	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
5	Sub_202024	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
5	Sub_202025	RB	0	1.2	1.2	m^2	-	€ 667.2	€ 667.2
5	Sub_202026	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
5	Sub_202001	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
5	Sub_202002	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
5	Sub_202003	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
5	Sub_202005	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
5	Sub_202006	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
6	Sub_206022	RB	0	0.24	0.24	m^2	-	€ 133.4	€ 133.4
6	Sub_206023	RB	0	0.24	0.24	m^2	-	€ 133.4	€ 133.4
6	Sub_206148	RB	0	0.24	0.24	m^2	-	€ 133.4	€ 133.4
6	Sub_206150	RB	0	0.24	0.24	m^2	-	€ 133.4	€ 133.4
6	Sub_206151	RB	0	0.24	0.24	m^2	-	€ 133.4	€ 133.4
6	Sub_206152	RB	0	0.24	0.24	m^2	-	€ 133.4	€ 133.4
6	Sub_206153	RB	0	0.24	0.24	m^2	-	€ 133.4	€ 133.4
7	Sub_290018	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
7	Sub_209009	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
7	Sub_209009X	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
7	Sub_209009Y	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
7	Sub_205103	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
7	Sub_205104	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
7	Sub_205105	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
7	Sub_205098	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
7	Sub_290000	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
7	Sub_205101	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
7	Sub_205102	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
7	Sub_290004	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
7	Sub_290012	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
7	Sub_290016	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
7	Sub_205033	RB	0	0	0	m^2	-	€ 0.0	€ 0.0

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
7	Sub_205034	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
7	Sub_205035	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
7	Sub_205036	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
7	Sub_205037	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
7	Sub_205038	RB	0	0	0	m^2	-	€ 0.0	€ 0.0
8	Sub_205224	RB	0	1.92	1.92	m^2	-	€ 1,067.5	€ 1,067.5
8	Sub_205225	RB	0	1.92	1.92	m^2	-	€ 1,067.5	€ 1,067.5
8	Sub_205226	RB	0	1.92	1.92	m^2	-	€ 1,067.5	€ 1,067.5
8	Sub_205220	RB	0	1.92	1.92	m^2	-	€ 1,067.5	€ 1,067.5
8	Sub_205221	RB	0	1.92	1.92	m^2	-	€ 1,067.5	€ 1,067.5
8	Sub_205222	RB	0	1.44	1.44	m^2	-	€ 800.6	€ 800.6
8	Sub_205223	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.8
8	Sub_205227	RB	0	1.92	1.92	m^2	-	€ 1,067.5	€ 1,067.5
8	Sub_205228	RB	0	1.92	1.92	m^2	-	€ 1,067.5	€ 1,067.5
8	Sub_205229	RB	0	1.92	1.92	m^2	-	€ 1,067.5	€ 1,067.5
8	Sub_215229	RB	0	1.92	1.92	m^2	-	€ 1,067.5	€ 1,067.5
8	Sub_205230	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
8	Sub_205105X	RB	0	1.44	1.44	m^2	-	€ 800.6	€ 800.6
8	Sub_209016	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.8
8	Sub_209017	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.8
8	Sub_209018	RB	0	1.44	1.44	m^2	-	€ 800.6	€ 800.6
8	Sub_209019	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
8	Sub_209020	RB	0	1.44	1.44	m^2	-	€ 800.6	€ 800.6
8	Sub_209021	RB	0	1.92	1.92	m^2	-	€ 1,067.5	€ 1,067.5
8	Sub_209023	RB	0	1.92	1.92	m^2	-	€ 1,067.5	€ 1,067.5
8	Sub_209024	RB	0	1.92	1.92	m^2	-	€ 1,067.5	€ 1,067.5
8	Sub_219021	RB	0	1.92	1.92	m^2	-	€ 1,067.5	€ 1,067.5
9	Sub_205217	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
9	Sub_205218	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.8
9	Sub_205219	RB	0	1.2	1.2	m^2	-	€ 667.2	€ 667.2
9	Sub_205025	RB	0	1.2	1.2	m^2	-	€ 667.2	€ 667.2
9	Sub_205026	RB	0	1.2	1.2	m^2	-	€ 667.2	€ 667.2
9	Sub_205027	RB	0	1.2	1.2	m^2	-	€ 667.2	€ 667.2
9	Sub_205028	RB	0	1.2	1.2	m^2	-	€ 667.2	€ 667.2
9	Sub_205029	RB	0	1.2	1.2	m^2	-	€ 667.2	€ 667.2
9	Sub_205030	RB	0	1.2	1.2	m^2	-	€ 667.2	€ 667.2

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
9	Sub_205031	RB	0	1.2	1.2	m^2	-	€ 667.2	€ 667.2
9	Sub_205032	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.8
10	Sub_RCplan17	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.8
10	Sub_205061	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.8
10	Sub_205062	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.8
10	Sub_205063	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
10	Sub_205064	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.8
10	Sub_205066	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
10	Sub_205041	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.8
10	Sub_205042	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.8
10	Sub_205042X	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.8
10	Sub_205043	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.8
10	Sub_205044	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.8
10	Sub_205045	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.8
10	Sub_205046	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
11	Sub_205162	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
11	Sub_205163	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
11	Sub_205164	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
11	Sub_205165	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
11	Sub_205166	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
11	Sub_205168	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
11	Sub_205169	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
11	Sub_205170	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
11	Sub_205171	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
11	Sub_205172	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
11	Sub_205173	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
11	Sub_205107	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
11	Sub_205108	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
11	Sub_205109	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
11	Sub_205110	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
11	Sub_205174	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
11	Sub_205175	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
11	Sub_205176	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
11	Sub_205177	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
11	Sub_205178	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
11	Sub_205179	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
11	Sub_205180	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
11	Sub_205115	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
11	Sub_205116	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
11	Sub_205126	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
11	Sub_205111	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
11	Sub_205112	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
11	Sub_205113	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
11	Sub_205114	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
11	Sub_205117	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
12	Sub_205181	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
12	Sub_205182	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
12	Sub_205184	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
12	Sub_205185	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
12	Sub_205186	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
12	Sub_205194	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
12	Sub_205195	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
12	Sub_205197	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
12	Sub_205187	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
12	Sub_205188	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
12	Sub_205189	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
12	Sub_205190	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
12	Sub_205191	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
12	Sub_205192	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
12	Sub_205199	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
12	Sub_205193	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
12	Sub_205200	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
12	Sub_205201	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
12	Sub_205209	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
12	Sub_205210	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
13	Sub_205118	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
13	Sub_205118A	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
13	Sub_205119	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
13	Sub_205124	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
13	Sub_205125	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
13	Sub_RCplan10	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
13	Sub_RCplan6	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
13	Sub_RCplan7	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
13	Sub_RCplan8	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
13	Sub_RCplan9	RB	0	0.72	0.72	m^2	-	€ 400.3	€ 400.3
13	Sub_205214	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
13	Sub_205080	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
14	Sub_205067	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
14	Sub_205068	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
14	Sub_205069	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
14	Sub_205070	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
14	Sub_205071	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
14	Sub_205072	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
14	Sub_205076	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
14	Sub_RCplan3	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
14	Sub_RCplan5	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
14	Sub_205073	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
14	Sub_205074	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
14	Sub_205075	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
14	Sub_205013	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
14	Sub_205014	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
14	Sub_205015	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
14	Sub_205016	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
14	Sub_205017	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
14	Sub_205300	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
15	Sub_205160	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
15	Sub_205161	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.8
15	Sub_205021	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
15	Sub_205022	RB	0	1.44	1.44	m^2	-	€ 800.6	€ 800.6
15	Sub_205023	RB	0	1.44	1.44	m^2	-	€ 800.6	€ 800.6
15	Sub_205048	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
15	Sub_205150	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
15	Sub_205151	RB	0	1.44	1.44	m^2	-	€ 800.6	€ 800.6
15	Sub_205154	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
15	Sub_205155	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
15	Sub_205156	RB	0	1.44	1.44	m^2	-	€ 800.6	€ 800.6
15	Sub_205139	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
15	Sub_205140	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
15	Sub_205141	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
15	Sub_205142	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
15	Sub_205143	RB	0	1.44	1.44	m^2	-	€ 800.6	€ 800.6
15	Sub_205145	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.8
15	Sub_205147	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
15	Sub_205148	RB	0	1.44	1.44	m^2	-	€ 800.6	€ 800.6
15	Sub_205149	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.8
15	Sub_205128	RB	0	1.44	1.44	m^2	-	€ 800.6	€ 800.6
15	Sub_205129	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
15	Sub_205130	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
15	Sub_205131	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.8
15	Sub_205132	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
15	Sub_205133	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.9
15	Sub_205134	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.8
16	Sub_206139	IT	0	20	20	m^2	-	€ 5,616.0	€ 5,616.0
16	Sub_206140	IT	0	15	15	m^2	-	€ 4,212.0	€ 4,212.0
16	Sub_206141	IT	0	30	30	m^2	-	€ 8,424.0	€ 8,424.0
17	Sub_290016	IT	0	24	24	m^2	-	€ 6,739.2	€ 6,739.2
17	Sub_205039	IT	0	24	24	m^2	-	€ 6,739.2	€ 6,739.2
17	Sub_209003	IT	0	10.4	10.4	m^2	-	€ 2,920.3	€ 2,920.3
17	Sub_205024	IT	0	41.6	41.6	m^2	-	€ 11,681.3	€ 11,681.3
17	Sub_205033	IT	0	48	48	m^2	-	€ 13,478.4	€ 13,478.4
17	Sub_205224	IT	0	28	28	m^2	-	€ 7,862.4	€ 7,862.4
17	Sub_205226	IT	0	46.4	46.4	m^2	-	€ 13,029.1	€ 13,029.1
17	Sub_209015	IT	0	42.4	42.4	m^2	-	€ 11,905.9	€ 11,905.9
17	Sub_209017	IT	0	60.8	60.8	m^2	-	€ 17,072.6	€ 17,072.6
17	Sub_209019	IT	0	40	40	m^2	-	€ 11,232.0	€ 11,232.0
17	Sub_205099	IT	0	12	12	m^2	-	€ 3,369.6	€ 3,369.6
17	Sub_205107	IT	0	16	16	m^2	-	€ 4,492.8	€ 4,492.8
18	Sub_205114	IT	0	15	15	m^2	-	€ 4,212.0	€ 4,212.0
18	Sub_RCplan11	IT	0	30	30	m^2	-	€ 8,424.0	€ 8,424.0
18	Sub_RCplan20_toe	IT	0	18	18	m^2	-	€ 5,054.4	€ 5,054.4
18	Sub_RCplan3	IT	0	30	30	m^2	-	€ 8,424.0	€ 8,424.0
18	Sub_205077	IT	0	30	30	m^2	-	€ 8,424.0	€ 8,424.0
18	Sub_RCplan5	IT	0	30	30	m^2	-	€ 8,424.0	€ 8,424.0
18	Sub_205180	IT	0	18	18	m^2	-	€ 5,054.4	€ 5,054.4

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
18	Sub_205182	IT	0	15	15	m^2	-	€ 4,212.0	€ 4,212.0
18	Sub_205183	IT	0	15	15	m^2	-	€ 4,212.0	€ 4,212.0
18	Sub_205196	IT	0	24	24	m^2	-	€ 6,739.2	€ 6,739.2
18	Sub_205197	IT	0	18	18	m^2	-	€ 5,054.4	€ 5,054.4
19	Sub_202001	PP	0	19	19	m^2	-	€ 3,385.8	€ 3,385.8
19	Sub_202002	PP	0	5	5	m^2	-	€ 891.0	€ 891.0
19	Sub_202003	PP	0	9.5	9.5	m^2	-	€ 1,692.9	€ 1,692.9
20	Sub_202020	PP	0	0	0	m^2	-	€ 0.0	€ 0.0
20	Sub_202021	PP	0	0	0	m^2	-	€ 0.0	€ 0.0
20	Sub_202022	PP	0	0	0	m^2	-	€ 0.0	€ 0.0
20	Sub_202023	PP	0	0	0	m^2	-	€ 0.0	€ 0.0
20	Sub_202024	PP	0	0	0	m^2	-	€ 0.0	€ 0.0
20	Sub_202025	PP	0	0	0	m^2	-	€ 0.0	€ 0.0
20	Sub_202026	PP	0	0	0	m^2	-	€ 0.0	€ 0.0
21	Sub_205024	PP	0	61.2	61.2	m^2	-	€ 10,905.8	€ 10,905.8
21	Sub_205041	PP	0	36	36	m^2	-	€ 6,415.2	€ 6,415.2
21	Sub_205042	PP	0	26.4	26.4	m^2	-	€ 4,704.5	€ 4,704.5
21	Sub_205042X	PP	0	32	32	m^2	-	€ 5,702.4	€ 5,702.4
21	Sub_205043	PP	0	26	26	m^2	-	€ 4,633.2	€ 4,633.2
21	Sub_205044	PP	0	20	20	m^2	-	€ 3,564.0	€ 3,564.0
21	Sub_205045	PP	0	34	34	m^2	-	€ 6,058.8	€ 6,058.8
21	Sub_205046	PP	0	34	34	m^2	-	€ 6,058.8	€ 6,058.8
21	Sub_209003	PP	0	10.8	10.8	m^2	-	€ 1,924.6	€ 1,924.6
21	Sub_205039	PP	0	28	28	m^2	-	€ 4,989.6	€ 4,989.6
21	Sub_205062	PP	0	22	22	m^2	-	€ 3,920.4	€ 3,920.4
21	Sub_205063	PP	0	28	28	m^2	-	€ 4,989.6	€ 4,989.6
21	Sub_205064	PP	0	12	12	m^2	-	€ 2,138.4	€ 2,138.4
21	Sub_205076	PP	0	20	20	m^2	-	€ 3,564.0	€ 3,564.0
22	Sub_RCplan7	PP	0	60	60	m^2	-	€ 10,692.0	€ 10,692.0
22	Sub_RCplan8	PP	0	60	60	m^2	-	€ 10,692.0	€ 10,692.0
22	Sub_RCplan9	PP	0	55	55	m^2	-	€ 9,801.0	€ 9,801.0
22	Sub_RCplan10	PP	0	60	60	m^2	-	€ 10,692.0	€ 10,692.0
22	Sub_RCplan11	PP	0	50	50	m^2	-	€ 8,910.0	€ 8,910.0
22	Sub_RCplan12	PP	0	150	150	m^2	-	€ 26,730.0	€ 26,730.0
22	Sub_RCplan13	PP	0	50	50	m^2	-	€ 8,910.0	€ 8,910.0
22	Sub_RCplan1	PP	0	60	60	m^2	-	€ 10,692.0	€ 10,692.0

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
22	Sub_RCplan17	PP	0	50	50	m^2	-	€ 8,910.0	€ 8,910.0
22	Sub_RCplan2	PP	0	75	75	m^2	-	€ 13,365.0	€ 13,365.0
22	Sub_RCplan3	PP	0	90	90	m^2	-	€ 16,038.0	€ 16,038.0
22	Sub_RCplan4	PP	0	75	75	m^2	-	€ 13,365.0	€ 13,365.0
22	Sub_RCplan5	PP	0	50	50	m^2	-	€ 8,910.0	€ 8,910.0
23	Sub_205100	PP	0	30	30	m^2	-	€ 5,346.0	€ 5,346.0
23	Sub_205101	PP	0	48	48	m^2	-	€ 8,553.6	€ 8,553.6
23	Sub_205102	PP	0	30	30	m^2	-	€ 5,346.0	€ 5,346.0
23	Sub_205103	PP	0	33	33	m^2	-	€ 5,880.6	€ 5,880.6
23	Sub_205104	PP	0	24	24	m^2	-	€ 4,276.8	€ 4,276.8
23	Sub_205105	PP	0	24	24	m^2	-	€ 4,276.8	€ 4,276.8
23	Sub_205105X	PP	0	42	42	m^2	-	€ 7,484.4	€ 7,484.4
23	Sub_205107	PP	0	18	18	m^2	-	€ 3,207.6	€ 3,207.6
23	Sub_290000	PP	0	30	30	m^2	-	€ 5,346.0	€ 5,346.0
23	Sub_290004	PP	0	42	42	m^2	-	€ 7,484.4	€ 7,484.4
23	Sub_290008	PP	0	31.5	31.5	m^2	-	€ 5,613.3	€ 5,613.3
23	Sub_290012	PP	0	42	42	m^2	-	€ 7,484.4	€ 7,484.4
23	Sub_290016	PP	0	30	30	m^2	-	€ 5,346.0	€ 5,346.0
23	Sub_290018	PP	0	51	51	m^2	-	€ 9,088.2	€ 9,088.2
23	Sub_209009X	PP	0	70.5	70.5	m^2	-	€ 12,563.1	€ 12,563.1
23	Sub_209009Y	PP	0	70.5	70.5	m^2	-	€ 12,563.1	€ 12,563.1
24	Sub_205111	PP	0	37.5	37.5	m^2	-	€ 6,682.5	€ 6,682.5
24	Sub_205112	PP	0	50	50	m^2	-	€ 8,910.0	€ 8,910.0
24	Sub_205113	PP	0	42.5	42.5	m^2	-	€ 7,573.5	€ 7,573.5
24	Sub_205115	PP	0	37.5	37.5	m^2	-	€ 6,682.5	€ 6,682.5
24	Sub_205116	PP	0	50	50	m^2	-	€ 8,910.0	€ 8,910.0
24	Sub_205117	PP	0	95	95	m^2	-	€ 16,929.0	€ 16,929.0
24	Sub_205162	PP	0	37.5	37.5	m^2	-	€ 6,682.5	€ 6,682.5
24	Sub_205163	PP	0	37.5	37.5	m^2	-	€ 6,682.5	€ 6,682.5
24	Sub_205164	PP	0	40	40	m^2	-	€ 7,128.0	€ 7,128.0
24	Sub_205165	PP	0	78.5	78.5	m^2	-	€ 13,988.7	€ 13,988.7
24	Sub_205166	PP	0	25	25	m^2	-	€ 4,455.0	€ 4,455.0
24	Sub_205168	PP	0	37.5	37.5	m^2	-	€ 6,682.5	€ 6,682.5
24	Sub_205169	PP	0	37.5	37.5	m^2	-	€ 6,682.5	€ 6,682.5
24	Sub_205170	PP	0	37.5	37.5	m^2	-	€ 6,682.5	€ 6,682.5
24	Sub_205171	PP	0	35	35	m^2	-	€ 6,237.0	€ 6,237.0

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
24	Sub_205172	PP	0	45	45	m^2	-	€ 8,019.0	€ 8,019.0
24	Sub_205175	PP	0	15	15	m^2	-	€ 2,673.0	€ 2,673.0
24	Sub_205176	PP	0	30	30	m^2	-	€ 5,346.0	€ 5,346.0
24	Sub_205177	PP	0	20	20	m^2	-	€ 3,564.0	€ 3,564.0
24	Sub_205178	PP	0	20	20	m^2	-	€ 3,564.0	€ 3,564.0
24	Sub_205179	PP	0	25	25	m^2	-	€ 4,455.0	€ 4,455.0
24	Sub_205180	PP	0	20	20	m^2	-	€ 3,564.0	€ 3,564.0
24	Sub_205184	PP	0	47.5	47.5	m^2	-	€ 8,464.5	€ 8,464.5
24	Sub_205185	PP	0	25	25	m^2	-	€ 4,455.0	€ 4,455.0
24	Sub_205186	PP	0	47.5	47.5	m^2	-	€ 8,464.5	€ 8,464.5
24	Sub_205187	PP	0	37.5	37.5	m^2	-	€ 6,682.5	€ 6,682.5
25	Sub_205118	PP	0	40	40	m^2	-	€ 7,128.0	€ 7,128.0
25	Sub_205118A	PP	0	20	20	m^2	-	€ 3,564.0	€ 3,564.0
25	Sub_205119	PP	0	60	60	m^2	-	€ 10,692.0	€ 10,692.0
25	Sub_205121	PP	0	60	60	m^2	-	€ 10,692.0	€ 10,692.0
25	Sub_205122	PP	0	50	50	m^2	-	€ 8,910.0	€ 8,910.0
25	Sub_205123	PP	0	30	30	m^2	-	€ 5,346.0	€ 5,346.0
25	Sub_205124	PP	0	30	30	m^2	-	€ 5,346.0	€ 5,346.0
25	Sub_205125	PP	0	20	20	m^2	-	€ 3,564.0	€ 3,564.0
25	Sub_205120	PP	0	71	71	m^2	-	€ 12,652.2	€ 12,652.2
25	Sub_295121	PP	0	90	90	m^2	-	€ 16,038.0	€ 16,038.0
26	Sub_205216	PP	0	18	18	m^2	-	€ 3,207.6	€ 3,207.6
26	Sub_205217	PP	0	22.5	22.5	m^2	-	€ 4,009.5	€ 4,009.5
26	Sub_205218	PP	0	27.45	27.45	m^2	-	€ 4,891.6	€ 4,891.6
26	Sub_205219	PP	0	27.45	27.45	m^2	-	€ 4,891.6	€ 4,891.6
27	Sub_205220	PP	0	25	25	m^2	-	€ 4,455.0	€ 4,455.0
27	Sub_205221	PP	0	25	25	m^2	-	€ 4,455.0	€ 4,455.0
27	Sub_205222	PP	0	28	28	m^2	-	€ 4,989.6	€ 4,989.6
27	Sub_205223	PP	0	25	25	m^2	-	€ 4,455.0	€ 4,455.0
27	Sub_205228	PP	0	25	25	m^2	-	€ 4,455.0	€ 4,455.0
27	Sub_205224	PP	0	20	20	m^2	-	€ 3,564.0	€ 3,564.0
27	Sub_205225	PP	0	35	35	m^2	-	€ 6,237.0	€ 6,237.0
27	Sub_205226	PP	0	11	11	m^2	-	€ 1,960.2	€ 1,960.2
27	Sub_209020	PP	0	17	17	m^2	-	€ 3,029.4	€ 3,029.4
27	Sub_209021	PP	0	15	15	m^2	-	€ 2,673.0	€ 2,673.0
27	Sub_209023	PP	0	20	20	m^2	-	€ 3,564.0	€ 3,564.0

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
27	Sub_209024	PP	0	20	20	m^2	-	€ 3,564.0	€ 3,564.0
27	Sub_219021	PP	0	14	14	m^2	-	€ 2,494.8	€ 2,494.8
27	Sub_209016	PP	0	12	12	m^2	-	€ 2,138.4	€ 2,138.4
27	Sub_209017	PP	0	10	10	m^2	-	€ 1,782.0	€ 1,782.0
27	Sub_209018	PP	0	25	25	m^2	-	€ 4,455.0	€ 4,455.0
27	Sub_209019	PP	0	16	16	m^2	-	€ 2,851.2	€ 2,851.2
28	Sub_206069	PP	0	7.5	7.5	m^2	-	€ 1,336.5	€ 1,336.5
28	Sub_206070	PP	0	29.25	29.25	m^2	-	€ 5,212.4	€ 5,212.4
28	Sub_206071	PP	0	33.75	33.75	m^2	-	€ 6,014.3	€ 6,014.3
28	Sub_206072	PP	0	7.5	7.5	m^2	-	€ 1,336.5	€ 1,336.5
28	Sub_206073	PP	0	39	39	m^2	-	€ 6,949.8	€ 6,949.8
28	Sub_206074	PP	0	7.5	7.5	m^2	-	€ 1,336.5	€ 1,336.5
28	Sub_206076	PP	0	16.5	16.5	m^2	-	€ 2,940.3	€ 2,940.3
28	Sub_206077	PP	0	25.5	25.5	m^2	-	€ 4,544.1	€ 4,544.1
28	Sub_206078	PP	0	22.5	22.5	m^2	-	€ 4,009.5	€ 4,009.5
28	Sub_206079	PP	0	31.5	31.5	m^2	-	€ 5,613.3	€ 5,613.3
29	Sub_206084	PP	0	7	7	m^2	-	€ 1,247.4	€ 1,247.4
29	Sub_206084A	PP	0	8.5	8.5	m^2	-	€ 1,514.7	€ 1,514.7
29	Sub_206085	PP	0	7.25	7.25	m^2	-	€ 1,292.0	€ 1,292.0
29	Sub_206086	PP	0	14.25	14.25	m^2	-	€ 2,539.4	€ 2,539.4
29	Sub_206089	PP	0	7.5	7.5	m^2	-	€ 1,336.5	€ 1,336.5
29	Sub_206087	PP	0	22.5	22.5	m^2	-	€ 4,009.5	€ 4,009.5
29	Sub_206088	PP	0	14.75	14.75	m^2	-	€ 2,628.5	€ 2,628.5
30	Sub_206099	PP	0	43.75	43.75	m^2	-	€ 7,796.3	€ 7,796.3
30	Sub_206100	PP	0	37.5	37.5	m^2	-	€ 6,682.5	€ 6,682.5
30	Sub_206101	PP	0	26.25	26.25	m^2	-	€ 4,677.8	€ 4,677.8
30	Sub_206102	PP	0	71.25	71.25	m^2	-	€ 12,696.8	€ 12,696.8
30	Sub_206103	PP	0	70	70	m^2	-	€ 12,474.0	€ 12,474.0
30	Sub_206104	PP	0	37.5	37.5	m^2	-	€ 6,682.5	€ 6,682.5
30	Sub_206105	PP	0	20	20	m^2	-	€ 3,564.0	€ 3,564.0
30	Sub_206108	PP	0	53.75	53.75	m^2	-	€ 9,578.3	€ 9,578.3
30	Sub_206106	PP	0	32.5	32.5	m^2	-	€ 5,791.5	€ 5,791.5
30	Sub_206107	PP	0	135	135	m^2	-	€ 24,057.0	€ 24,057.0
30	Sub_206109	PP	0	12.5	12.5	m^2	-	€ 2,227.5	€ 2,227.5
30	Sub_206110	PP	0	60	60	m^2	-	€ 10,692.0	€ 10,692.0
30	Sub_206111	PP	0	50	50	m^2	-	€ 8,910.0	€ 8,910.0

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
31	Sub_207006	PP	0	40.5	40.5	m^2	-	€ 7,217.1	€ 7,217.1
31	Sub_207007	PP	0	27	27	m^2	-	€ 4,811.4	€ 4,811.4
31	Sub_207009	PP	0	15	15	m^2	-	€ 2,673.0	€ 2,673.0
31	Sub_207010	PP	0	24	24	m^2	-	€ 4,276.8	€ 4,276.8
31	Sub_207011	PP	0	10.5	10.5	m^2	-	€ 1,871.1	€ 1,871.1
32	Con_202009.2	Pump	Curve_202009.2	Curve_202009.2	Curve_202009.2	m^3 / hour	-	€ 0.0	€ 0.0
33	Con_206014.2	Pump	Curve_206014.2	Curve_206014.2	Curve_206014.2	m^3 / hour	-	€ 0.0	€ 0.0
34	Con_207011.1	Pump	Curve_207011.1	Curve_202009.2	Curve_202009.2	m^3 / hour	-	€ 81,556.5	€ 81,556.5
35	Con_202002.2	Pipe	0.151	0.2353	0.2353	m	22.5	€ 8,612.0	€ 8,612.0
35	Con_202004.1	Pipe	0.188	0.25	0.25	m	81.6	€ 32,040.5	€ 32,040.5
35	Con_202005.1	Pipe	0.188	0.25	0.25	m	81.0	€ 31,803.8	€ 31,803.8
35	Con_202006.1	Pipe	0.188	0.25	0.25	m	81.6	€ 32,040.5	€ 32,040.5
35	Con_202007.1	Pipe	0.188	0.25	0.25	m	61.1	€ 23,991.5	€ 23,991.5
35	Con_202008.1	Pipe	0.188	0.25	0.25	m	5.0	€ 1,960.3	€ 1,960.3
36	Con_202023.1	Pipe	0.188	0.5	0.5	m	15.2	€ 9,048.0	€ 9,048.0
36	Con_202021.1	Pipe	0.188	0.5	0.5	m	80.2	€ 47,659.6	€ 47,659.6
36	Con_202022.1	Pipe	0.188	0.5	0.5	m	78.7	€ 46,777.7	€ 46,777.7
36	Con_202018.1	Pipe	0.188	0.5	0.5	m	13.0	€ 7,722.4	€ 7,722.4
36	Con_202019.1	Pipe	0.188	0.5	0.5	m	35.1	€ 20,858.8	€ 20,858.8
36	Con_202020.1	Pipe	0.188	0.5	0.5	m	81.6	€ 48,478.1	€ 48,478.1
37	Con_202012.1	Pipe	0.188	0.3	0.3	m	100.6	€ 43,218.2	€ 43,218.2
37	Con_202013.1	Pipe	0.188	0.3	0.3	m	32.6	€ 14,019.8	€ 14,019.8
37	Con_202014.1	Pipe	0.188	0.3	0.3	m	70.7	€ 30,363.2	€ 30,363.2
37	Con_202009.1	Pipe	0.188	0.3	0.3	m	73.9	€ 31,722.9	€ 31,722.9
37	Con_202011.1	Pipe	0.188	0.3	0.3	m	100.7	€ 43,241.7	€ 43,241.7
37	Con_202015.1	Pipe	0.188	0.3	0.3	m	41.1	€ 17,652.5	€ 17,652.5
37	Con_202016.1	Pipe	0.188	0.3	0.3	m	80.6	€ 34,614.0	€ 34,614.0
37	Con_202017.1	Pipe	0.188	0.3	0.3	m	81.8	€ 35,142.7	€ 35,142.7
38	Con_206023.1	Pipe	0.3	0.7	0.7	m	24.0	€ 20,458.3	€ 20,458.3
38	Con_206024.1	Pipe	0.3	0.7	0.7	m	38.3	€ 32,671.5	€ 32,671.5
38	Con_206025.1	Pipe	0.3	0.7	0.7	m	55.0	€ 46,906.9	€ 46,906.9
38	Con_206026.1	Pipe	0.3	0.7	0.7	m	37.4	€ 31,909.1	€ 31,909.1
38	Con_206018.1	Pipe	0.3	0.7	0.7	m	16.0	€ 13,638.9	€ 13,638.9
38	Con_206019.1	Pipe	0.3	0.7	0.7	m	10.3	€ 8,776.3	€ 8,776.3
38	Con_206020.1	Pipe	0.3	0.7	0.7	m	40.1	€ 34,193.0	€ 34,193.0
38	Con_206021.1	Pipe	0.3	0.7	0.7	m	37.2	€ 31,723.7	€ 31,723.7

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
38	Con_206022.1	Pipe	0.3	0.7	0.7	m	61.4	€ 52,339.5	€ 52,339.5
38	Con_206014.1	Pipe	0.3	0.7	0.7	m	45.8	€ 39,000.4	€ 39,000.4
38	Con_206015.1	Pipe	0.3	0.7	0.7	m	50.8	€ 43,306.5	€ 43,306.5
38	Con_206016.1	Pipe	0.3	0.7	0.7	m	35.1	€ 29,944.4	€ 29,944.4
38	Con_206017.1	Pipe	0.3	0.7	0.7	m	61.0	€ 52,005.2	€ 52,005.2
39	Con_206150.1	Pipe	0.188	0.1882	0.1882	m	53.4	€ 0.0	€ 0.0
39	Con_206151.1	Pipe	0.188	0.1882	0.1882	m	64.3	€ 0.0	€ 0.0
39	Con_206152.1	Pipe	0.188	0.1882	0.1882	m	48.8	€ 0.0	€ 0.0
39	Con_206146.2	Pipe	0.188	0.1882	0.1882	m	50.4	€ 0.0	€ 0.0
39	Con_206149.1	Pipe	0.188	0.1882	0.1882	m	51.2	€ 0.0	€ 0.0
39	Con_206018.2	Pipe	0.188	0.1882	0.1882	m	25.0	€ 0.0	€ 0.0
40	Con_206012.1	Pipe	0.4	0.4	0.4	m	8.8	€ 0.0	€ 0.0
40	Con_206012.2	Pipe	0.4	0.4	0.4	m	38.6	€ 0.0	€ 0.0
40	Con_206013.1	Pipe	0.4	0.4	0.4	m	65.1	€ 0.0	€ 0.0
40	Con_206028.1	Pipe	0.4	0.4	0.4	m	15.0	€ 0.0	€ 0.0
40	Con_206029.1	Pipe	0.4	0.4	0.4	m	82.3	€ 0.0	€ 0.0
40	Con_206030.1	Pipe	0.4	0.4	0.4	m	78.4	€ 0.0	€ 0.0
40	Con_206031.1	Pipe	0.4	0.4	0.4	m	67.7	€ 0.0	€ 0.0
40	Con_206032.1	Pipe	0.4	0.4	0.4	m	46.4	€ 0.0	€ 0.0
40	Con_206033.1	Pipe	0.4	0.4	0.4	m	45.6	€ 0.0	€ 0.0
41	Con_206040.1	Pipe	0.188	0.2353	0.2353	m	51.5	€ 19,728.0	€ 19,728.0
41	Con_206041.1	Pipe	0.188	0.2353	0.2353	m	51.6	€ 19,783.7	€ 19,783.7
41	Con_206039.1	Pipe	0.188	0.2353	0.2353	m	50.2	€ 19,222.7	€ 19,222.7
41	Con_206034.1	Pipe	0.3	0.4	0.4	m	18.1	€ 9,160.8	€ 9,160.8
41	Con_206036.1	Pipe	0.3	0.4	0.4	m	37.3	€ 18,845.5	€ 18,845.5
41	Con_206037.1	Pipe	0.3	0.4	0.4	m	38.3	€ 19,345.8	€ 19,345.8
41	Con_206038.1	Pipe	0.3	0.4	0.4	m	45.9	€ 23,158.1	€ 23,158.1
41	Con_206039.2	Pipe	0.3	0.4	0.4	m	53.4	€ 26,936.8	€ 26,936.8
41	Con_206043.1	Pipe	0.3	0.4	0.4	m	56.5	€ 28,499.4	€ 28,499.4
41	Con_206044.1	Pipe	0.3	0.4	0.4	m	40.8	€ 20,602.2	€ 20,602.2
41	Con_206045.1	Pipe	0.3	0.4	0.4	m	58.8	€ 29,690.3	€ 29,690.3
41	Con_206046.1	Pipe	0.3	0.4	0.4	m	14.2	€ 7,173.8	€ 7,173.8
41	Con_206047.1	Pipe	0.3	0.4	0.4	m	56.6	€ 28,588.6	€ 28,588.6
41	Con_206048.1	Pipe	0.3	0.4	0.4	m	17.0	€ 8,595.6	€ 8,595.6
41	Con_206049.1	Pipe	0.3	0.4	0.4	m	66.6	€ 33,621.8	€ 33,621.8
41	Con_206050.1	Pipe	0.3	0.4	0.4	m	57.8	€ 29,175.2	€ 29,175.2

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
41	Con_206051.2	Pipe	0.3	0.4	0.4	m	80.4	€ 40,597.1	€ 40,597.1
41	Con_206055.1	Pipe	0.3	0.4	0.4	m	56.9	€ 28,695.4	€ 28,695.4
41	Con_206056.1	Pipe	0.3	0.4	0.4	m	56.6	€ 28,561.9	€ 28,561.9
41	Con_206057.1	Pipe	0.3	0.4	0.4	m	57.4	€ 28,964.9	€ 28,964.9
41	Con_206058.2	Pipe	0.3	0.4	0.4	m	49.6	€ 25,024.6	€ 25,024.6
41	Con_206080.1	Pipe	0.3	0.4	0.4	m	51.7	€ 26,115.6	€ 26,115.6
41	Con_206081.1	Pipe	0.3	0.4	0.4	m	43.4	€ 21,914.5	€ 21,914.5
41	Con_206082.1	Pipe	0.3	0.4	0.4	m	60.1	€ 30,339.6	€ 30,339.6
41	Con_206083.2	Pipe	0.3	0.4	0.4	m	13.6	€ 6,865.3	€ 6,865.3
41	Con_206090.1	Pipe	0.3	0.4	0.4	m	60.4	€ 30,507.1	€ 30,507.1
41	Con_206090.2	Pipe	0.3	0.4	0.4	m	73.6	€ 37,136.0	€ 37,136.0
42	Con_206067.1	Pipe	0.151	0.1506	0.1882	m	17.0	€ 0.0	€ 6,036.6
42	Con_206067.2	Pipe	0.151	0.1506	0.1882	m	15.3	€ 0.0	€ 5,422.5
42	Con_206068.1	Pipe	0.151	0.1506	0.1882	m	28.3	€ 0.0	€ 10,038.7
42	Con_206070.1	Pipe	0.151	0.1506	0.1882	m	33.3	€ 0.0	€ 11,804.8
42	Con_206066.1	Pipe	0.188	0.1882	0.2353	m	34.7	€ 0.0	€ 13,281.0
42	Con_206060.2	Pipe	0.188	0.1882	0.2353	m	10.3	€ 0.0	€ 3,945.6
42	Con_206058.1	Pipe	0.188	0.1882	0.2353	m	32.6	€ 0.0	€ 12,477.1
42	Con_206059.1	Pipe	0.188	0.1882	0.2353	m	38.2	€ 0.0	€ 14,643.2
43	Con_206066.2	Pipe	0.188	0.1882	0.1882	m	19.7	€ 0.0	€ 0.0
43	Con_206072.1	Pipe	0.188	0.1882	0.1882	m	81.0	€ 0.0	€ 0.0
43	Con_206073.1	Pipe	0.188	0.1882	0.1882	m	49.7	€ 0.0	€ 0.0
43	Con_206074.1	Pipe	0.188	0.1882	0.1882	m	29.1	€ 0.0	€ 0.0
43	Con_206075.1	Pipe	0.151	0.1506	0.1506	m	16.3	€ 0.0	€ 0.0
43	Con_206075.2	Pipe	0.151	0.1506	0.1506	m	15.1	€ 0.0	€ 0.0
43	Con_206076.1	Pipe	0.151	0.1506	0.1506	m	29.0	€ 0.0	€ 0.0
43	Con_206078.1	Pipe	0.151	0.1506	0.1506	m	29.0	€ 0.0	€ 0.0
44	Con_206083.1	Pipe	0.188	0.3	0.3	m	51.6	€ 22,163.0	€ 22,163.0
44	Con_206086.2	Pipe	0.188	0.3	0.3	m	55.2	€ 23,691.1	€ 23,691.1
45	Con_206093.1	Pipe	0.188	0.1882	0.1882	m	38.6	€ 0.0	€ 0.0
45	Con_206094.2	Pipe	0.188	0.1882	0.1882	m	33.3	€ 0.0	€ 0.0
45	Con_206098.1	Pipe	0.188	0.1882	0.1882	m	34.7	€ 0.0	€ 0.0
45	Con_206099.1	Pipe	0.188	0.1882	0.1882	m	31.2	€ 0.0	€ 0.0
45	Con_206100.1	Pipe	0.151	0.1506	0.1506	m	24.0	€ 0.0	€ 0.0
45	Con_206100.2	Pipe	0.151	0.1506	0.1506	m	22.2	€ 0.0	€ 0.0
45	Con_206102.1	Pipe	0.151	0.1506	0.1506	m	28.3	€ 0.0	€ 0.0

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
45	Con_206104.1	Pipe	0.188	0.1882	0.1882	m	42.4	€ 0.0	€ 0.0
45	Con_206105.1	Pipe	0.188	0.1882	0.1882	m	41.0	€ 0.0	€ 0.0
45	Con_206105.3	Pipe	0.188	0.1882	0.1882	m	30.4	€ 0.0	€ 0.0
45	Con_206108.1	Pipe	0.188	0.1882	0.1882	m	48.3	€ 0.0	€ 0.0
45	Con_206109.1	Pipe	0.151	0.1506	0.1506	m	29.0	€ 0.0	€ 0.0
45	Con_206109.2	Pipe	0.188	0.1882	0.1882	m	20.5	€ 0.0	€ 0.0
45	Con_206111.1	Pipe	0.151	0.1506	0.1506	m	29.0	€ 0.0	€ 0.0
46	Con_206093.2	Pipe	0.235	0.2353	0.2353	m	54.8	€ 0.0	€ 0.0
46	Con_206113.1	Pipe	0.235	0.2353	0.2353	m	55.3	€ 0.0	€ 0.0
46	Con_206114.1	Pipe	0.235	0.2353	0.2353	m	53.1	€ 0.0	€ 0.0
46	Con_206115.1	Pipe	0.235	0.2353	0.2353	m	51.9	€ 0.0	€ 0.0
46	Con_206116.1	Pipe	0.235	0.2353	0.2353	m	55.2	€ 0.0	€ 0.0
46	Con_206117.1	Pipe	0.235	0.2353	0.2353	m	55.9	€ 0.0	€ 0.0
46	Con_206118.2	Pipe	0.235	0.2353	0.2353	m	54.1	€ 0.0	€ 0.0
46	Con_206134.1	Pipe	0.235	0.2353	0.2353	m	53.7	€ 0.0	€ 0.0
46	Con_206135.1	Pipe	0.235	0.2353	0.2353	m	24.8	€ 0.0	€ 0.0
46	Con_206136.1	Pipe	0.235	0.2353	0.2353	m	30.9	€ 0.0	€ 0.0
46	Con_206136.2	Pipe	0.235	0.2353	0.2353	m	42.2	€ 0.0	€ 0.0
46	Con_206137.1	Pipe	0.235	0.2353	0.2353	m	24.8	€ 0.0	€ 0.0
47	Con_207007.1	Pipe	0.151	0.6	0.6	m	70.9	€ 49,687.7	€ 49,687.7
47	Con_207006.1	Pipe	0.151	0.6	0.6	m	64.3	€ 45,066.8	€ 45,066.8
47	Con_207006.2	Pipe	0.151	0.6	0.6	m	10.2	€ 7,127.0	€ 7,127.0
48	Con_207002.2	Pipe	0.188	0.5	0.5	m	57.3	€ 34,046.8	€ 34,046.8
48	Con_207005.1	Pipe	0.188	0.5	0.5	m	59.0	€ 35,067.9	€ 35,067.9
49	Con_205154.1	Pipe	0.188	0.3	0.3	m	10.8	€ 4,644.7	€ 4,644.7
49	Con_205155.1	Pipe	0.188	0.3	0.3	m	59.6	€ 25,598.9	€ 25,598.9
49	Con_205150.1	Pipe	0.188	0.3	0.3	m	36.9	€ 15,841.3	€ 15,841.3
50	Con_205148.1	Pipe	0.3	0.6	0.6	m	58.5	€ 41,025.6	€ 41,025.6
50	Con_205149.1	Pipe	0.3	0.6	0.6	m	57.7	€ 40,440.4	€ 40,440.4
50	Con_205150.2	Pipe	0.3	0.6	0.6	m	49.7	€ 34,811.3	€ 34,811.3
50	Con_205153.1	Pipe	0.3	0.6	0.6	m	39.4	€ 27,616.6	€ 27,616.6
50	Con_205143.1	Pipe	0.3	0.6	0.6	m	44.1	€ 30,916.1	€ 30,916.1
50	Con_205144.1	Pipe	0.3	0.6	0.6	m	49.1	€ 34,413.8	€ 34,413.8
50	Con_205145.1	Pipe	0.3	0.6	0.6	m	31.0	€ 21,742.6	€ 21,742.6
50	Con_205146.1	Pipe	0.3	0.6	0.6	m	52.0	€ 36,479.5	€ 36,479.5
50	Con_205147.1	Pipe	0.3	0.6	0.6	m	58.5	€ 41,025.6	€ 41,025.6

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
50	Con_205134.2	Pipe	0.3	0.6	0.6	m	37.9	€ 26,536.7	€ 26,536.7
50	Con_205139.1	Pipe	0.3	0.6	0.6	m	54.0	€ 37,880.5	€ 37,880.5
50	Con_205140.1	Pipe	0.3	0.6	0.6	m	51.0	€ 35,758.4	€ 35,758.4
50	Con_205141.1	Pipe	0.3	0.6	0.6	m	50.0	€ 35,057.5	€ 35,057.5
50	Con_205142.1	Pipe	0.3	0.6	0.6	m	50.0	€ 35,078.5	€ 35,078.5
51	Con_205130.1	Pipe	0.3	0.4	0.4	m	43.0	€ 21,727.7	€ 21,727.7
51	Con_205131.1	Pipe	0.3	0.4	0.4	m	54.2	€ 27,359.1	€ 27,359.1
51	Con_205132.1	Pipe	0.3	0.4	0.4	m	45.8	€ 23,114.0	€ 23,114.0
51	Con_205133.1	Pipe	0.3	0.4	0.4	m	49.4	€ 24,932.8	€ 24,932.8
51	Con_205127.1	Pipe	0.3	0.4	0.4	m	47.9	€ 24,170.1	€ 24,170.1
51	Con_205127.2	Pipe	0.3	0.4	0.4	m	28.2	€ 14,222.8	€ 14,222.8
51	Con_205128.1	Pipe	0.3	0.4	0.4	m	47.0	€ 23,728.6	€ 23,728.6
51	Con_205129.1	Pipe	0.3	0.4	0.4	m	50.1	€ 25,298.0	€ 25,298.0
51	Con_205018.2	Pipe	0.3	0.4	0.4	m	20.1	€ 10,157.9	€ 10,157.9
52	Con_205223.1	Pipe	0.3	0.3	0.3	m	65.9	€ 0.0	€ 0.0
52	Con_205224.1	Pipe	0.3	0.3	0.3	m	51.9	€ 0.0	€ 0.0
52	Con_205224.2	Pipe	0.3	0.3	0.3	m	41.1	€ 0.0	€ 0.0
52	Con_205225.1	Pipe	0.3	0.3	0.3	m	52.4	€ 0.0	€ 0.0
52	Con_205226.1	Pipe	0.3	0.3	0.3	m	60.1	€ 0.0	€ 0.0
52	Con_209015.1	Pipe	0.3	0.3	0.3	m	9.5	€ 0.0	€ 0.0
53	Con_209018.1	Pipe	0.3	0.4	0.4	m	43.6	€ 21,986.4	€ 21,986.4
53	Con_209020.1	Pipe	0.3	0.4	0.4	m	31.3	€ 15,814.9	€ 15,814.9
53	Con_209021.1	Pipe	0.3	0.4	0.4	m	42.5	€ 21,455.2	€ 21,455.2
53	Con_209021.2	Pipe	0.3	0.4	0.4	m	12.2	€ 6,147.4	€ 6,147.4
53	Con_209023.1	Pipe	0.3	0.4	0.4	m	27.7	€ 13,987.8	€ 13,987.8
53	Con_205230.2	Pipe	0.3	0.4	0.4	m	16.1	€ 8,149.3	€ 8,149.3
53	Con_205033.3	Pipe	0.4	0.5	0.5	m	78.3	€ 46,505.3	€ 46,505.3
53	Con_209016.1	Pipe	0.3	0.4	0.4	m	40.3	€ 20,342.0	€ 20,342.0
53	Con_209016.2	Pipe	0.3	0.4	0.4	m	69.5	€ 35,059.6	€ 35,059.6
53	Con_209017.1	Pipe	0.3	0.4	0.4	m	38.0	€ 19,186.0	€ 19,186.0
53	Con_205230.1	Pipe	0.3	0.4	0.4	m	13.7	€ 6,907.1	€ 6,907.1
54	Con_205222.2	Pipe	0.3	0.7	0.7	m	47.1	€ 40,127.6	€ 40,127.6
54	Con_205223.2	Pipe	0.3	0.7	0.7	m	46.1	€ 39,267.3	€ 39,267.3
54	Con_205227.1	Pipe	0.3	0.7	0.7	m	42.0	€ 35,781.8	€ 35,781.8
54	Con_205228.1	Pipe	0.3	0.7	0.7	m	43.4	€ 36,980.1	€ 36,980.1
54	Con_205229.1	Pipe	0.3	0.7	0.7	m	41.9	€ 35,730.5	€ 35,730.5

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
54	Con_205230.3	Pipe	0.3	0.7	0.7	m	33.4	€ 28,500.3	€ 28,500.3
54	Con_205220.1	Pipe	0.3	0.7	0.7	m	61.2	€ 52,158.7	€ 52,158.7
54	Con_205220.2	Pipe	0.3	0.7	0.7	m	60.1	€ 51,254.6	€ 51,254.6
54	Con_205221.1	Pipe	0.3	0.7	0.7	m	60.2	€ 51,287.7	€ 51,287.7
54	Con_205222.1	Pipe	0.3	0.7	0.7	m	22.1	€ 18,869.3	€ 18,869.3
54	Con_205105X.1	Pipe	0.297	0.7	0.7	m	5.9	€ 4,990.5	€ 4,990.5
55	Con_205033.2	Pipe	0.188	0.1882	0.1882	m	16.9	€ 0.0	€ 0.0
55	Con_205216.1	Pipe	0.188	0.1882	0.1882	m	50.6	€ 0.0	€ 0.0
55	Con_205217.1	Pipe	0.188	0.1882	0.1882	m	51.6	€ 0.0	€ 0.0
55	Con_205218.1	Pipe	0.188	0.1882	0.1882	m	43.9	€ 0.0	€ 0.0
56	Con_205033.1	Pipe	0.3	0.3	0.3	m	33.0	€ 0.0	€ 0.0
56	Con_205034.1	Pipe	0.3	0.3	0.3	m	61.3	€ 0.0	€ 0.0
56	Con_205035.1	Pipe	0.3	0.3	0.3	m	42.6	€ 0.0	€ 0.0
56	Con_205036.1	Pipe	0.3	0.3	0.3	m	49.2	€ 0.0	€ 0.0
56	Con_205037.1	Pipe	0.3	0.3	0.3	m	39.8	€ 0.0	€ 0.0
56	Con_205038.1	Pipe	0.3	0.3	0.3	m	47.1	€ 0.0	€ 0.0
57	Con_205029.1	Pipe	0.3	0.3	0.4	m	43.3	€ 0.0	€ 21,838.8
57	Con_205030.1	Pipe	0.3	0.3	0.4	m	67.8	€ 0.0	€ 34,211.5
57	Con_205031.1	Pipe	0.3	0.3	0.4	m	70.7	€ 0.0	€ 35,691.2
57	Con_205032.1	Pipe	0.3	0.3	0.4	m	47.7	€ 0.0	€ 24,055.7
57	Con_205024.1	Pipe	0.3	0.3	0.4	m	44.7	€ 0.0	€ 22,539.2
57	Con_205025.1	Pipe	0.3	0.3	0.4	m	52.3	€ 0.0	€ 26,386.1
57	Con_205026.1	Pipe	0.3	0.3	0.4	m	48.4	€ 0.0	€ 24,415.7
57	Con_205027.1	Pipe	0.3	0.3	0.4	m	48.8	€ 0.0	€ 24,629.5
57	Con_205028.1	Pipe	0.3	0.3	0.4	m	53.7	€ 0.0	€ 27,125.3
58	Con_205017.1	Pipe	0.4	0.6	0.6	m	31.6	€ 22,167.9	€ 22,167.9
58	Con_205018.1	Pipe	0.4	0.6	0.6	m	25.5	€ 17,903.7	€ 17,903.7
58	Con_205017.2	Pipe	0.6	0.8	0.8	m	61.4	€ 58,994.0	€ 58,994.0
58	Con_205022.1	Pipe	0.6	0.8	0.8	m	48.6	€ 46,695.8	€ 46,695.8
58	Con_205022.2	Pipe	0.6	0.8	0.8	m	10.8	€ 10,392.7	€ 10,392.7
58	Con_205023.1	Pipe	0.6	0.8	0.8	m	53.3	€ 51,248.2	€ 51,248.2
59	Con_205041.1	Pipe	0.6	0.8	0.8	m	60.3	€ 57,936.1	€ 57,936.1
59	Con_205041.2	Pipe	0.6	0.8	0.8	m	53.0	€ 50,959.2	€ 50,959.2
59	Con_205042X.1	Pipe	0.6	0.8	0.8	m	40.0	€ 38,449.7	€ 38,449.7
59	Con_205043.2	Pipe	0.6	0.8	0.8	m	80.2	€ 77,059.5	€ 77,059.5
59	Con_205043.1	Pipe	0.6	0.8	0.8	m	54.5	€ 52,317.8	€ 52,317.8

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
59	Con_G01.1	Pipe	0.6	0.8	0.8	m	54.8	€ 52,642.2	€ 52,642.2
59	Con_205046.1	Pipe	0.6	0.8	0.8	m	40.7	€ 39,064.0	€ 39,064.0
59	Con_219003.1	Pipe	0.6	0.8	0.8	m	14.4	€ 13,882.3	€ 13,882.3
59	Con_205039.1	Pipe	0.6	0.8	0.8	m	29.4	€ 28,283.1	€ 28,283.1
59	Con_205101.1	Pipe	0.6	0.8	0.8	m	61.2	€ 58,789.7	€ 58,789.7
59	Con_205102.1	Pipe	0.6	0.8	0.8	m	49.0	€ 47,082.3	€ 47,082.3
59	Con_205103.1	Pipe	0.6	0.8	0.8	m	60.9	€ 58,481.5	€ 58,481.5
59	Con_205104.1	Pipe	0.6	0.8	0.8	m	51.5	€ 49,484.0	€ 49,484.0
59	Con_205105.1	Pipe	0.6	0.8	0.8	m	51.9	€ 49,853.6	€ 49,853.6
59	Con_205105.2	Pipe	0.6	0.8	0.8	m	41.9	€ 40,229.9	€ 40,229.9
59	Con_209005.1	Pipe	0.6	0.8	0.8	m	60.4	€ 58,053.8	€ 58,053.8
59	Con_205039.2	Pipe	0.6	0.8	0.8	m	5.4	€ 5,174.1	€ 5,174.1
59	Con_205103.2	Pipe	0.297	0.5	0.5	m	13.8	€ 8,185.6	€ 8,185.6
59	Con_209009X.1	Pipe	0.297	0.5	0.5	m	52.7	€ 31,332.7	€ 31,332.7
59	Con_209009X.2	Pipe	0.297	0.5	0.5	m	51.3	€ 30,459.6	€ 30,459.6
60	Con_290018.1	Pipe	0.4	0.4	0.4	m	44.5	€ 0.0	€ 0.0
60	Con_205105X.2	Pipe	0.4	0.4	0.4	m	59.9	€ 0.0	€ 0.0
60	Con_290000.1	Pipe	0.4	0.4	0.4	m	48.8	€ 0.0	€ 0.0
60	Con_290004.1	Pipe	0.4	0.4	0.4	m	63.0	€ 0.0	€ 0.0
60	Con_290008.1	Pipe	0.4	0.4	0.4	m	50.4	€ 0.0	€ 0.0
60	Con_290012.1	Pipe	0.4	0.4	0.4	m	62.8	€ 0.0	€ 0.0
60	Con_290016.1	Pipe	0.4	0.4	0.4	m	50.7	€ 0.0	€ 0.0
61	Con_205099.1	Pipe	0.4	1	1	m	5.9	€ 7,255.9	€ 7,255.9
61	Con_205099.2	Pipe	0.3	0.8	0.8	m	28.3	€ 27,175.8	€ 27,175.8
61	Con_205107.1	Pipe	0.3	0.8	0.8	m	21.1	€ 20,268.3	€ 20,268.3
61	Con_205108.1	Pipe	0.3	0.8	0.8	m	41.4	€ 39,812.8	€ 39,812.8
61	Con_205109.1	Pipe	0.3	0.8	0.8	m	39.5	€ 37,912.4	€ 37,912.4
61	Con_205173.1	Pipe	0.3	0.8	0.8	m	31.4	€ 30,170.0	€ 30,170.0
61	Con_205173.2	Pipe	0.3	0.8	0.8	m	54.9	€ 52,765.9	€ 52,765.9
61	Con_205126.2	Pipe	0.3	0.8	0.8	m	19.9	€ 19,144.0	€ 19,144.0
61	Con_205110.2	Pipe	0.3	0.8	0.8	m	52.2	€ 50,155.8	€ 50,155.8
62	Con_205126.1	Pipe	0.3	0.3	0.3	m	30.1	€ 0.0	€ 0.0
62	Con_205162.1	Pipe	0.3	0.3	0.3	m	26.9	€ 0.0	€ 0.0
62	Con_205163.1	Pipe	0.3	0.3	0.3	m	25.7	€ 0.0	€ 0.0
62	Con_205163.2	Pipe	0.3	0.3	0.3	m	18.7	€ 0.0	€ 0.0
62	Con_205165.1	Pipe	0.3	0.3	0.3	m	33.5	€ 0.0	€ 0.0

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
62	Con_205170.2	Pipe	0.3	0.3	0.3	m	31.6	€ 0.0	€ 0.0
62	Con_205172.1	Pipe	0.3	0.3	0.3	m	33.5	€ 0.0	€ 0.0
62	Con_205165.2	Pipe	0.3	0.3	0.3	m	46.6	€ 0.0	€ 0.0
62	Con_205168.1	Pipe	0.3	0.3	0.3	m	30.1	€ 0.0	€ 0.0
62	Con_205169.1	Pipe	0.3	0.3	0.3	m	30.1	€ 0.0	€ 0.0
62	Con_205170.1	Pipe	0.3	0.3	0.3	m	36.0	€ 0.0	€ 0.0
63	Con_205181.2	Pipe	0.4	0.4	0.6	m	23.3	€ 0.0	€ 16,350.2
63	Con_205184.1	Pipe	0.4	0.4	0.6	m	39.6	€ 0.0	€ 27,776.3
64	Con_205175.1	Pipe	0.3	0.3	0.3	m	37.9	€ 0.0	€ 0.0
64	Con_205176.1	Pipe	0.3	0.3	0.3	m	17.0	€ 0.0	€ 0.0
64	Con_205177.1	Pipe	0.3	0.3	0.3	m	18.7	€ 0.0	€ 0.0
64	Con_205177.2	Pipe	0.3	0.3	0.3	m	23.1	€ 0.0	€ 0.0
64	Con_205179.1	Pipe	0.3	0.3	0.3	m	24.7	€ 0.0	€ 0.0
64	Con_205115.2	Pipe	0.3	0.3	0.3	m	13.9	€ 0.0	€ 0.0
65	Con_205112.2	Pipe	0.3	0.3	0.3	m	44.6	€ 0.0	€ 0.0
65	Con_205111.1	Pipe	0.3	0.3	0.3	m	29.4	€ 0.0	€ 0.0
65	Con_205110.1	Pipe	0.3	0.3	0.3	m	36.4	€ 0.0	€ 0.0
66	Con_205120.1	Pipe	0.3	0.7	0.7	m	35.7	€ 30,461.7	€ 30,461.7
66	Con_205120.2	Pipe	0.3	0.7	0.7	m	23.5	€ 20,063.8	€ 20,063.8
66	Con_205121.1	Pipe	0.188	0.4	0.4	m	50.0	€ 25,227.4	€ 25,227.4
66	Con_205121.2	Pipe	0.188	0.4	0.4	m	21.5	€ 10,837.4	€ 10,837.4
66	Con_205122.1	Pipe	0.3	0.7	0.7	m	39.2	€ 33,430.0	€ 33,430.0
66	Con_205124.1	Pipe	0.3	0.7	0.7	m	37.0	€ 31,551.4	€ 31,551.4
66	Con_G10.2	Pipe	0.3	0.7	0.7	m	57.4	€ 48,887.3	€ 48,887.3
67	Con_G11.1	Pipe	0.6	0.8	0.8	m	38.2	€ 36,669.3	€ 36,669.3
67	Con_G11.2	Pipe	0.6	0.8	0.8	m	67.1	€ 64,470.4	€ 64,470.4
67	Con_G12.1	Pipe	0.6	0.8	0.8	m	60.1	€ 57,707.8	€ 57,707.8
67	Con_G13.1	Pipe	0.6	0.8	0.8	m	60.0	€ 57,603.3	€ 57,603.3
67	Con_G14.2	Pipe	0.6	0.8	0.8	m	49.0	€ 47,073.2	€ 47,073.2
67	Con_G15.1	Pipe	0.6	0.8	0.8	m	18.0	€ 17,259.8	€ 17,259.8
68	Con_G07.2	Pipe	0.3	0.6	0.6	m	57.0	€ 39,949.8	€ 39,949.8
68	Con_G06.1	Pipe	0.3	0.6	0.6	m	59.9	€ 42,008.5	€ 42,008.5
68	Con_G04.2	Pipe	0.3	0.6	0.6	m	41.8	€ 29,289.1	€ 29,289.1
68	Con_G02.2	Pipe	0.3	0.6	0.6	m	41.2	€ 28,912.3	€ 28,912.3
68	Con_G01.2	Pipe	0.3	0.6	0.6	m	11.2	€ 7,837.5	€ 7,837.5
69	Con_RCplan1.2	Pipe	0.3	0.6	0.6	m	28.5	€ 19,954.7	€ 19,954.7

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
69	Con_RCplan12.2	Pipe	0.3	0.6	0.6	m	36.5	€ 25,566.7	€ 25,566.7
69	Con_RCplan2.2	Pipe	0.3	0.6	0.6	m	34.3	€ 24,012.7	€ 24,012.7
69	Con_RCplan4.1	Pipe	0.3	0.6	0.6	m	39.2	€ 27,481.7	€ 27,481.7
69	Con_RCplan5.1	Pipe	0.3	0.6	0.6	m	41.7	€ 29,205.4	€ 29,205.4
69	Con_RCplan2.1	Pipe	0.3	0.6	0.6	m	14.6	€ 10,252.7	€ 10,252.7
69	Con_RCplan21.1	Pipe	0.3	0.6	0.6	m	39.9	€ 27,967.7	€ 27,967.7
69	Con_RCplan3.1	Pipe	0.3	0.6	0.6	m	54.8	€ 38,386.5	€ 38,386.5
70	Con_RCplan10.1	Pipe	0.6	0.7	0.7	m	32.8	€ 27,938.1	€ 27,938.1
70	Con_RCplan11.1	Pipe	0.6	0.7	0.7	m	38.8	€ 33,041.7	€ 33,041.7
70	Con_RCplan12.1	Pipe	0.6	0.7	0.7	m	50.9	€ 43,385.3	€ 43,385.3
70	Con_RCplan6.1	Pipe	0.6	0.7	0.7	m	55.9	€ 47,633.1	€ 47,633.1
70	Con_RCplan6.2	Pipe	0.6	0.7	0.7	m	46.7	€ 39,794.2	€ 39,794.2
70	Con_RCplan7.1	Pipe	0.6	0.7	0.7	m	48.9	€ 41,697.7	€ 41,697.7
70	Con_RCplan8.1	Pipe	0.6	0.7	0.7	m	59.8	€ 50,966.2	€ 50,966.2
70	Con_RCplan9.1	Pipe	0.6	0.7	0.7	m	40.3	€ 34,354.7	€ 34,354.7
70	Con_RCplan20.2	Pipe	0.6	0.7	0.7	m	34.8	€ 29,703.9	€ 29,703.9
70	Con_RCplan14.2	Pipe	0.6	0.7	0.7	m	14.5	€ 12,374.3	€ 12,374.3
71	Con_205012.3	Pipe	0.7	1	1	m	5.7	€ 6,943.2	€ 6,943.2
71	Con_205012.1	Pipe	0.6	1	1	m	43.7	€ 53,392.1	€ 53,392.1
71	Con_205013.1	Pipe	0.6	1	1	m	46.1	€ 56,246.1	€ 56,246.1
71	Con_205014.1	Pipe	0.6	1	1	m	21.6	€ 26,349.8	€ 26,349.8
71	Con_205300.2	Pipe	0.6	1	1	m	22.5	€ 27,424.3	€ 27,424.3
71	Con_205015.1	Pipe	0.6	1	1	m	46.8	€ 57,106.8	€ 57,106.8
71	Con_205016.1	Pipe	0.6	1	1	m	29.2	€ 35,723.1	€ 35,723.1
72	Con_206140.1	Pipe	0.188	0.25	0.25	m	27.7	€ 10,860.7	€ 10,860.7
72	Con_206141.1	Pipe	0.188	0.25	0.25	m	32.6	€ 12,820.5	€ 12,820.5
72	Con_206142.1	Pipe	0.188	0.25	0.25	m	45.3	€ 17,778.9	€ 17,778.9
72	Con_206143.1	Pipe	0.188	0.25	0.25	m	63.6	€ 24,973.9	€ 24,973.9
72	Con_206144.1	Pipe	0.188	0.25	0.25	m	65.3	€ 25,623.0	€ 25,623.0

Appendix L - Formal Optimisation Results

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
1	Sub_207001	RB	0	0.24	2.4	m^2	-	€ 133.4	€ 1,334.40
1	Sub_207002	RB	0	0.24	1.44	m^2	-	€ 133.4	€ 800.64
1	Sub_207003	RB	0	0.24	0.96	m^2	-	€ 133.4	€ 533.76
1	Sub_207005	RB	0	0.24	2.4	m^2	-	€ 133.4	€ 1,334.40
1	Sub_207009	RB	0	0.24	0.48	m^2	-	€ 133.4	€ 266.88
1	Sub_207010	RB	0	0.24	0.48	m^2	-	€ 133.4	€ 266.88
1	Sub_207006	RB	0	0.24	0.48	m^2	-	€ 133.4	€ 266.88
1	Sub_296131	RB	0	0.24	0.48	m^2	-	€ 133.4	€ 266.88
1	Sub_296132	RB	0	0.24	0.48	m^2	-	€ 133.4	€ 266.88
1	Sub_206133	RB	0	0.24	0.48	m^2	-	€ 133.4	€ 266.88
1	Sub_206122	RB	0	0.24	0.48	m^2	-	€ 133.4	€ 266.88
1	Sub_206123	RB	0	0.24	0.48	m^2	-	€ 133.4	€ 266.88
1	Sub_206127	RB	0	0.24	0.96	m^2	-	€ 133.4	€ 533.76
1	Sub_206128	RB	0	0.24	0.48	m^2	-	€ 133.4	€ 266.88
1	Sub_206129	RB	0	0.24	2.4	m^2	-	€ 133.4	€ 1,334.40
1	Sub_206119	RB	0	0.24	0.96	m^2	-	€ 133.4	€ 533.76
1	Sub_206120	RB	0	0.24	0.48	m^2	-	€ 133.4	€ 266.88
1	Sub_206138	RB	0	0.24	1.92	m^2	-	€ 133.4	€ 1,067.52
1	Sub_206139	RB	0	0.24	0.48	m^2	-	€ 133.4	€ 266.88
1	Sub_206140	RB	0	0.24	0.48	m^2	-	€ 133.4	€ 266.88
1	Sub_206142	RB	0	0.24	2.4	m^2	-	€ 133.4	€ 1,334.40
1	Sub_206143	RB	0	0.24	0.48	m^2	-	€ 133.4	€ 266.88
1	Sub_206145	RB	0	0.24	0.96	m^2	-	€ 133.4	€ 533.76
2	Sub_206108	RB	0	0.72	1.44	m^2	-	€ 400.3	€ 800.64
2	Sub_206109	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
2	Sub_206110	RB	0	0.72	1.44	m^2	-	€ 400.3	€ 800.64
2	Sub_206111	RB	0	0.72	1.44	m^2	-	€ 400.3	€ 800.64

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
2	Sub_206104	RB	0	0.72	0.96	m^2	-	€ 400.3	€ 533.76
2	Sub_206105	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
2	Sub_206106	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
2	Sub_206107	RB	0	0.72	2.64	m^2	-	€ 400.3	€ 1,467.84
2	Sub_206099	RB	0	0.72	0.96	m^2	-	€ 400.3	€ 533.76
2	Sub_206100	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
2	Sub_206101	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
2	Sub_206102	RB	0	0.72	1.92	m^2	-	€ 400.3	€ 1,067.52
2	Sub_206103	RB	0	0.72	1.92	m^2	-	€ 400.3	€ 1,067.52
2	Sub_206095	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
2	Sub_206096	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
2	Sub_206097	RB	0	0.72	0.96	m^2	-	€ 400.3	€ 533.76
2	Sub_206097A	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
2	Sub_206091	RB	0	0.72	0.96	m^2	-	€ 400.3	€ 533.76
2	Sub_206092	RB	0	0.72	0.96	m^2	-	€ 400.3	€ 533.76
3	Sub_206084	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
3	Sub_206084A	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
3	Sub_206085	RB	0	0.48	0.96	m^2	-	€ 266.9	€ 533.76
3	Sub_206086	RB	0	0.48	1.68	m^2	-	€ 266.9	€ 934.08
3	Sub_206087	RB	0	0.48	1.68	m^2	-	€ 266.9	€ 934.08
3	Sub_206088	RB	0	0.48	1.68	m^2	-	€ 266.9	€ 934.08
3	Sub_206089	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
3	Sub_206072	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
3	Sub_206073	RB	0	0.48	1.44	m^2	-	€ 266.9	€ 800.64
3	Sub_206074	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
3	Sub_206076	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
3	Sub_206077	RB	0	0.48	0.96	m^2	-	€ 266.9	€ 533.76
3	Sub_206078	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
3	Sub_206079	RB	0	0.48	1.44	m^2	-	€ 266.9	€ 800.64
3	Sub_206065	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
3	Sub_206069	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
3	Sub_206070	RB	0	0.48	0.96	m^2	-	€ 266.9	€ 533.76
3	Sub_206071	RB	0	0.48	1.44	m^2	-	€ 266.9	€ 800.64
4	Sub_206051	RB	0	0.48	1.44	m^2	-	€ 266.9	€ 800.64
4	Sub_206055	RB	0	0.48	4.8	m^2	-	€ 266.9	€ 2,668.80
4	Sub_206056	RB	0	0.48	1.44	m^2	-	€ 266.9	€ 800.64
4	Sub_206052	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
4	Sub_206053	RB	0	0.48	0.96	m^2	-	€ 266.9	€ 533.76
4	Sub_206054	RB	0	0.48	1.44	m^2	-	€ 266.9	€ 800.64
4	Sub_206039	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
4	Sub_206043	RB	0	0.48	1.92	m^2	-	€ 266.9	€ 1,067.52
4	Sub_206046	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
4	Sub_206048	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
4	Sub_206040	RB	0	0.48	5.04	m^2	-	€ 266.9	€ 2,802.24
4	Sub_206041	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
4	Sub_206042	RB	0	0.48	0.96	m^2	-	€ 266.9	€ 533.76
5	Sub_202021	RB	0	0	0.96	m^2	-	€ 0.0	€ 533.76
5	Sub_202022	RB	0	0	0.48	m^2	-	€ 0.0	€ 266.88
5	Sub_202023	RB	0	0	0.48	m^2	-	€ 0.0	€ 266.88
5	Sub_202024	RB	0	0	0.48	m^2	-	€ 0.0	€ 266.88
5	Sub_202025	RB	0	0	1.2	m^2	-	€ 0.0	€ 667.20
5	Sub_202026	RB	0	0	0.48	m^2	-	€ 0.0	€ 266.88
5	Sub_202001	RB	0	0	0.48	m^2	-	€ 0.0	€ 266.88
5	Sub_202002	RB	0	0	0.48	m^2	-	€ 0.0	€ 266.88
5	Sub_202003	RB	0	0	0.48	m^2	-	€ 0.0	€ 266.88
5	Sub_202005	RB	0	0	0.48	m^2	-	€ 0.0	€ 266.88
5	Sub_202006	RB	0	0	0.48	m^2	-	€ 0.0	€ 266.88
6	Sub_206022	RB	0	2.16	1.68	m^2	-	€ 1,201.0	€ 934.08
6	Sub_206023	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.76
6	Sub_206148	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
6	Sub_206150	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
6	Sub_206151	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
6	Sub_206152	RB	0	2.16	1.68	m^2	-	€ 1,201.0	€ 934.08
6	Sub_206153	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.76
7	Sub_290018	RB	0	3.36	3.12	m^2	-	€ 1,868.2	€ 1,734.72
7	Sub_209009	RB	0	1.44	1.44	m^2	-	€ 800.6	€ 800.64
7	Sub_209009X	RB	0	4.08	3.12	m^2	-	€ 2,268.5	€ 1,734.72
7	Sub_209009Y	RB	0	3.36	3.12	m^2	-	€ 1,868.2	€ 1,734.72
7	Sub_205103	RB	0	1.44	1.44	m^2	-	€ 800.6	€ 800.64
7	Sub_205104	RB	0	1.92	1.92	m^2	-	€ 1,067.5	€ 1,067.52
7	Sub_205105	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
7	Sub_205098	RB	0	1.92	1.92	m^2	-	€ 1,067.5	€ 1,067.52
7	Sub_290000	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.76
7	Sub_205101	RB	0	4.08	3.12	m^2	-	€ 2,268.5	€ 1,734.72
7	Sub_205102	RB	0	3.36	3.12	m^2	-	€ 1,868.2	€ 1,734.72
7	Sub_290004	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
7	Sub_290012	RB	0	3.36	3.12	m^2	-	€ 1,868.2	€ 1,734.72
7	Sub_290016	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.76
7	Sub_205033	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
7	Sub_205034	RB	0	1.92	1.92	m^2	-	€ 1,067.5	€ 1,067.52
7	Sub_205035	RB	0	2.88	2.88	m^2	-	€ 1,601.3	€ 1,601.28
7	Sub_205036	RB	0	1.92	1.92	m^2	-	€ 1,067.5	€ 1,067.52
7	Sub_205037	RB	0	3.36	3.12	m^2	-	€ 1,868.2	€ 1,734.72
7	Sub_205038	RB	0	3.36	3.12	m^2	-	€ 1,868.2	€ 1,734.72
8	Sub_205224	RB	0	2.4	2.4	m^2	-	€ 1,334.4	€ 1,334.40
8	Sub_205225	RB	0	3.12	4.32	m^2	-	€ 1,734.7	€ 2,401.92
8	Sub_205226	RB	0	2.88	2.88	m^2	-	€ 1,601.3	€ 1,601.28
8	Sub_205220	RB	0	3.12	4.32	m^2	-	€ 1,734.7	€ 2,401.92
8	Sub_205221	RB	0	3.12	4.32	m^2	-	€ 1,734.7	€ 2,401.92
8	Sub_205222	RB	0	1.44	1.44	m^2	-	€ 800.6	€ 800.64
8	Sub_205223	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.76
8	Sub_205227	RB	0	1.92	1.92	m^2	-	€ 1,067.5	€ 1,067.52
8	Sub_205228	RB	0	1.92	1.92	m^2	-	€ 1,067.5	€ 1,067.52

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
8	Sub_205229	RB	0	2.88	2.88	m^2	-	€ 1,601.3	€ 1,601.28
8	Sub_215229	RB	0	1.92	1.92	m^2	-	€ 1,067.5	€ 1,067.52
8	Sub_205230	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
8	Sub_205105X	RB	0	1.44	1.44	m^2	-	€ 800.6	€ 800.64
8	Sub_209016	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.76
8	Sub_209017	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.76
8	Sub_209018	RB	0	1.44	1.44	m^2	-	€ 800.6	€ 800.64
8	Sub_209019	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
8	Sub_209020	RB	0	1.44	1.44	m^2	-	€ 800.6	€ 800.64
8	Sub_209021	RB	0	1.92	1.92	m^2	-	€ 1,067.5	€ 1,067.52
8	Sub_209023	RB	0	3.12	3.36	m^2	-	€ 1,734.7	€ 1,868.16
8	Sub_209024	RB	0	2.4	2.4	m^2	-	€ 1,334.4	€ 1,334.40
8	Sub_219021	RB	0	1.92	1.92	m^2	-	€ 1,067.5	€ 1,067.52
9	Sub_205217	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
9	Sub_205218	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.76
9	Sub_205219	RB	0	1.92	1.92	m^2	-	€ 1,067.5	€ 1,067.52
9	Sub_205025	RB	0	1.44	1.44	m^2	-	€ 800.6	€ 800.64
9	Sub_205026	RB	0	1.44	1.44	m^2	-	€ 800.6	€ 800.64
9	Sub_205027	RB	0	1.44	1.44	m^2	-	€ 800.6	€ 800.64
9	Sub_205028	RB	0	2.88	2.64	m^2	-	€ 1,601.3	€ 1,467.84
9	Sub_205029	RB	0	1.92	1.92	m^2	-	€ 1,067.5	€ 1,067.52
9	Sub_205030	RB	0	1.92	1.92	m^2	-	€ 1,067.5	€ 1,067.52
9	Sub_205031	RB	0	3.12	2.64	m^2	-	€ 1,734.7	€ 1,467.84
9	Sub_205032	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.76
10	Sub_RCplan17	RB	0	0.72	1.44	m^2	-	€ 400.3	€ 800.64
10	Sub_205061	RB	0	0.72	1.92	m^2	-	€ 400.3	€ 1,067.52
10	Sub_205062	RB	0	0.72	0.96	m^2	-	€ 400.3	€ 533.76
10	Sub_205063	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
10	Sub_205064	RB	0	0.72	0.96	m^2	-	€ 400.3	€ 533.76
10	Sub_205066	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
10	Sub_205041	RB	0	0.72	0.96	m^2	-	€ 400.3	€ 533.76

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
10	Sub_205042	RB	0	0.72	1.44	m^2	-	€ 400.3	€ 800.64
10	Sub_205042X	RB	0	0.72	1.92	m^2	-	€ 400.3	€ 1,067.52
10	Sub_205043	RB	0	0.72	0.96	m^2	-	€ 400.3	€ 533.76
10	Sub_205044	RB	0	0.72	1.92	m^2	-	€ 400.3	€ 1,067.52
10	Sub_205045	RB	0	0.72	1.44	m^2	-	€ 400.3	€ 800.64
10	Sub_205046	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
11	Sub_205162	RB	0	0.72	0.24	m^2	-	€ 400.3	€ 133.44
11	Sub_205163	RB	0	0.48	0.24	m^2	-	€ 266.9	€ 133.44
11	Sub_205164	RB	0	0.72	0.24	m^2	-	€ 400.3	€ 133.44
11	Sub_205165	RB	0	0.72	0.24	m^2	-	€ 400.3	€ 133.44
11	Sub_205166	RB	0	0.48	0.24	m^2	-	€ 266.9	€ 133.44
11	Sub_205168	RB	0	0.72	0.24	m^2	-	€ 400.3	€ 133.44
11	Sub_205169	RB	0	0.72	0.24	m^2	-	€ 400.3	€ 133.44
11	Sub_205170	RB	0	0.72	0.24	m^2	-	€ 400.3	€ 133.44
11	Sub_205171	RB	0	0.72	0.24	m^2	-	€ 400.3	€ 133.44
11	Sub_205172	RB	0	0.72	0.24	m^2	-	€ 400.3	€ 133.44
11	Sub_205173	RB	0	0.72	0.24	m^2	-	€ 400.3	€ 133.44
11	Sub_205107	RB	0	0.72	0.24	m^2	-	€ 400.3	€ 133.44
11	Sub_205108	RB	0	0.72	0.24	m^2	-	€ 400.3	€ 133.44
11	Sub_205109	RB	0	0.72	0.24	m^2	-	€ 400.3	€ 133.44
11	Sub_205110	RB	0	0.72	0.24	m^2	-	€ 400.3	€ 133.44
11	Sub_205174	RB	0	0.72	0.24	m^2	-	€ 400.3	€ 133.44
11	Sub_205175	RB	0	0.72	0.24	m^2	-	€ 400.3	€ 133.44
11	Sub_205176	RB	0	0.72	0.24	m^2	-	€ 400.3	€ 133.44
11	Sub_205177	RB	0	0.48	0.24	m^2	-	€ 266.9	€ 133.44
11	Sub_205178	RB	0	0.72	0.24	m^2	-	€ 400.3	€ 133.44
11	Sub_205179	RB	0	0.72	0.24	m^2	-	€ 400.3	€ 133.44
11	Sub_205180	RB	0	0.48	0.24	m^2	-	€ 266.9	€ 133.44
11	Sub_205115	RB	0	0.72	0.24	m^2	-	€ 400.3	€ 133.44
11	Sub_205116	RB	0	0.72	0.24	m^2	-	€ 400.3	€ 133.44
11	Sub_205126	RB	0	0.48	0.24	m^2	-	€ 266.9	€ 133.44

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
11	Sub_205111	RB	0	0.72	0.24	m^2	-	€ 400.3	€ 133.44
11	Sub_205112	RB	0	0.72	0.24	m^2	-	€ 400.3	€ 133.44
11	Sub_205113	RB	0	0.72	0.24	m^2	-	€ 400.3	€ 133.44
11	Sub_205114	RB	0	0.72	0.24	m^2	-	€ 400.3	€ 133.44
11	Sub_205117	RB	0	0.48	0.24	m^2	-	€ 266.9	€ 133.44
12	Sub_205181	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
12	Sub_205182	RB	0	1.92	0.72	m^2	-	€ 1,067.5	€ 400.32
12	Sub_205184	RB	0	1.92	0.72	m^2	-	€ 1,067.5	€ 400.32
12	Sub_205185	RB	0	2.4	0.72	m^2	-	€ 1,334.4	€ 400.32
12	Sub_205186	RB	0	1.92	0.72	m^2	-	€ 1,067.5	€ 400.32
12	Sub_205194	RB	0	1.92	0.72	m^2	-	€ 1,067.5	€ 400.32
12	Sub_205195	RB	0	0.96	0.72	m^2	-	€ 533.8	€ 400.32
12	Sub_205197	RB	0	0.96	0.72	m^2	-	€ 533.8	€ 400.32
12	Sub_205187	RB	0	2.4	0.72	m^2	-	€ 1,334.4	€ 400.32
12	Sub_205188	RB	0	0.96	0.72	m^2	-	€ 533.8	€ 400.32
12	Sub_205189	RB	0	0.96	0.72	m^2	-	€ 533.8	€ 400.32
12	Sub_205190	RB	0	1.44	0.72	m^2	-	€ 800.6	€ 400.32
12	Sub_205191	RB	0	2.4	0.72	m^2	-	€ 1,334.4	€ 400.32
12	Sub_205192	RB	0	2.4	0.72	m^2	-	€ 1,334.4	€ 400.32
12	Sub_205199	RB	0	0.96	0.72	m^2	-	€ 533.8	€ 400.32
12	Sub_205193	RB	0	2.4	0.72	m^2	-	€ 1,334.4	€ 400.32
12	Sub_205200	RB	0	2.4	0.72	m^2	-	€ 1,334.4	€ 400.32
12	Sub_205201	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
12	Sub_205209	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
12	Sub_205210	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
13	Sub_205118	RB	0	3.84	3.6	m^2	-	€ 2,135.0	€ 2,001.60
13	Sub_205118A	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.76
13	Sub_205119	RB	0	2.88	2.88	m^2	-	€ 1,601.3	€ 1,601.28
13	Sub_205124	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
13	Sub_205125	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.76
13	Sub_RCplan10	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.76

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
13	Sub_RCplan6	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.76
13	Sub_RCplan7	RB	0	2.88	2.88	m^2	-	€ 1,601.3	€ 1,601.28
13	Sub_RCplan8	RB	0	1.92	1.92	m^2	-	€ 1,067.5	€ 1,067.52
13	Sub_RCplan9	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.76
13	Sub_205214	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
13	Sub_205080	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
14	Sub_205067	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.76
14	Sub_205068	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.76
14	Sub_205069	RB	0	1.2	1.44	m^2	-	€ 667.2	€ 800.64
14	Sub_205070	RB	0	1.2	1.44	m^2	-	€ 667.2	€ 800.64
14	Sub_205071	RB	0	1.2	1.44	m^2	-	€ 667.2	€ 800.64
14	Sub_205072	RB	0	1.2	1.44	m^2	-	€ 667.2	€ 800.64
14	Sub_205076	RB	0	1.2	1.44	m^2	-	€ 667.2	€ 800.64
14	Sub_RCplan3	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.76
14	Sub_RCplan5	RB	0	1.2	1.44	m^2	-	€ 667.2	€ 800.64
14	Sub_205073	RB	0	1.2	1.44	m^2	-	€ 667.2	€ 800.64
14	Sub_205074	RB	0	1.2	1.44	m^2	-	€ 667.2	€ 800.64
14	Sub_205075	RB	0	1.2	1.44	m^2	-	€ 667.2	€ 800.64
14	Sub_205013	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.76
14	Sub_205014	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.76
14	Sub_205015	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
14	Sub_205016	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
14	Sub_205017	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
14	Sub_205300	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
15	Sub_205160	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
15	Sub_205161	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.76
15	Sub_205021	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
15	Sub_205022	RB	0	1.92	1.92	m^2	-	€ 1,067.5	€ 1,067.52
15	Sub_205023	RB	0	2.88	2.88	m^2	-	€ 1,601.3	€ 1,601.28
15	Sub_205048	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
15	Sub_205150	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
15	Sub_205151	RB	0	2.88	3.6	m^2	-	€ 1,601.3	€ 2,001.60
15	Sub_205154	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
15	Sub_205155	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
15	Sub_205156	RB	0	2.88	3.6	m^2	-	€ 1,601.3	€ 2,001.60
15	Sub_205139	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
15	Sub_205140	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
15	Sub_205141	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
15	Sub_205142	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
15	Sub_205143	RB	0	1.44	1.44	m^2	-	€ 800.6	€ 800.64
15	Sub_205145	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.76
15	Sub_205147	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
15	Sub_205148	RB	0	1.44	1.44	m^2	-	€ 800.6	€ 800.64
15	Sub_205149	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.76
15	Sub_205128	RB	0	1.44	1.44	m^2	-	€ 800.6	€ 800.64
15	Sub_205129	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
15	Sub_205130	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
15	Sub_205131	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.76
15	Sub_205132	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
15	Sub_205133	RB	0	0.48	0.48	m^2	-	€ 266.9	€ 266.88
15	Sub_205134	RB	0	0.96	0.96	m^2	-	€ 533.8	€ 533.76
16	Sub_206139	IT	0	0	18	m^2	-	€ 0.0	€ 5,054.40
16	Sub_206140	IT	0	0	13.5	m^2	-	€ 0.0	€ 3,790.80
16	Sub_206141	IT	0	0	27	m^2	-	€ 0.0	€ 7,581.60
17	Sub_290016	IT	0	3	6	m^2	-	€ 842.4	€ 1,684.80
17	Sub_205039	IT	0	3	6	m^2	-	€ 842.4	€ 1,684.80
17	Sub_209003	IT	0	1.3	2.6	m^2	-	€ 365.0	€ 730.08
17	Sub_205024	IT	0	5.2	10.4	m^2	-	€ 1,460.2	€ 2,920.32
17	Sub_205033	IT	0	6	12	m^2	-	€ 1,684.8	€ 3,369.60
17	Sub_205224	IT	0	3.5	7	m^2	-	€ 982.8	€ 1,965.60
17	Sub_205226	IT	0	5.8	11.6	m^2	-	€ 1,628.6	€ 3,257.28
17	Sub_209015	IT	0	5.3	10.6	m^2	-	€ 1,488.2	€ 2,976.48

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
17	Sub_209017	IT	0	7.6	15.2	m^2	-	€ 2,134.1	€ 4,268.16
17	Sub_209019	IT	0	5	10	m^2	-	€ 1,404.0	€ 2,808.00
17	Sub_205099	IT	0	1.5	3	m^2	-	€ 421.2	€ 842.40
17	Sub_205107	IT	0	2	4	m^2	-	€ 561.6	€ 1,123.20
18	Sub_205114	IT	0	10	5	m^2	-	€ 2,808.0	€ 1,404.00
18	Sub_RCplan11	IT	0	20	10	m^2	-	€ 5,616.0	€ 2,808.00
18	Sub_RCplan20_toe	IT	0	12	6	m^2	-	€ 3,369.6	€ 1,684.80
18	Sub_RCplan3	IT	0	20	10	m^2	-	€ 5,616.0	€ 2,808.00
18	Sub_205077	IT	0	20	10	m^2	-	€ 5,616.0	€ 2,808.00
18	Sub_RCplan5	IT	0	20	10	m^2	-	€ 5,616.0	€ 2,808.00
18	Sub_205180	IT	0	12	6	m^2	-	€ 3,369.6	€ 1,684.80
18	Sub_205182	IT	0	10	5	m^2	-	€ 2,808.0	€ 1,404.00
18	Sub_205183	IT	0	10	5	m^2	-	€ 2,808.0	€ 1,404.00
18	Sub_205196	IT	0	16	8	m^2	-	€ 4,492.8	€ 2,246.40
18	Sub_205197	IT	0	12	6	m^2	-	€ 3,369.6	€ 1,684.80
19	Sub_202001	PP	0	323	19	m^2	-	€ 57,558.6	€ 3,385.80
19	Sub_202002	PP	0	85	5	m^2	-	€ 15,147.0	€ 891.00
19	Sub_202003	PP	0	161.5	9.5	m^2	-	€ 28,779.3	€ 1,692.90
20	Sub_202020	PP	0	0	0	m^2	-	€ 0.0	€ 0.00
20	Sub_202021	PP	0	0	0	m^2	-	€ 0.0	€ 0.00
20	Sub_202022	PP	0	0	0	m^2	-	€ 0.0	€ 0.00
20	Sub_202023	PP	0	0	0	m^2	-	€ 0.0	€ 0.00
20	Sub_202024	PP	0	0	0	m^2	-	€ 0.0	€ 0.00
20	Sub_202025	PP	0	0	0	m^2	-	€ 0.0	€ 0.00
20	Sub_202026	PP	0	0	0	m^2	-	€ 0.0	€ 0.00
21	Sub_205024	PP	0	76.5	137.7	m^2	-	€ 13,632.3	€ 24,538.14
21	Sub_205041	PP	0	45	81	m^2	-	€ 8,019.0	€ 14,434.20
21	Sub_205042	PP	0	33	59.4	m^2	-	€ 5,880.6	€ 10,585.08
21	Sub_205042X	PP	0	40	72	m^2	-	€ 7,128.0	€ 12,830.40
21	Sub_205043	PP	0	32.5	58.5	m^2	-	€ 5,791.5	€ 10,424.70
21	Sub_205044	PP	0	25	45	m^2	-	€ 4,455.0	€ 8,019.00

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
21	Sub_205045	PP	0	42.5	76.5	m^2	-	€ 7,573.5	€ 13,632.30
21	Sub_205046	PP	0	42.5	76.5	m^2	-	€ 7,573.5	€ 13,632.30
21	Sub_209003	PP	0	13.5	24.3	m^2	-	€ 2,405.7	€ 4,330.26
21	Sub_205039	PP	0	35	63	m^2	-	€ 6,237.0	€ 11,226.60
21	Sub_205062	PP	0	27.5	49.5	m^2	-	€ 4,900.5	€ 8,820.90
21	Sub_205063	PP	0	35	63	m^2	-	€ 6,237.0	€ 11,226.60
21	Sub_205064	PP	0	15	27	m^2	-	€ 2,673.0	€ 4,811.40
21	Sub_205076	PP	0	25	45	m^2	-	€ 4,455.0	€ 8,019.00
22	Sub_RCplan7	PP	0	12	54	m^2	-	€ 2,138.4	€ 9,622.80
22	Sub_RCplan8	PP	0	12	54	m^2	-	€ 2,138.4	€ 9,622.80
22	Sub_RCplan9	PP	0	11	49.5	m^2	-	€ 1,960.2	€ 8,820.90
22	Sub_RCplan10	PP	0	12	54	m^2	-	€ 2,138.4	€ 9,622.80
22	Sub_RCplan11	PP	0	10	45	m^2	-	€ 1,782.0	€ 8,019.00
22	Sub_RCplan12	PP	0	30	135	m^2	-	€ 5,346.0	€ 24,057.00
22	Sub_RCplan13	PP	0	10	45	m^2	-	€ 1,782.0	€ 8,019.00
22	Sub_RCplan1	PP	0	12	54	m^2	-	€ 2,138.4	€ 9,622.80
22	Sub_RCplan17	PP	0	10	45	m^2	-	€ 1,782.0	€ 8,019.00
22	Sub_RCplan2	PP	0	15	67.5	m^2	-	€ 2,673.0	€ 12,028.50
22	Sub_RCplan3	PP	0	18	81	m^2	-	€ 3,207.6	€ 14,434.20
22	Sub_RCplan4	PP	0	15	67.5	m^2	-	€ 2,673.0	€ 12,028.50
22	Sub_RCplan5	PP	0	10	45	m^2	-	€ 1,782.0	€ 8,019.00
23	Sub_205100	PP	0	0	10	m^2	-	€ 0.0	€ 1,782.00
23	Sub_205101	PP	0	0	16	m^2	-	€ 0.0	€ 2,851.20
23	Sub_205102	PP	0	0	10	m^2	-	€ 0.0	€ 1,782.00
23	Sub_205103	PP	0	0	11	m^2	-	€ 0.0	€ 1,960.20
23	Sub_205104	PP	0	0	8	m^2	-	€ 0.0	€ 1,425.60
23	Sub_205105	PP	0	0	8	m^2	-	€ 0.0	€ 1,425.60
23	Sub_205105X	PP	0	0	14	m^2	-	€ 0.0	€ 2,494.80
23	Sub_205107	PP	0	0	6	m^2	-	€ 0.0	€ 1,069.20
23	Sub_290000	PP	0	0	10	m^2	-	€ 0.0	€ 1,782.00
23	Sub_290004	PP	0	0	14	m^2	-	€ 0.0	€ 2,494.80

No. DV	**Object ID**	**Type**	**Old Value**	**New Value 2030**	**New Value 2085**	**Unit**	**Pipe Length m**	**Cost for 2030**	**Cost for 2085**
23	Sub_290008	PP	0	0	10.5	m^2	-	€ 0.0	€ 1,871.10
23	Sub_290012	PP	0	0	14	m^2	-	€ 0.0	€ 2,494.80
23	Sub_290016	PP	0	0	10	m^2	-	€ 0.0	€ 1,782.00
23	Sub_290018	PP	0	0	17	m^2	-	€ 0.0	€ 3,029.40
23	Sub_209009X	PP	0	0	23.5	m^2	-	€ 0.0	€ 4,187.70
23	Sub_209009Y	PP	0	0	23.5	m^2	-	€ 0.0	€ 4,187.70
24	Sub_205111	PP	0	30	7.5	m^2	-	€ 5,346.0	€ 1,336.50
24	Sub_205112	PP	0	40	10	m^2	-	€ 7,128.0	€ 1,782.00
24	Sub_205113	PP	0	34	8.5	m^2	-	€ 6,058.8	€ 1,514.70
24	Sub_205115	PP	0	30	7.5	m^2	-	€ 5,346.0	€ 1,336.50
24	Sub_205116	PP	0	40	10	m^2	-	€ 7,128.0	€ 1,782.00
24	Sub_205117	PP	0	76	19	m^2	-	€ 13,543.2	€ 3,385.80
24	Sub_205162	PP	0	30	7.5	m^2	-	€ 5,346.0	€ 1,336.50
24	Sub_205163	PP	0	30	7.5	m^2	-	€ 5,346.0	€ 1,336.50
24	Sub_205164	PP	0	32	8	m^2	-	€ 5,702.4	€ 1,425.60
24	Sub_205165	PP	0	62.8	15.7	m^2	-	€ 11,191.0	€ 2,797.74
24	Sub_205166	PP	0	20	5	m^2	-	€ 3,564.0	€ 891.00
24	Sub_205168	PP	0	30	7.5	m^2	-	€ 5,346.0	€ 1,336.50
24	Sub_205169	PP	0	30	7.5	m^2	-	€ 5,346.0	€ 1,336.50
24	Sub_205170	PP	0	30	7.5	m^2	-	€ 5,346.0	€ 1,336.50
24	Sub_205171	PP	0	28	7	m^2	-	€ 4,989.6	€ 1,247.40
24	Sub_205172	PP	0	36	9	m^2	-	€ 6,415.2	€ 1,603.80
24	Sub_205175	PP	0	12	3	m^2	-	€ 2,138.4	€ 534.60
24	Sub_205176	PP	0	24	6	m^2	-	€ 4,276.8	€ 1,069.20
24	Sub_205177	PP	0	16	4	m^2	-	€ 2,851.2	€ 712.80
24	Sub_205178	PP	0	16	4	m^2	-	€ 2,851.2	€ 712.80
24	Sub_205179	PP	0	20	5	m^2	-	€ 3,564.0	€ 891.00
24	Sub_205180	PP	0	16	4	m^2	-	€ 2,851.2	€ 712.80
24	Sub_205184	PP	0	38	9.5	m^2	-	€ 6,771.6	€ 1,692.90
24	Sub_205185	PP	0	20	5	m^2	-	€ 3,564.0	€ 891.00
24	Sub_205186	PP	0	38	9.5	m^2	-	€ 6,771.6	€ 1,692.90

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
24	Sub_205187	PP	0	30	7.5	m^2	-	€ 5,346.0	€ 1,336.50
25	Sub_205118	PP	0	0	30	m^2	-	€ 0.0	€ 5,346.00
25	Sub_205118A	PP	0	0	15	m^2	-	€ 0.0	€ 2,673.00
25	Sub_205119	PP	0	0	45	m^2	-	€ 0.0	€ 8,019.00
25	Sub_205121	PP	0	0	45	m^2	-	€ 0.0	€ 8,019.00
25	Sub_205122	PP	0	0	37.5	m^2	-	€ 0.0	€ 6,682.50
25	Sub_205123	PP	0	0	22.5	m^2	-	€ 0.0	€ 4,009.50
25	Sub_205124	PP	0	0	22.5	m^2	-	€ 0.0	€ 4,009.50
25	Sub_205125	PP	0	0	15	m^2	-	€ 0.0	€ 2,673.00
25	Sub_205120	PP	0	0	53.25	m^2	-	€ 0.0	€ 9,489.15
25	Sub_295121	PP	0	0	67.5	m^2	-	€ 0.0	€ 12,028.50
26	Sub_205216	PP	0	60	30	m^2	-	€ 10,692.0	€ 5,346.00
26	Sub_205217	PP	0	75	37.5	m^2	-	€ 13,365.0	€ 6,682.50
26	Sub_205218	PP	0	91.5	45.75	m^2	-	€ 16,305.3	€ 8,152.65
26	Sub_205219	PP	0	91.5	45.75	m^2	-	€ 16,305.3	€ 8,152.65
27	Sub_205220	PP	0	12.5	50	m^2	-	€ 2,227.5	€ 8,910.00
27	Sub_205221	PP	0	12.5	50	m^2	-	€ 2,227.5	€ 8,910.00
27	Sub_205222	PP	0	14	56	m^2	-	€ 2,494.8	€ 9,979.20
27	Sub_205223	PP	0	12.5	50	m^2	-	€ 2,227.5	€ 8,910.00
27	Sub_205228	PP	0	12.5	50	m^2	-	€ 2,227.5	€ 8,910.00
27	Sub_205224	PP	0	10	40	m^2	-	€ 1,782.0	€ 7,128.00
27	Sub_205225	PP	0	17.5	70	m^2	-	€ 3,118.5	€ 12,474.00
27	Sub_205226	PP	0	5.5	22	m^2	-	€ 980.1	€ 3,920.40
27	Sub_209020	PP	0	8.5	34	m^2	-	€ 1,514.7	€ 6,058.80
27	Sub_209021	PP	0	7.5	30	m^2	-	€ 1,336.5	€ 5,346.00
27	Sub_209023	PP	0	10	40	m^2	-	€ 1,782.0	€ 7,128.00
27	Sub_209024	PP	0	10	40	m^2	-	€ 1,782.0	€ 7,128.00
27	Sub_219021	PP	0	7	28	m^2	-	€ 1,247.4	€ 4,989.60
27	Sub_209016	PP	0	6	24	m^2	-	€ 1,069.2	€ 4,276.80
27	Sub_209017	PP	0	5	20	m^2	-	€ 891.0	€ 3,564.00
27	Sub_209018	PP	0	12.5	50	m^2	-	€ 2,227.5	€ 8,910.00

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
27	Sub_209019	PP	0	8	32	m^2	-	€ 1,425.6	€ 5,702.40
28	Sub_206069	PP	0	15	0	m^2	-	€ 2,673.0	€ 0.00
28	Sub_206070	PP	0	58.5	0	m^2	-	€ 10,424.7	€ 0.00
28	Sub_206071	PP	0	67.5	0	m^2	-	€ 12,028.5	€ 0.00
28	Sub_206072	PP	0	15	0	m^2	-	€ 2,673.0	€ 0.00
28	Sub_206073	PP	0	78	0	m^2	-	€ 13,899.6	€ 0.00
28	Sub_206074	PP	0	15	0	m^2	-	€ 2,673.0	€ 0.00
28	Sub_206076	PP	0	33	0	m^2	-	€ 5,880.6	€ 0.00
28	Sub_206077	PP	0	51	0	m^2	-	€ 9,088.2	€ 0.00
28	Sub_206078	PP	0	45	0	m^2	-	€ 8,019.0	€ 0.00
28	Sub_206079	PP	0	63	0	m^2	-	€ 11,226.6	€ 0.00
29	Sub_206084	PP	0	7	14	m^2	-	€ 1,247.4	€ 2,494.80
29	Sub_206084A	PP	0	8.5	17	m^2	-	€ 1,514.7	€ 3,029.40
29	Sub_206085	PP	0	7.25	14.5	m^2	-	€ 1,292.0	€ 2,583.90
29	Sub_206086	PP	0	14.25	28.5	m^2	-	€ 2,539.4	€ 5,078.70
29	Sub_206089	PP	0	7.5	15	m^2	-	€ 1,336.5	€ 2,673.00
29	Sub_206087	PP	0	22.5	45	m^2	-	€ 4,009.5	€ 8,019.00
29	Sub_206088	PP	0	14.75	29.5	m^2	-	€ 2,628.5	€ 5,256.90
30	Sub_206099	PP	0	61.25	17.5	m^2	-	€ 10,914.8	€ 3,118.50
30	Sub_206100	PP	0	52.5	15	m^2	-	€ 9,355.5	€ 2,673.00
30	Sub_206101	PP	0	36.75	10.5	m^2	-	€ 6,548.9	€ 1,871.10
30	Sub_206102	PP	0	99.75	28.5	m^2	-	€ 17,775.5	€ 5,078.70
30	Sub_206103	PP	0	98	28	m^2	-	€ 17,463.6	€ 4,989.60
30	Sub_206104	PP	0	52.5	15	m^2	-	€ 9,355.5	€ 2,673.00
30	Sub_206105	PP	0	28	8	m^2	-	€ 4,989.6	€ 1,425.60
30	Sub_206108	PP	0	75.25	21.5	m^2	-	€ 13,409.6	€ 3,831.30
30	Sub_206106	PP	0	45.5	13	m^2	-	€ 8,108.1	€ 2,316.60
30	Sub_206107	PP	0	189	54	m^2	-	€ 33,679.8	€ 9,622.80
30	Sub_206109	PP	0	17.5	5	m^2	-	€ 3,118.5	€ 891.00
30	Sub_206110	PP	0	84	24	m^2	-	€ 14,968.8	€ 4,276.80
30	Sub_206111	PP	0	70	20	m^2	-	€ 12,474.0	€ 3,564.00

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
31	Sub_207006	PP	0	81	54	m^2	-	€ 14,434.2	€ 9,622.80
31	Sub_207007	PP	0	54	36	m^2	-	€ 9,622.8	€ 6,415.20
31	Sub_207009	PP	0	30	20	m^2	-	€ 5,346.0	€ 3,564.00
31	Sub_207010	PP	0	48	32	m^2	-	€ 8,553.6	€ 5,702.40
31	Sub_207011	PP	0	21	14	m^2	-	€ 3,742.2	€ 2,494.80
32	Con_202009.2	Pump	Curve_202009.2	Curve_206014.2	Curve_202009.2	m^3 / hour	-	€ 97,136.2	€ 0.00
33	Con_206014.2	Pump	Curve_206014.2	Curve_206014.2	Curve_206014.2	m^3 / hour	-	€ 0.0	€ 0.00
34	Con_207011.1	Pump	Curve_207011.1	Curve_100000.1	Curve_202009.2	m^3 / hour	-	€ 104,193.1	€ 81,556.54
35	Con_202002.2	Pipe	0.151	0.1506	0.25	m	22.5	€ 0.0	€ 8,824.16
35	Con_202004.1	Pipe	0.188	0.1882	0.3	m	81.6	€ 0.0	€ 35,037.57
35	Con_202005.1	Pipe	0.188	0.1882	0.3	m	81.0	€ 0.0	€ 34,778.75
35	Con_202006.1	Pipe	0.188	0.1882	0.3	m	81.6	€ 0.0	€ 35,037.57
35	Con_202007.1	Pipe	0.188	0.1882	0.3	m	61.1	€ 0.0	€ 26,235.60
35	Con_202008.1	Pipe	0.188	0.1882	0.3	m	5.0	€ 0.0	€ 2,143.70
36	Con_202023.1	Pipe	0.188	0.8	0.6	m	15.2	€ 14,634.6	€ 10,677.47
36	Con_202021.1	Pipe	0.188	0.8	0.6	m	80.2	€ 77,086.7	€ 56,242.68
36	Con_202022.1	Pipe	0.188	0.8	0.6	m	78.7	€ 75,660.4	€ 55,202.03
36	Con_202018.1	Pipe	0.188	0.8	0.6	m	13.0	€ 12,490.5	€ 9,113.13
36	Con_202019.1	Pipe	0.188	0.8	0.6	m	35.1	€ 33,738.0	€ 24,615.34
36	Con_202020.1	Pipe	0.188	0.8	0.6	m	81.6	€ 78,410.6	€ 57,208.60
37	Con_202012.1	Pipe	0.188	0.1882	0.1882	m	100.6	€ 0.0	€ 0.00
37	Con_202013.1	Pipe	0.188	0.1882	0.1882	m	32.6	€ 0.0	€ 0.00
37	Con_202014.1	Pipe	0.188	0.1882	0.1882	m	70.7	€ 0.0	€ 0.00
37	Con_202009.1	Pipe	0.188	0.1882	0.1882	m	73.9	€ 0.0	€ 0.00
37	Con_202011.1	Pipe	0.188	0.1882	0.1882	m	100.7	€ 0.0	€ 0.00
37	Con_202015.1	Pipe	0.188	0.1882	0.1882	m	41.1	€ 0.0	€ 0.00
37	Con_202016.1	Pipe	0.188	0.1882	0.1882	m	80.6	€ 0.0	€ 0.00
37	Con_202017.1	Pipe	0.188	0.1882	0.1882	m	81.8	€ 0.0	€ 0.00
38	Con_206023.1	Pipe	0.3	0.6	0.7	m	24.0	€ 16,824.2	€ 20,458.32
38	Con_206024.1	Pipe	0.3	0.6	0.7	m	38.3	€ 26,868.0	€ 32,671.54
38	Con_206025.1	Pipe	0.3	0.6	0.7	m	55.0	€ 38,574.7	€ 46,906.89
38	Con_206026.1	Pipe	0.3	0.6	0.7	m	37.4	€ 26,240.9	€ 31,909.05
38	Con_206018.1	Pipe	0.3	0.6	0.7	m	16.0	€ 11,216.2	€ 13,638.88
38	Con_206019.1	Pipe	0.3	0.6	0.7	m	10.3	€ 7,217.3	€ 8,776.30
38	Con_206020.1	Pipe	0.3	0.6	0.7	m	40.1	€ 28,119.2	€ 34,192.96

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
38	Con_206021.1	Pipe	0.3	0.6	0.7	m	37.2	€ 26,088.5	€ 31,723.68
38	Con_206022.1	Pipe	0.3	0.6	0.7	m	61.4	€ 43,042.2	€ 52,339.48
38	Con_206014.1	Pipe	0.3	0.6	0.7	m	45.8	€ 32,072.6	€ 39,000.36
38	Con_206015.1	Pipe	0.3	0.6	0.7	m	50.8	€ 35,613.8	€ 43,306.46
38	Con_206016.1	Pipe	0.3	0.6	0.7	m	35.1	€ 24,625.3	€ 29,944.45
38	Con_206017.1	Pipe	0.3	0.6	0.7	m	61.0	€ 42,767.4	€ 52,005.22
39	Con_206150.1	Pipe	0.188	0.3	0.2353	m	53.4	€ 22,915.6	€ 20,451.70
39	Con_206151.1	Pipe	0.188	0.3	0.2353	m	64.3	€ 27,605.4	€ 24,637.25
39	Con_206152.1	Pipe	0.188	0.3	0.2353	m	48.8	€ 20,939.6	€ 18,688.11
39	Con_206146.2	Pipe	0.188	0.3	0.2353	m	50.4	€ 21,624.0	€ 19,298.97
39	Con_206149.1	Pipe	0.188	0.3	0.2353	m	51.2	€ 21,983.4	€ 19,619.73
39	Con_206018.2	Pipe	0.188	0.3	0.2353	m	25.0	€ 10,743.6	€ 9,588.41
40	Con_206012.1	Pipe	0.4	0.4	0.4	m	8.8	€ 0.0	€ 0.00
40	Con_206012.2	Pipe	0.4	0.4	0.4	m	38.6	€ 0.0	€ 0.00
40	Con_206013.1	Pipe	0.4	0.4	0.4	m	65.1	€ 0.0	€ 0.00
40	Con_206028.1	Pipe	0.4	0.4	0.4	m	15.0	€ 0.0	€ 0.00
40	Con_206029.1	Pipe	0.4	0.4	0.4	m	82.3	€ 0.0	€ 0.00
40	Con_206030.1	Pipe	0.4	0.4	0.4	m	78.4	€ 0.0	€ 0.00
40	Con_206031.1	Pipe	0.4	0.4	0.4	m	67.7	€ 0.0	€ 0.00
40	Con_206032.1	Pipe	0.4	0.4	0.4	m	46.4	€ 0.0	€ 0.00
40	Con_206033.1	Pipe	0.4	0.4	0.4	m	45.6	€ 0.0	€ 0.00
41	Con_206040.1	Pipe	0.188	0.2353	0.2353	m	51.5	€ 19,728.0	€ 19,727.97
41	Con_206041.1	Pipe	0.188	0.2353	0.2353	m	51.6	€ 19,783.7	€ 19,783.73
41	Con_206039.1	Pipe	0.188	0.2353	0.2353	m	50.2	€ 19,222.7	€ 19,222.72
41	Con_206034.1	Pipe	0.3	0.4	0.4	m	18.1	€ 9,160.8	€ 9,160.81
41	Con_206036.1	Pipe	0.3	0.4	0.4	m	37.3	€ 18,845.5	€ 18,845.50
41	Con_206037.1	Pipe	0.3	0.4	0.4	m	38.3	€ 19,345.8	€ 19,345.82
41	Con_206038.1	Pipe	0.3	0.4	0.4	m	45.9	€ 23,158.1	€ 23,158.07
41	Con_206039.2	Pipe	0.3	0.4	0.4	m	53.4	€ 26,936.8	€ 26,936.82
41	Con_206043.1	Pipe	0.3	0.4	0.4	m	56.5	€ 28,499.4	€ 28,499.38
41	Con_206044.1	Pipe	0.3	0.4	0.4	m	40.8	€ 20,602.2	€ 20,602.21
41	Con_206045.1	Pipe	0.3	0.4	0.4	m	58.8	€ 29,690.3	€ 29,690.29
41	Con_206046.1	Pipe	0.3	0.4	0.4	m	14.2	€ 7,173.8	€ 7,173.85
41	Con_206047.1	Pipe	0.3	0.4	0.4	m	56.6	€ 28,588.6	€ 28,588.64
41	Con_206048.1	Pipe	0.3	0.4	0.4	m	17.0	€ 8,595.6	€ 8,595.58
41	Con_206049.1	Pipe	0.3	0.4	0.4	m	66.6	€ 33,621.8	€ 33,621.81

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
41	Con_206050.1	Pipe	0.3	0.4	0.4	m	57.8	€ 29,175.2	€ 29,175.25
41	Con_206051.2	Pipe	0.3	0.4	0.4	m	80.4	€ 40,597.1	€ 40,597.09
41	Con_206055.1	Pipe	0.3	0.4	0.4	m	56.9	€ 28,695.4	€ 28,695.38
41	Con_206056.1	Pipe	0.3	0.4	0.4	m	56.6	€ 28,561.9	€ 28,561.89
41	Con_206057.1	Pipe	0.3	0.4	0.4	m	57.4	€ 28,964.9	€ 28,964.91
41	Con_206058.2	Pipe	0.3	0.4	0.4	m	49.6	€ 25,024.6	€ 25,024.61
41	Con_206080.1	Pipe	0.3	0.4	0.4	m	51.7	€ 26,115.6	€ 26,115.63
41	Con_206081.1	Pipe	0.3	0.4	0.4	m	43.4	€ 21,914.5	€ 21,914.52
41	Con_206082.1	Pipe	0.3	0.4	0.4	m	60.1	€ 30,339.6	€ 30,339.63
41	Con_206083.2	Pipe	0.3	0.4	0.4	m	13.6	€ 6,865.3	€ 6,865.34
41	Con_206090.1	Pipe	0.3	0.4	0.4	m	60.4	€ 30,507.1	€ 30,507.12
41	Con_206090.2	Pipe	0.3	0.4	0.4	m	73.6	€ 37,136.0	€ 37,136.02
42	Con_206067.1	Pipe	0.151	0.1506	0.1506	m	17.0	€ 0.0	€ 0.00
42	Con_206067.2	Pipe	0.151	0.1506	0.1506	m	15.3	€ 0.0	€ 0.00
42	Con_206068.1	Pipe	0.151	0.1506	0.1506	m	28.3	€ 0.0	€ 0.00
42	Con_206070.1	Pipe	0.151	0.1506	0.1506	m	33.3	€ 0.0	€ 0.00
42	Con_206066.1	Pipe	0.188	0.1882	0.1882	m	34.7	€ 0.0	€ 0.00
42	Con_206060.2	Pipe	0.188	0.1882	0.1882	m	10.3	€ 0.0	€ 0.00
42	Con_206058.1	Pipe	0.188	0.1882	0.1882	m	32.6	€ 0.0	€ 0.00
42	Con_206059.1	Pipe	0.188	0.1882	0.1882	m	38.2	€ 0.0	€ 0.00
43	Con_206066.2	Pipe	0.188	0.1882	0.2353	m	19.7	€ 0.0	€ 7,558.48
43	Con_206072.1	Pipe	0.188	0.1882	0.2353	m	81.0	€ 0.0	€ 31,025.07
43	Con_206073.1	Pipe	0.188	0.1882	0.2353	m	49.7	€ 0.0	€ 19,057.75
43	Con_206074.1	Pipe	0.188	0.1882	0.2353	m	29.1	€ 0.0	€ 11,140.07
43	Con_206075.1	Pipe	0.151	0.1506	0.1882	m	16.3	€ 0.0	€ 5,770.52
43	Con_206075.2	Pipe	0.151	0.1506	0.1882	m	15.1	€ 0.0	€ 5,364.26
43	Con_206076.1	Pipe	0.151	0.1506	0.1882	m	29.0	€ 0.0	€ 10,279.92
43	Con_206078.1	Pipe	0.151	0.1506	0.1882	m	29.0	€ 0.0	€ 10,279.92
44	Con_206083.1	Pipe	0.188	0.4	0.5	m	51.6	€ 26,052.1	€ 30,660.24
44	Con_206086.2	Pipe	0.188	0.4	0.5	m	55.2	€ 27,848.3	€ 32,774.09
45	Con_206093.1	Pipe	0.188	0.1882	0.4	m	38.6	€ 0.0	€ 19,483.61
45	Con_206094.2	Pipe	0.188	0.1882	0.4	m	33.3	€ 0.0	€ 16,809.01
45	Con_206098.1	Pipe	0.188	0.1882	0.4	m	34.7	€ 0.0	€ 17,499.62
45	Con_206099.1	Pipe	0.188	0.1882	0.4	m	31.2	€ 0.0	€ 15,773.09
45	Con_206100.1	Pipe	0.151	0.1506	0.3	m	24.0	€ 0.0	€ 10,295.93
45	Con_206100.2	Pipe	0.151	0.1506	0.3	m	22.2	€ 0.0	€ 9,527.65

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
45	Con_206102.1	Pipe	0.151	0.1506	0.3	m	28.3	€ 0.0	€ 12,145.27
45	Con_206104.1	Pipe	0.188	0.1882	0.4	m	42.4	€ 0.0	€ 21,414.73
45	Con_206105.1	Pipe	0.188	0.1882	0.4	m	41.0	€ 0.0	€ 20,700.90
45	Con_206105.3	Pipe	0.188	0.1882	0.4	m	30.4	€ 0.0	€ 15,351.37
45	Con_206108.1	Pipe	0.188	0.1882	0.4	m	48.3	€ 0.0	€ 24,359.09
45	Con_206109.1	Pipe	0.151	0.1506	0.3	m	29.0	€ 0.0	€ 12,452.60
45	Con_206109.2	Pipe	0.188	0.1882	0.4	m	20.5	€ 0.0	€ 10,356.60
45	Con_206111.1	Pipe	0.151	0.1506	0.3	m	29.0	€ 0.0	€ 12,452.60
46	Con_206093.2	Pipe	0.235	0.2353	0.2353	m	54.8	€ 0.0	€ 0.00
46	Con_206113.1	Pipe	0.235	0.2353	0.2353	m	55.3	€ 0.0	€ 0.00
46	Con_206114.1	Pipe	0.235	0.2353	0.2353	m	53.1	€ 0.0	€ 0.00
46	Con_206115.1	Pipe	0.235	0.2353	0.2353	m	51.9	€ 0.0	€ 0.00
46	Con_206116.1	Pipe	0.235	0.2353	0.2353	m	55.2	€ 0.0	€ 0.00
46	Con_206117.1	Pipe	0.235	0.2353	0.2353	m	55.9	€ 0.0	€ 0.00
46	Con_206118.2	Pipe	0.235	0.2353	0.2353	m	54.1	€ 0.0	€ 0.00
46	Con_206134.1	Pipe	0.235	0.2353	0.2353	m	53.7	€ 0.0	€ 0.00
46	Con_206135.1	Pipe	0.235	0.2353	0.2353	m	24.8	€ 0.0	€ 0.00
46	Con_206136.1	Pipe	0.235	0.2353	0.2353	m	30.9	€ 0.0	€ 0.00
46	Con_206136.2	Pipe	0.235	0.2353	0.2353	m	42.2	€ 0.0	€ 0.00
46	Con_206137.1	Pipe	0.235	0.2353	0.2353	m	24.8	€ 0.0	€ 0.00
47	Con_207007.1	Pipe	0.151	0.1506	0.8	m	70.9	€ 0.0	€ 68,102.39
47	Con_207006.1	Pipe	0.151	0.1506	0.8	m	64.3	€ 0.0	€ 61,768.95
47	Con_207006.2	Pipe	0.151	0.1506	0.8	m	10.2	€ 0.0	€ 9,768.33
48	Con_207002.2	Pipe	0.188	0.7	0.3	m	57.3	€ 48,857.0	€ 24,611.03
48	Con_207005.1	Pipe	0.188	0.7	0.3	m	59.0	€ 50,322.3	€ 25,349.15
49	Con_205154.1	Pipe	0.188	0.3	0.6	m	10.8	€ 4,644.7	€ 7,582.58
49	Con_205155.1	Pipe	0.188	0.3	0.6	m	59.6	€ 25,598.9	€ 41,791.02
49	Con_205150.1	Pipe	0.188	0.3	0.6	m	36.9	€ 15,841.3	€ 25,861.47
50	Con_205148.1	Pipe	0.3	0.6	0.6	m	58.5	€ 41,025.6	€ 41,025.56
50	Con_205149.1	Pipe	0.3	0.6	0.6	m	57.7	€ 40,440.4	€ 40,440.44
50	Con_205150.2	Pipe	0.3	0.6	0.6	m	49.7	€ 34,811.3	€ 34,811.34
50	Con_205153.1	Pipe	0.3	0.6	0.6	m	39.4	€ 27,616.6	€ 27,616.59
50	Con_205143.1	Pipe	0.3	0.6	0.6	m	44.1	€ 30,916.1	€ 30,916.05
50	Con_205144.1	Pipe	0.3	0.6	0.6	m	49.1	€ 34,413.8	€ 34,413.81
50	Con_205145.1	Pipe	0.3	0.6	0.6	m	31.0	€ 21,742.6	€ 21,742.61
50	Con_205146.1	Pipe	0.3	0.6	0.6	m	52.0	€ 36,479.5	€ 36,479.47

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
50	Con_205147.1	Pipe	0.3	0.6	0.6	m	58.5	€ 41,025.6	€ 41,025.56
50	Con_205134.2	Pipe	0.3	0.6	0.6	m	37.9	€ 26,536.7	€ 26,536.72
50	Con_205139.1	Pipe	0.3	0.6	0.6	m	54.0	€ 37,880.5	€ 37,880.49
50	Con_205140.1	Pipe	0.3	0.6	0.6	m	51.0	€ 35,758.4	€ 35,758.38
50	Con_205141.1	Pipe	0.3	0.6	0.6	m	50.0	€ 35,057.5	€ 35,057.51
50	Con_205142.1	Pipe	0.3	0.6	0.6	m	50.0	€ 35,078.5	€ 35,078.53
51	Con_205130.1	Pipe	0.3	0.8	0.3	m	43.0	€ 41,359.5	€ 0.00
51	Con_205131.1	Pipe	0.3	0.8	0.3	m	54.2	€ 52,079.1	€ 0.00
51	Con_205132.1	Pipe	0.3	0.8	0.3	m	45.8	€ 43,998.4	€ 0.00
51	Con_205133.1	Pipe	0.3	0.8	0.3	m	49.4	€ 47,460.5	€ 0.00
51	Con_205127.1	Pipe	0.3	0.8	0.3	m	47.9	€ 46,008.7	€ 0.00
51	Con_205127.2	Pipe	0.3	0.8	0.3	m	28.2	€ 27,073.7	€ 0.00
51	Con_205128.1	Pipe	0.3	0.8	0.3	m	47.0	€ 45,168.3	€ 0.00
51	Con_205129.1	Pipe	0.3	0.8	0.3	m	50.1	€ 48,155.7	€ 0.00
51	Con_205018.2	Pipe	0.3	0.8	0.3	m	20.1	€ 19,335.9	€ 0.00
52	Con_205223.1	Pipe	0.3	0.8	0.3	m	65.9	€ 63,340.6	€ 0.00
52	Con_205224.1	Pipe	0.3	0.8	0.3	m	51.9	€ 49,860.4	€ 0.00
52	Con_205224.2	Pipe	0.3	0.8	0.3	m	41.1	€ 39,533.6	€ 0.00
52	Con_205225.1	Pipe	0.3	0.8	0.3	m	52.4	€ 50,325.3	€ 0.00
52	Con_205226.1	Pipe	0.3	0.8	0.3	m	60.1	€ 57,738.8	€ 0.00
52	Con_209015.1	Pipe	0.3	0.8	0.3	m	9.5	€ 9,121.0	€ 0.00
53	Con_209018.1	Pipe	0.3	0.3	0.8	m	43.6	€ 0.0	€ 41,851.85
53	Con_209020.1	Pipe	0.3	0.3	0.8	m	31.3	€ 0.0	€ 30,104.32
53	Con_209021.1	Pipe	0.3	0.3	0.8	m	42.5	€ 0.0	€ 40,840.72
53	Con_209021.2	Pipe	0.3	0.3	0.8	m	12.2	€ 0.0	€ 11,701.71
53	Con_209023.1	Pipe	0.3	0.3	0.8	m	27.7	€ 0.0	€ 26,626.20
53	Con_205230.2	Pipe	0.3	0.3	0.8	m	16.1	€ 0.0	€ 15,512.41
53	Con_205033.3	Pipe	0.4	0.4	1	m	78.3	€ 0.0	€ 95,613.65
53	Con_209016.1	Pipe	0.3	0.3	0.8	m	40.3	€ 0.0	€ 38,721.75
53	Con_209016.2	Pipe	0.3	0.3	0.8	m	69.5	€ 0.0	€ 66,737.25
53	Con_209017.1	Pipe	0.3	0.3	0.8	m	38.0	€ 0.0	€ 36,521.32
53	Con_205230.1	Pipe	0.3	0.3	0.8	m	13.7	€ 0.0	€ 13,147.94
54	Con_205222.2	Pipe	0.3	0.6	0.7	m	47.1	€ 32,999.6	€ 40,127.64
54	Con_205223.2	Pipe	0.3	0.6	0.7	m	46.1	€ 32,292.1	€ 39,267.33
54	Con_205227.1	Pipe	0.3	0.6	0.7	m	42.0	€ 29,425.7	€ 35,781.76
54	Con_205228.1	Pipe	0.3	0.6	0.7	m	43.4	€ 30,411.2	€ 36,980.14

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
54	Con_205229.1	Pipe	0.3	0.6	0.7	m	41.9	€ 29,383.6	€ 35,730.54
54	Con_205230.3	Pipe	0.3	0.6	0.7	m	33.4	€ 23,437.7	€ 28,500.26
54	Con_205220.1	Pipe	0.3	0.6	0.7	m	61.2	€ 42,893.6	€ 52,158.69
54	Con_205220.2	Pipe	0.3	0.6	0.7	m	60.1	€ 42,150.1	€ 51,254.64
54	Con_205221.1	Pipe	0.3	0.6	0.7	m	60.2	€ 42,177.3	€ 51,287.68
54	Con_205222.1	Pipe	0.3	0.6	0.7	m	22.1	€ 15,517.5	€ 18,869.34
54	Con_205105X.1	Pipe	0.297	0.6	0.7	m	5.9	€ 4,104.0	€ 4,990.47
55	Con_205033.2	Pipe	0.188	0.1882	0.1882	m	16.9	€ 0.0	€ 0.00
55	Con_205216.1	Pipe	0.188	0.1882	0.1882	m	50.6	€ 0.0	€ 0.00
55	Con_205217.1	Pipe	0.188	0.1882	0.1882	m	51.6	€ 0.0	€ 0.00
55	Con_205218.1	Pipe	0.188	0.1882	0.1882	m	43.9	€ 0.0	€ 0.00
56	Con_205033.1	Pipe	0.3	0.4	0.3	m	33.0	€ 16,676.8	€ 0.00
56	Con_205034.1	Pipe	0.3	0.4	0.3	m	61.3	€ 30,931.4	€ 0.00
56	Con_205035.1	Pipe	0.3	0.4	0.3	m	42.6	€ 21,491.9	€ 0.00
56	Con_205036.1	Pipe	0.3	0.4	0.3	m	49.2	€ 24,856.1	€ 0.00
56	Con_205037.1	Pipe	0.3	0.4	0.3	m	39.8	€ 20,095.1	€ 0.00
56	Con_205038.1	Pipe	0.3	0.4	0.3	m	47.1	€ 23,760.8	€ 0.00
57	Con_205029.1	Pipe	0.3	0.3	0.5	m	43.3	€ 0.0	€ 25,701.67
57	Con_205030.1	Pipe	0.3	0.3	0.5	m	67.8	€ 0.0	€ 40,262.79
57	Con_205031.1	Pipe	0.3	0.3	0.5	m	70.7	€ 0.0	€ 42,004.26
57	Con_205032.1	Pipe	0.3	0.3	0.5	m	47.7	€ 0.0	€ 28,310.72
57	Con_205024.1	Pipe	0.3	0.3	0.5	m	44.7	€ 0.0	€ 26,525.95
57	Con_205025.1	Pipe	0.3	0.3	0.5	m	52.3	€ 0.0	€ 31,053.21
57	Con_205026.1	Pipe	0.3	0.3	0.5	m	48.4	€ 0.0	€ 28,734.36
57	Con_205027.1	Pipe	0.3	0.3	0.5	m	48.8	€ 0.0	€ 28,985.99
57	Con_205028.1	Pipe	0.3	0.3	0.5	m	53.7	€ 0.0	€ 31,923.24
58	Con_205017.1	Pipe	0.4	0.7	0.4	m	31.6	€ 26,956.2	€ 0.00
58	Con_205018.1	Pipe	0.4	0.7	0.4	m	25.5	€ 21,770.9	€ 0.00
58	Con_205017.2	Pipe	0.6	1	0.6	m	61.4	€ 74,988.8	€ 0.00
58	Con_205022.1	Pipe	0.6	1	0.6	m	48.6	€ 59,356.2	€ 0.00
58	Con_205022.2	Pipe	0.6	1	0.6	m	10.8	€ 13,210.5	€ 0.00
58	Con_205023.1	Pipe	0.6	1	0.6	m	53.3	€ 65,142.9	€ 0.00
59	Con_205041.1	Pipe	0.6	0.6	0.6	m	60.3	€ 0.0	€ 0.00
59	Con_205041.2	Pipe	0.6	0.6	0.6	m	53.0	€ 0.0	€ 0.00
59	Con_205042X.1	Pipe	0.6	0.6	0.6	m	40.0	€ 0.0	€ 0.00
59	Con_205043.2	Pipe	0.6	0.6	0.6	m	80.2	€ 0.0	€ 0.00

No. DV	**Object ID**	**Type**	**Old Value**	**New Value 2030**	**New Value 2085**	**Unit**	**Pipe Length m**	**Cost for 2030**	**Cost for 2085**
59	Con_205043.1	Pipe	0.6	0.6	0.6	m	54.5	€ 0.0	€ 0.00
59	Con_G01.1	Pipe	0.6	0.6	0.6	m	54.8	€ 0.0	€ 0.00
59	Con_205046.1	Pipe	0.6	0.6	0.6	m	40.7	€ 0.0	€ 0.00
59	Con_219003.1	Pipe	0.6	0.6	0.6	m	14.4	€ 0.0	€ 0.00
59	Con_205039.1	Pipe	0.6	0.6	0.6	m	29.4	€ 0.0	€ 0.00
59	Con_205101.1	Pipe	0.6	0.6	0.6	m	61.2	€ 0.0	€ 0.00
59	Con_205102.1	Pipe	0.6	0.6	0.6	m	49.0	€ 0.0	€ 0.00
59	Con_205103.1	Pipe	0.6	0.6	0.6	m	60.9	€ 0.0	€ 0.00
59	Con_205104.1	Pipe	0.6	0.6	0.6	m	51.5	€ 0.0	€ 0.00
59	Con_205105.1	Pipe	0.6	0.6	0.6	m	51.9	€ 0.0	€ 0.00
59	Con_205105.2	Pipe	0.6	0.6	0.6	m	41.9	€ 0.0	€ 0.00
59	Con_209005.1	Pipe	0.6	0.6	0.6	m	60.4	€ 0.0	€ 0.00
59	Con_205039.2	Pipe	0.6	0.6	0.6	m	5.4	€ 0.0	€ 0.00
59	Con_205103.2	Pipe	0.297	0.3	0.3	m	13.8	€ 5,917.1	€ 5,917.05
59	Con_209009X.1	Pipe	0.297	0.3	0.3	m	52.7	€ 22,649.2	€ 22,649.15
59	Con_209009X.2	Pipe	0.297	0.3	0.3	m	51.3	€ 22,018.0	€ 22,017.99
60	Con_290018.1	Pipe	0.4	0.4	0.4	m	44.5	€ 0.0	€ 0.00
60	Con_205105X.2	Pipe	0.4	0.4	0.4	m	59.9	€ 0.0	€ 0.00
60	Con_290000.1	Pipe	0.4	0.4	0.4	m	48.8	€ 0.0	€ 0.00
60	Con_290004.1	Pipe	0.4	0.4	0.4	m	63.0	€ 0.0	€ 0.00
60	Con_290008.1	Pipe	0.4	0.4	0.4	m	50.4	€ 0.0	€ 0.00
60	Con_290012.1	Pipe	0.4	0.4	0.4	m	62.8	€ 0.0	€ 0.00
60	Con_290016.1	Pipe	0.4	0.4	0.4	m	50.7	€ 0.0	€ 0.00
61	Con_205099.1	Pipe	0.4	1	0.8	m	5.9	€ 7,255.9	€ 5,708.25
61	Con_205099.2	Pipe	0.3	1	0.7	m	28.3	€ 34,543.9	€ 24,110.36
61	Con_205107.1	Pipe	0.3	1	0.7	m	21.1	€ 25,763.6	€ 17,982.03
61	Con_205108.1	Pipe	0.3	1	0.7	m	41.4	€ 50,607.1	€ 35,321.89
61	Con_205109.1	Pipe	0.3	1	0.7	m	39.5	€ 48,191.5	€ 33,635.90
61	Con_205173.1	Pipe	0.3	1	0.7	m	31.4	€ 38,349.9	€ 26,766.84
61	Con_205173.2	Pipe	0.3	1	0.7	m	54.9	€ 67,072.1	€ 46,813.85
61	Con_205126.2	Pipe	0.3	1	0.7	m	19.9	€ 24,334.4	€ 16,984.55
61	Con_205110.2	Pipe	0.3	1	0.7	m	52.2	€ 63,754.3	€ 44,498.15
62	Con_205126.1	Pipe	0.3	0.3	0.3	m	30.1	€ 0.0	€ 0.00
62	Con_205162.1	Pipe	0.3	0.3	0.3	m	26.9	€ 0.0	€ 0.00
62	Con_205163.1	Pipe	0.3	0.3	0.3	m	25.7	€ 0.0	€ 0.00
62	Con_205163.2	Pipe	0.3	0.3	0.3	m	18.7	€ 0.0	€ 0.00

No. DV	Object ID	Type	Old Value	New Value 2030	New Value 2085	Unit	Pipe Length m	Cost for 2030	Cost for 2085
62	Con_205165.1	Pipe	0.3	0.3	0.3	m	33.5	€ 0.0	€ 0.00
62	Con_205170.2	Pipe	0.3	0.3	0.3	m	31.6	€ 0.0	€ 0.00
62	Con_205172.1	Pipe	0.3	0.3	0.3	m	33.5	€ 0.0	€ 0.00
62	Con_205165.2	Pipe	0.3	0.3	0.3	m	46.6	€ 0.0	€ 0.00
62	Con_205168.1	Pipe	0.3	0.3	0.3	m	30.1	€ 0.0	€ 0.00
62	Con_205169.1	Pipe	0.3	0.3	0.3	m	30.1	€ 0.0	€ 0.00
62	Con_205170.1	Pipe	0.3	0.3	0.3	m	36.0	€ 0.0	€ 0.00
63	Con_205181.2	Pipe	0.4	1	1	m	23.3	€ 28,485.6	€ 28,485.60
63	Con_205184.1	Pipe	0.4	1	1	m	39.6	€ 48,392.2	€ 48,392.24
64	Con_205175.1	Pipe	0.3	0.3	0.3	m	37.9	€ 0.0	€ 0.00
64	Con_205176.1	Pipe	0.3	0.3	0.3	m	17.0	€ 0.0	€ 0.00
64	Con_205177.1	Pipe	0.3	0.3	0.3	m	18.7	€ 0.0	€ 0.00
64	Con_205177.2	Pipe	0.3	0.3	0.3	m	23.1	€ 0.0	€ 0.00
64	Con_205179.1	Pipe	0.3	0.3	0.3	m	24.7	€ 0.0	€ 0.00
64	Con_205115.2	Pipe	0.3	0.3	0.3	m	13.9	€ 0.0	€ 0.00
65	Con_205112.2	Pipe	0.3	1	1	m	44.6	€ 54,413.4	€ 54,413.44
65	Con_205111.1	Pipe	0.3	1	1	m	29.4	€ 35,919.8	€ 35,919.80
65	Con_205110.1	Pipe	0.3	1	1	m	36.4	€ 44,456.4	€ 44,456.35
66	Con_205120.1	Pipe	0.3	0.5	1	m	35.7	€ 21,227.7	€ 43,643.68
66	Con_205120.2	Pipe	0.3	0.5	1	m	23.5	€ 13,981.8	€ 28,746.22
66	Con_205121.1	Pipe	0.188	0.25	0.8	m	50.0	€ 19,625.6	€ 48,021.28
66	Con_205121.2	Pipe	0.188	0.25	0.8	m	21.5	€ 8,431.0	€ 20,629.47
66	Con_205122.1	Pipe	0.3	0.5	1	m	39.2	€ 23,296.3	€ 47,896.53
66	Con_205124.1	Pipe	0.3	0.5	1	m	37.0	€ 21,987.1	€ 45,204.97
66	Con_G10.2	Pipe	0.3	0.5	1	m	57.4	€ 34,067.9	€ 70,042.77
67	Con_G11.1	Pipe	0.6	0.6	0.6	m	38.2	€ 0.0	€ 0.00
67	Con_G11.2	Pipe	0.6	0.6	0.6	m	67.1	€ 0.0	€ 0.00
67	Con_G12.1	Pipe	0.6	0.6	0.6	m	60.1	€ 0.0	€ 0.00
67	Con_G13.1	Pipe	0.6	0.6	0.6	m	60.0	€ 0.0	€ 0.00
67	Con_G14.2	Pipe	0.6	0.6	0.6	m	49.0	€ 0.0	€ 0.00
67	Con_G15.1	Pipe	0.6	0.6	0.6	m	18.0	€ 0.0	€ 0.00
68	Con_G07.2	Pipe	0.3	0.7	0.8	m	57.0	€ 48,579.0	€ 54,755.47
68	Con_G06.1	Pipe	0.3	0.7	0.8	m	59.9	€ 51,082.4	€ 57,577.14
68	Con_G04.2	Pipe	0.3	0.7	0.8	m	41.8	€ 35,615.7	€ 40,143.93
68	Con_G02.2	Pipe	0.3	0.7	0.8	m	41.2	€ 35,157.4	€ 39,627.44
68	Con_G01.2	Pipe	0.3	0.7	0.8	m	11.2	€ 9,530.5	€ 10,742.18

No. DV	**Object ID**	**Type**	**Old Value**	**New Value 2030**	**New Value 2085**	**Unit**	**Pipe Length m**	**Cost for 2030**	**Cost for 2085**
69	Con_RCplan1.2	Pipe	0.3	0.4	0.3	m	28.5	€ 14,368.0	€ 0.00
69	Con_RCplan12.2	Pipe	0.3	0.4	0.3	m	36.5	€ 18,408.8	€ 0.00
69	Con_RCplan2.2	Pipe	0.3	0.4	0.3	m	34.3	€ 17,289.9	€ 0.00
69	Con_RCplan4.1	Pipe	0.3	0.4	0.3	m	39.2	€ 19,787.8	€ 0.00
69	Con_RCplan5.1	Pipe	0.3	0.4	0.3	m	41.7	€ 21,028.8	€ 0.00
69	Con_RCplan2.1	Pipe	0.3	0.4	0.3	m	14.6	€ 7,382.3	€ 0.00
69	Con_RCplan21.1	Pipe	0.3	0.4	0.3	m	39.9	€ 20,137.6	€ 0.00
69	Con_RCplan3.1	Pipe	0.3	0.4	0.3	m	54.8	€ 27,639.5	€ 0.00
70	Con_RCplan10.1	Pipe	0.6	1	0.7	m	32.8	€ 40,028.0	€ 27,938.07
70	Con_RCplan11.1	Pipe	0.6	1	0.7	m	38.8	€ 47,340.2	€ 33,041.74
70	Con_RCplan12.1	Pipe	0.6	1	0.7	m	50.9	€ 62,159.8	€ 43,385.25
70	Con_RCplan6.1	Pipe	0.6	1	0.7	m	55.9	€ 68,245.8	€ 47,633.09
70	Con_RCplan6.2	Pipe	0.6	1	0.7	m	46.7	€ 57,014.7	€ 39,794.16
70	Con_RCplan7.1	Pipe	0.6	1	0.7	m	48.9	€ 59,741.9	€ 41,697.69
70	Con_RCplan8.1	Pipe	0.6	1	0.7	m	59.8	€ 73,021.3	€ 50,966.20
70	Con_RCplan9.1	Pipe	0.6	1	0.7	m	40.3	€ 49,221.3	€ 34,354.70
70	Con_RCplan20.2	Pipe	0.6	1	0.7	m	34.8	€ 42,557.9	€ 29,703.88
70	Con_RCplan14.2	Pipe	0.6	1	0.7	m	14.5	€ 17,729.1	€ 12,374.30
71	Con_205012.3	Pipe	0.7	0.7	0.8	m	5.7	€ 0.0	€ 5,462.27
71	Con_205012.1	Pipe	0.6	0.6	0.7	m	43.7	€ 0.0	€ 37,265.78
71	Con_205013.1	Pipe	0.6	0.6	0.7	m	46.1	€ 0.0	€ 39,257.73
71	Con_205014.1	Pipe	0.6	0.6	0.7	m	21.6	€ 0.0	€ 18,391.23
71	Con_205300.2	Pipe	0.6	0.6	0.7	m	22.5	€ 0.0	€ 19,141.14
71	Con_205015.1	Pipe	0.6	0.6	0.7	m	46.8	€ 0.0	€ 39,858.49
71	Con_205016.1	Pipe	0.6	0.6	0.7	m	29.2	€ 0.0	€ 24,933.39
72	Con_206140.1	Pipe	0.188	0.5	0.25	m	27.7	€ 16,430.1	€ 10,860.72
72	Con_206141.1	Pipe	0.188	0.5	0.25	m	32.6	€ 19,394.9	€ 12,820.54
72	Con_206142.1	Pipe	0.188	0.5	0.25	m	45.3	€ 26,895.9	€ 17,778.89
72	Con_206143.1	Pipe	0.188	0.5	0.25	m	63.6	€ 37,780.5	€ 24,973.94
72	Con_206144.1	Pipe	0.188	0.5	0.25	m	65.3	€ 38,762.4	€ 25,623.03