TRANSFORMING FROM INTERMITTENT WATER SUPPLY SYSTEMS TO CONTINOUS SYSTEMS BY USING OPTIMISATION AND PROGRAMMES SUCH AS EPANET AND GANETXL

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ABSTRACT

TRANSFORMING FROM INTERMITTENT WATER SUPPLY SYSTEMS TO CONTINOUS SYSTEMS BY USING OPTIMISATION AND PROGRAMMES SUCH AS EPANET AND GANETEXL

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Water has always been important for humanity and will its importance into the future. Therefore, all of the stages involved in its retrieval, purification, and distribution be understood well, from the sources from which it is gained, to how it is treated, to when it is finally used by consumers and then released into the environment. In this study, the water supply systems, which is the part of the process at which water is taken from the source and delivered to the consumer, will be examined. There are two types of water supply system: an intermittent water supply system and a continuous water supply system. Both will be considered, and the advantages and disadvantages, as well as the reasons for and the consequences of intermittency situations, will be discussed. Later, the conversion system from intermittent to 24/7 will be mentioned. Such situations are more common in developing countries. In general, there is sufficient water in the system, but there is not enough money for investment, so such situations arise due to the lack of capes in the pipes. It shall be suggested that, in order to ameliorate this situation and in order to discover the optimal rehabilitation solution for large water systems, the methodologies of "Multi-objective optimisation" and "Cluster-based technics" can be used. Exnet will be this research's case study. EPANET software will be utilised to simulate the system, whereas the GANetXL programme will be used to optimise the system. Their results shall then be presented. In the result and discussion chapter, two scenarios will be revealed. The first scenario is that of "minimum cost," which provides the minimum pressure requirement for continuous systems. The second will be "maximum efficiency." This can be achieved by investing 1 million pounds, considering that this would be optimal for developing countries, even though they do not have enough money to invest.

Key words: Water supply systems, Intermittent water supply systems, Continuous water supply systems, Transformation from IWS to 24/7, optimisation, rehabilitation, Genetic algorithm

DEDICATION

I am dedicating this dissertation to my lovely family, mother, father and siblings for their patience and support.

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CHAPTER 1 – INTRODUCTION

1.1 General

Water has been a vital requirement for life which has no other alternatives. According to Rothschild and Mancinelli (2001), the last decades have shown that life on Earth is only possible because of liquid water. Thus, water is of great importance to human life. Water, though, is not distributed equally over the world. Brazil, Canada, China, Columbia, the Democratic Republic of the Congo, Russia, India, Indonesia and the U.S. all have 60% of the available freshwater in the world (Fry, 2005). Therefore, the countries which suffer from water scarcity must find alternative water resources and use and distribute their resources with the most efficiency in line with their requirements.

Water is of great import for all aspects of the economy, from, agriculture, energy, industry, tourism and so on. Therefore, from ancient times till the modern period, societies have preferred to live in places which are close to water resources since it plays such a significant role in ensuring a better-quality life. This human wish, though, has brought with it some conflicts between states. Gleick and Heberger (2014), for instance, state that violence for the sake of water began around 5000 years ago. With relation to the 20th century, although it seemed as if oil overthrew water in terms of importance, the following statement of the Secretary-General of the United Nations Conference on Human Settlement demonstrates how important water will remain to be in the next decades: According to expectation of N'Dow (1996), in the next five decades water as the reason of huge conflicts between peoples and nations will take the place of oil.

Water is crucial for life; however, since water resources are limited, it makes it very precious. In developing countries such as India where there are imbalances between water resources and population, this problem is getting worse. According to the World Water Development Report, over one billion people — and according to UNDESA (2016), nearly 1.2 billion people — live in areas of physical water scarcity. In addition, 500 million people cannot reach potable water, with this number projected to double by 2050. Moreover, around 1.5 million people die every year because of diseases based on poor sanitation and polluted water. The availability of fresh water in urban areas can be negatively affected by climate change, not to mention other socioeconomic factors (Liu et al., 2017). The influence of climate change, having been monitored worldwide, consists in changes to rainfall patterns (Bangash et al., 2013). The acceleration of global urbanisation over the last sixty years, however, has resulted in rapid population growth. For this reason, cities are critical areas in which enormous stress upon freshwater supplies may be examined (Padowski and Gorelick, 2014). Therefore, it is expected that climate change and human-induced changes will have dramatic effects on global water availability and quality (Boithias et al., 2014). In order to solve these problems, as well as other issues, the United Nations announced the Millennium Development Goals (MDGs) in 2015. One of its goals is that of guaranteeing sustainable water supplies in developing countries. Each member country have indigenised the same goals (Dahasahasra, 2007).

The Goals

1. Eradicate extreme poverty and hunger
2. Achieve universal primary education
3. Promote gender eqality and empower women
4. Reduce child mortality
5. Improve maternal health
6. Combat HIV/AIDS, malaria and other diseases
7. Ensure environmental sustainability
8. Develop a global partnership for development

Figure 1: Millennium Development Goals

(Sanjay and V. Dahasahasra, 2007)

As may be seen from Figure 1, the Millennium Development Goals consist of eight goals. The first one is to struggle with poverty and hunger and to possibly reduce it by half. The second one is for obtaining universal primary education. Its third goal is to encourage gender equality and the empowerment of women. The fourth is that of decreasing child mortality by two thirds among children under five years of age. The next two goals are that of improving maternal health and combatting HIV/AIDS, malaria and other diseases. The last two goals concern ensuring environmental sustainability and a global partnership for development.

1.2 Research Content

Up till now, the importance of water for human life, the reason why it is essential for people to have access to water, the possible undesirable situations that might occur when there is water scarcity, and the goals determined by the United Nations in order to cope with all of these issues have been examined.

The second chapter is a literature review of intermittent and continuous water supply systems. Chapter 3 includes a description and explanation of the methodology chosen for this study with a relevant case study. Chapter 4, entitled “result & discussion” proffers the result of the case study and discusses its results. Finally, the last chapter will summarise and conclude the study.

1.3 Assumption

In this study, it is assumed that there is enough water in the network and that the reason for any recurring intermittency is due to the dissatisfactory pressure requirements for each node caused by the inefficient design of the systems.

1.4 The Aim

The main aim of my project is to convert an intermittent water supply system into a continuous supply system by optimising the results and by utilising programs such as EPANET and MATLAB so as to better provide water for all consumers at the same time. Besides that, the objective of this conversion is that of optimising the system in order to minimise the total cost while also providing the requisite water pressure.

1.5 Objectives

The objectives are as follows:

- Develop a methodology for converting from an IWS to a CWS;
- Use EPANET and Optimisation for the purpose of modelling the system and identifying intervention options;
- Investigate the effectiveness of genetic algorithms in optimisation problems;
- Find the optimum design for the network.

CHAPTER 2 - LITARETURE REVIEW

This chapter includes some information about intermittent and continuous water supply systems, the differences between them, the negative side of intermittency, some problems and solutions for intermittent water supply systems, and the necessity of transforming systems from intermittent supply to 24/7 by reviewing previously published studies and methods.

2.1 Water Supply Systems

In this section, two kinds of water supply method are discussed.

A water supply system is a system for providing potable water to users and consists of hydraulic components. Drinking water supply systems should be able to supply water to users twenty-four hours a day, seven days a week. Nevertheless, due to several reasons (e.g. financial limitations), sometimes drinking water can only be supplied to consumers intermittently vis-à-vis continuously. This is the case in several developing countries (Batish, 2003).

Thus, water can be supplied to consumers by means of the following two methods:

- Continuous systems, which supply water to consumers twenty-four hours a day.
- Intermittent systems, which supply water to consumers for less than twenty-four hours a day.

The following sub-section shall examine these two types of water supply system in more detail.

2.2 Intermittent and Continuous Water Supply Systems

In this sub-section, the main differences between intermittent and continuous water supply systems are explored. It also demonstrates the prevalence of intermittent water supply systems throughout the world, especially in some Indian cities.

Intermittent water supply (IWS) is defined by Mcintosh (2003) as a piped water supply service distributing water to consumers for less than 24 hours in one day. Even though, according to Mcintosh (2003), intermittent water supply systems are caused because of insufficient hydraulic capacities and/or a lack of an available supply for the water supply system, the reason of using intermittent water supply systems, according to Fontanazza (2007) it is caused because of an imbalance between water demand and supply and occurs when water consumption is temporarily increased, and the accessibility of water resources decreases. For these reasons, nowadays, millions of people worldwide only have access to water intermittently (Ilaya-Ayza, 2017). Indeed, according to the World Health Organisation (WHO), around 33% of the population of Latin America and more than 50% of the population of Asia collect water intermittently (Water Supply and Sanitation Collaborative Council, 2000). As may be seen in Figure 2, IWSs are very common in developing countries, such as South Asia, India, and some African countries, whereas it is very rare to find them in developed countries. For example, it is estimated that 91% of water supplies in Southeast Asia and approximately 100% in India are run intermittently (Vairmoorthy, 2001). Average water supply hours per day for Indian cities, for instance, are between 1 and 3 hours, as seen in Table 1.

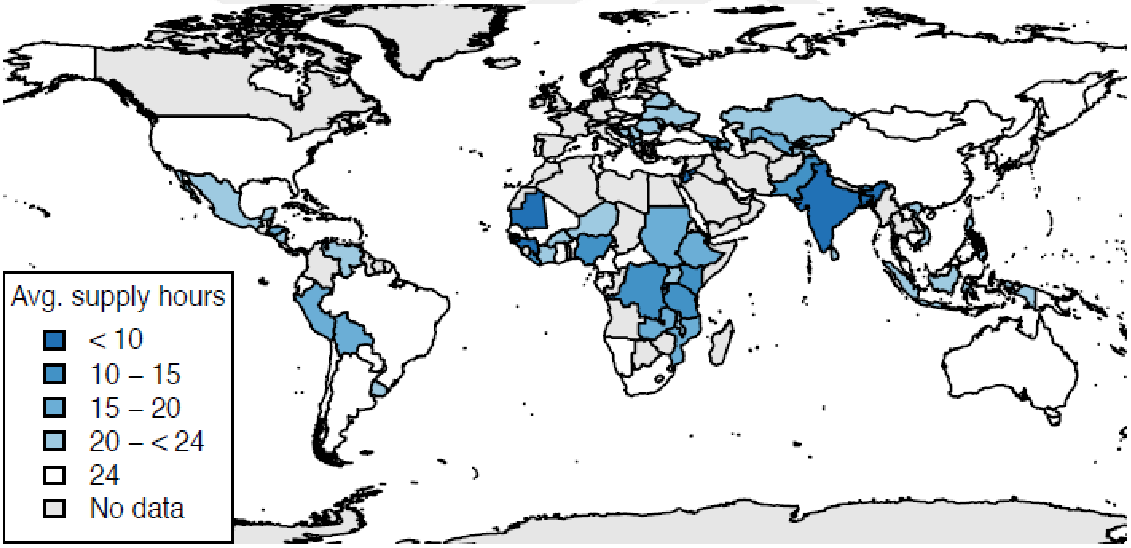


Figure 2: Average hours of water supply in the world (Kumpel, 2016)

Table 1: Water supply hours for India cities (Dahasahasra, 2016)

Indian city	Hours of water supply per day
Kolhapur	3
Bhopal	1.4
Bangalore	3
Ahmedabad	2
Bhbaneshwar	2
Bokaro	1.3
Delhi	3
Hyderabad	1
Nashik	3
Simla	1.5

According to Batish (2003), the main differences between intermittent and continuous water supply systems is that IWSs generally run when network supply is less than the demand — something which is defined by Fontanazza (2007) as unbalances. If it is assumed that the demand at a specific node is both met and equal to the supply, intermittent supply may not appear. Thus, in continuous systems, users tend to consume water in accordance with their needs, whereas users in intermittent supply tend to consume much water than their needs (Batish, 2003).

2.3 The Reasons of Intermittent Water Supply Systems

The common reasons given by Mcintosh (2003) and Fontanazza (2007) for intermittency are unbalances in demand and supply. These unbalances result from the extension of distribution networks over their hydraulic capacities to deliver 24-hour service on the behest of elected officials (Mcintosh, 2003). Other causes of intermittent supply for Mcintosh are:

- Source scarcity;
- Poor management of systems:
    - high leakage & wastage;
    - governance issues, such as illegal connections;
    - poor O & M practices.

2.4 The Consequences of Intermittent Water Supply Systems

Intermittency in water supply systems is a negative and unwanted case, especially since its repercussions are likewise negative. These probable negative results will be detailed in this section.

Much more money for pumping, storing and treating water is required for consumers who are relying on intermittent water supply systems and are, thus, also likely to consume more water than others since they are never certain when they will be able to access clean drinking water again. It is not safe to drink water from an intermittent water supply system because foul water can be drawn into the pipes due to vacuum conditions during non-supply hours (Mcintosh, 2003). In other words, when pipelines are empty, they lack the requisite pressure to keep outside dirt from entering into the system; it cannot, on the other hand, enter into pressurized pipelines, as seen in Figure 2. This means that the use of intermittent water supply systems consequently forces consumers to take extra precautions with the water that they receive in order to maintain their hygiene.

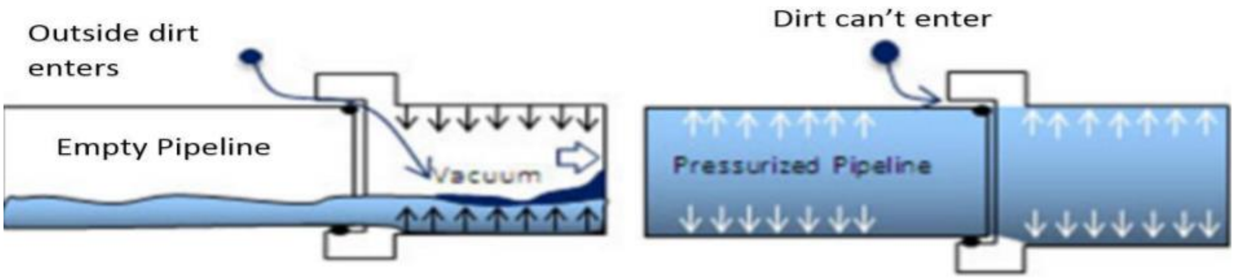


Figure 3: The case of an empty pipeline and a pressurized pipeline (Farmani, 2018)

2.5 Advantages of Intermittent Water Supply Systems

There are limited and fewer advantages for intermittent water supply systems compared to their disadvantages. Their advantages can be listed as follows:

- The pressure in intermittent water supply systems is lower, thereby helping to lower leakages;
- There is time for repair and maintenance during out-of-water-supply hours;
- It is much easier to keep a balance between supply and demand and to distribute water equally between consumers. (Mcintosh, 2003)

2.6 Disadvantages of Intermittent Water Supply Systems

In this section, the disadvantages of intermittent water supply systems is tabulated. As shall clearly be seen, there are more drawbacks to this system than there are advantages. Some of these drawbacks, however, can be improved with small retouches; in order to solve the others, on the other hand, more radical measures, such as transforming the system from an intermittent water supply to a 24/7 water supply system.

As previously stated, the first disadvantage of intermittent water supply systems is that, according to Kelkar P. S. (2001), its water quality is at high risk because its pipelines are contaminated during non-supply hours, which subsequently leads to diseases. The second drawback is that, in the case of an emergency, such as a fire, there may be no water in the system in order to be used by firefighters in order to extinguish the flames. In countries with such water supply systems, firefighting safeguards tend to only be constructed in important building. In such emergencies, it is preferred to use separate storage tanks (Batish, 2003).

In practical terms, the situation for water supply systems is always different from the way they are originally designed. It comes as no surprise, then, that the reservoir capacities of IWSSs may become underutilised or, likewise, that it is highly likely that the valves in such systems may generate much wear and tear. Besides, since the distribution system branches out into many zones, more manpower may then be required in order to manage the system (Dahasahasra, 2007).

Depending on the limited hours, the peak factor in most systems is between 4 and 6 (Dahasahasra, 2007). For this reason, large pipelines are required in order to meet the hydraulic requirements of the network. Since there are non-supply hours in IWSSs, users require large storage space and even need to pay for pumping.

The disadvantages of these systems, which Mcintosh (2003) posits in his book Asian Water Supplies: Reaching the Urban Poor, are listed below:

- The operation and design of systems are different: components are not used efficiently, whereas others are overused and damaged;
- Reservoir capacities are underused;
- Wear and tear on valves is common;
- More manpower and infrastructure are required;
- Pipelines are exposed to the vacuum condition after the supply period;
- Users have to treat their water for contaminates, as well as higher doses of chlorine;
- Poor consumers are mostly affected by inconvenient supply times (for example, a person for each household is charged to store the water during supply times);
- Consumers tend to store more water than they need between supplies, which causes water wastage and increased storage costs;
- There is no immediate supply of water in case of emergencies, such as fire.

2.7 Improvement of Intermittent Water Supply Systems

In the light of the information mentioned so far, the problems with intermittent water supply systems can be categorised into four main types; viz., low pressure, inequitable distribution of water, water contamination, and consumers' coping costs (Vairavamoorthy, 2007). The reasons and results of these problems have been mentioned before. Some improvements can be made to IWSSs. Nevertheless, even though they contribute to improving the systems, they are not final solutions.

The key solutions to the key problems which were mentioned before are summarised in Mcintosh's (2003) as shown below:

“- Promote awareness among stakeholders.

- Address governance issues related to the autonomy of utilities.

- Introduce higher tariffs for 24-hour zones.

- Place moratoriums on new connections.

- Invest in hydraulic modification of distribution systems.

- Start with 24-hour zones, and then expand these.

- Enforce strict metering and collection.

- Reduce non-revenue water.”

2.8 The Advantages of Continuous Water Supply Systems

Continuous supply systems have some benefits. The first benefit is that of reducing leakage, increasing the life of the distribution network, improving energy efficiency, as well as reducing capital costs, coping costs, and waterborne diseases. If the chart below is examined, when supply systems change from being intermittent to 24/7 type systems, the quality of tap water in pressurised pipes improves and the availability of water increases. Moreover, by increasing tap water availability, no household storage of potable water is then required, thereby reducing the use of risky water sources and, in turn, improving hygiene. These three results improve the quality of tap water in pressurised pipes, thereby improving the quality of the point of use, in turn reducing the number of waterborne diseases and, thus, improving hygiene in the population in general.

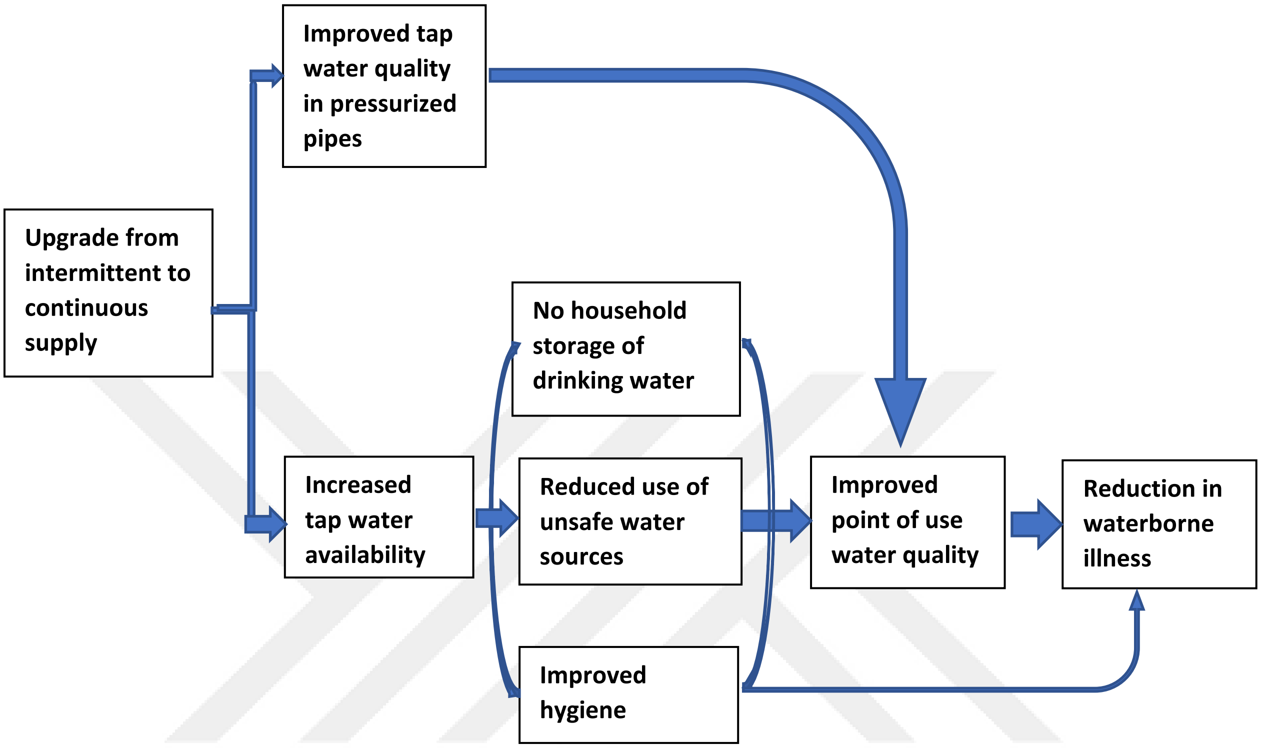


Figure 4: The indirect effect of transforming from an intermittent to a continuous water supply system on the reduction of water-borne diseases (Ercumen, 2015)

2.9 Converting Supply Systems from Intermittent to Continuous

Mcintosh (2003) states in his book that, in order to transform a water supply system from an intermittent to a continuous one, governance and tariffs should firstly be addressed. Next, it will be necessary to launch comprehensive stakeholder awareness programs to persuade the public that the water supply system will become a 24/7 one which will be linked to every home via pipeline. In order to standardise such a service, moratoriums need to be imposed on new connections while the distribution network are being hydraulically developed. Firstly, 24-hour supply zones should first be established. Then, other areas may be improved and then linked to those original zones. At the same time, higher tariffs can also be applied to the 24-hour zones, thereby supplying extra funds with which to improve the rest of the system. Since the tariffs will be priced high enough in order to cause less water to be used in the 24-hour zones, the extension of the 24-hour zones will also lead to making more water available to use. It is necessary that these zones work at 100% and that the measurement of all meters should be correct and errorless.

Furthermore, Klingel and Nestmann (2014) proffer six main steps towards introducing continuous distribution into a system (all of which are also proffered by McIntosh, 2003):

(1) Prevent illegal connections, set up domestic meters, fit float valves to household tanks;
(2) Transformation of the sector (hydraulic separation from the rest of the distribution network);
(3) Began monitoring;
(4) Change the water distribution system from intermittent to 24/7;
(5) Maintenance and decrease of water losses and leakage as a continuing process;
(6) adjustment of network capacities.

Having thoroughly reviewed the literature regarding water supply systems and their apparent strengths and weaknesses, the next chapter shall examine the methodology adopted by this research.

CHAPTER 3 – METHODOLOGY

In this chapter, the methodology which the author of this study has opted to adopt shall be described and explained in detail. Two software will be described, GANetXL for genetic algorithm and EPANET for simulation.

3.1 GANetXL for optimisation

GANetXL is a programme which works with Microsoft Excel and the work principle of GANetXL is exactly same as the general work principle of the genetic algorithm (GA). Therefore, GA shall be described and explained instead of GANetXL after that. A genetic algorithm is an artificial intelligence method which is very functional in the solution of complex problems and is very popular in solving optimisation problems. The basis of the genetic algorithm is based on Darwin's Theory of Evolution. According to Darwin's theory, those who adopt the best adaptations remain alive and have a higher chance of survival. He called that process natural selection (Darwin, 1859). Therefore, the offspring who have obtained effective genetic properties, either partly or completely, will have a higher chance of generating new generations and will be able to transfer their genetic information to new generations. This ongoing genetic process was tested in a computer environment in 1975 by Holland. In 1989, Holland's student Goldberg published his work as a book, proving that the genetic algorithm could be used in practice (Goldberg, 1989).

A genetic algorithm (GA) is a method used to solve optimization problems based on natural selection based on biological development (Nils, 1998). GA continuously progresses by modifying previous individuals. At each step, the new population selects two parents at random from the existing population to create new individuals. After each successful election, an optimal result is then obtained. GA can be used to solve many different optimization problems.

GA acts on three basic rules. Each rule tries to create a new generation from older populations. These rules are as follows:

- Selection; this rule chooses the genes that will constitute the new gene "parent;"
- Crossover; this rule merges parents to create a new generation;

- Mutation; this rule allows the new generation to be stronger by randomly changing each parent individually.

The first step in the genetic algorithm is the calculation of the fitness value of the first population. In the current population, the basic genetic operators are multiplication, crossover and mutation. The compliance value is also calculated for each generation. This continues until the stopping criterion is applied. The steps through which the GA goes through are provided as follows:

- A group of all possible solutions is coded as a solution index;
- Generally, a random set of solutions is selected and accepted as a starting population;
- An adjustment value is calculated for each series. The alignment values found indicate the resolution of the arrays;
- A group sequence is chosen randomly according to a certain probability value;
- The alignment values of new sequences are calculated and subjected to crossover and mutation processes. It is displaced by the new population;
- The above procedures are continued until the specified stop criterion is met;
- The loop is terminated when the stop criterion is satisfied. The most suitable sequence is selected according to the objective function.

In order to understand the GA's process, its flow diagram is provided in Figure 5.

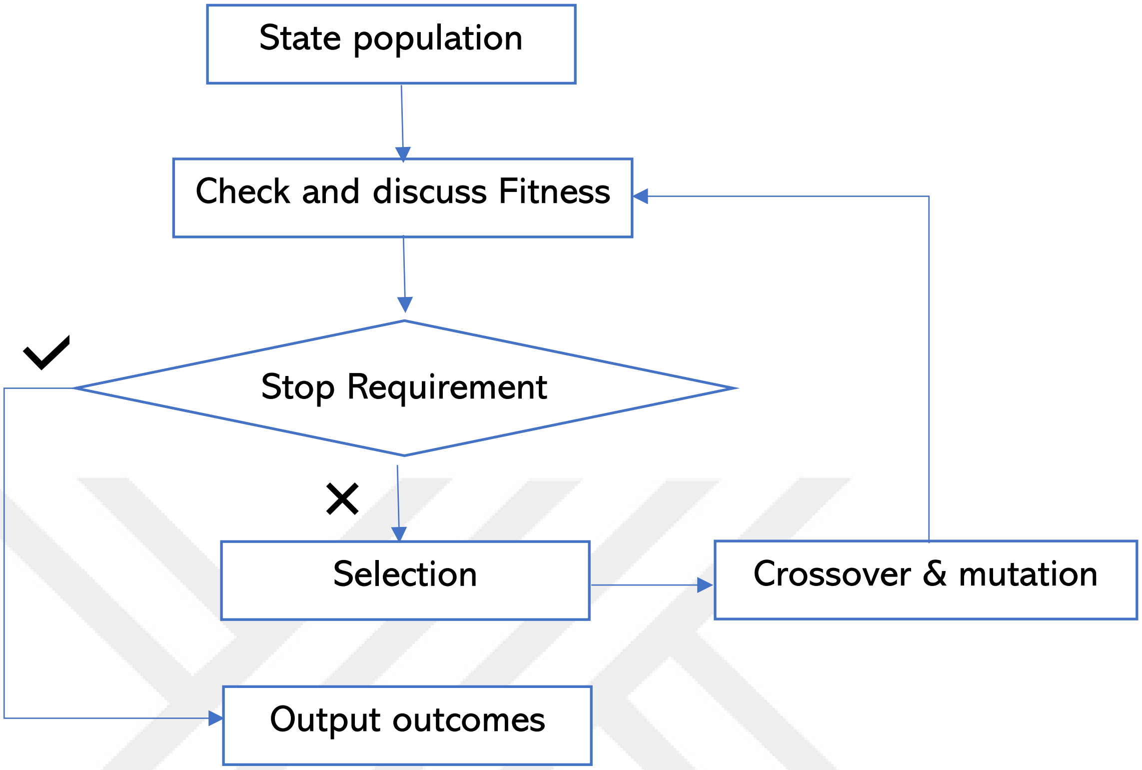


Figure 5: Genetic algorithm flowchart (Ahmadi, 2014)

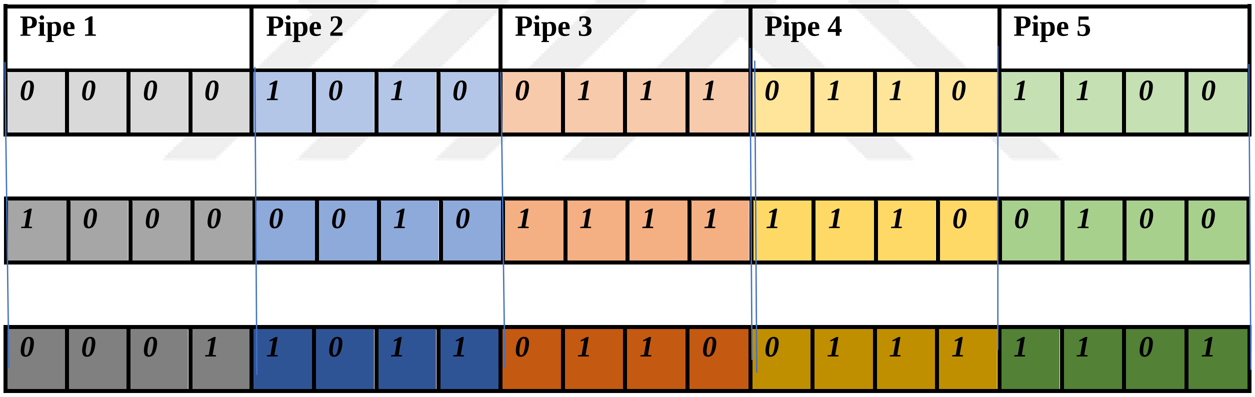
The details of each step shall be further extrapolated upon in the following sub-sub-sections. The first step to be examined is that of coding.

3.1.1 Coding

Coding is the first step of the genetic algorithm. It stipulates each decision variable in genes, which is analogous to chromosomes producing other chromosomes in DNA. GA consists of binary coding, grey coding, real-valued coding and tree coding. In this study, binary coding is used since it is more appropriate. If a given a binary code is given to each pipe size, Table 2, which is shown below, will occur.

Table 2: Binary Coding for each pipe size and possible pipe solutions

Pipe Size	Binary Code	Pipe Size	Binary Code
110 (mm)	0000	400 (mm)	0101
159 (mm)	0001	500 (mm)	0110
200 (mm)	0010	600 (mm)	0111
250 (mm)	0011	750 (mm)	1000
300 (mm)	0100	900 (mm)	1001



Pipe 1				**Pipe 2**				**Pipe 3**				**Pipe 4**				**Pipe 5**			
0	*0*	*0*	*0*	*1*	*0*	*1*	*0*	*0*	*1*	*1*	*1*	*0*	*1*	*1*	*0*	*1*	*1*	*0*	*0*
1	*0*	*0*	*0*	*0*	*0*	*1*	*0*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*0*	*0*	*1*	*0*	*0*
0	*0*	*0*	*1*	*1*	*0*	*1*	*1*	*0*	*1*	*1*	*0*	*0*	*1*	*1*	*1*	*1*	*1*	*0*	*1*

3.1.2 Selection

To create a new generation, a certain number of individuals are fortuitously chosen from the available individuals. The purpose of the selection process is to identify the parents who will create the new generation. This is consistent with the principle of life that is most appropriate in natural selection. Since the new generation is considered to have a better fitness value, this is the reason that the parents who derive that generation will also have good fitness values. Therefore, randomly selected individuals should be compared according to their fitness values. Consequently, only “fit” individuals should participate in the next genetic algorithm operations to form offspring. The most common selection methods are tournament choice, roulette wheel selection, and elitism. Each of these shall be considered in detail in what follows.

Tournament Selection

In this method, two or more individuals are randomly selected from the existing chromosomes. The chromosome with the best fitness value in the selected chromosomes is selected for use in subsequent operations. In the tournament method, randomly selected chromosomes are compared according to their fitness values and it is planned that the best will contribute to the formation of a new generation.

Roulette Wheel Selection

Chromosomes with higher fitness values are more likely to be selected than others. The compliance values of all individuals are collected. The percentage of the total eligibility value that each individual has been determined. The percentage of those who have the best eligibility value will be higher than others.

A default roulette wheel area is assumed to be 100%, and it is assumed that each roulette wheel occupies the position corresponding to the fitness value of each individual. When a ball is placed on a roulette to perform the selection process, it is assumed that the chromosome with the fitness value in the place where the ball lands will be selected. Figure 6 shows how chromosomes are placed on the roulette wheel according to their suitability.

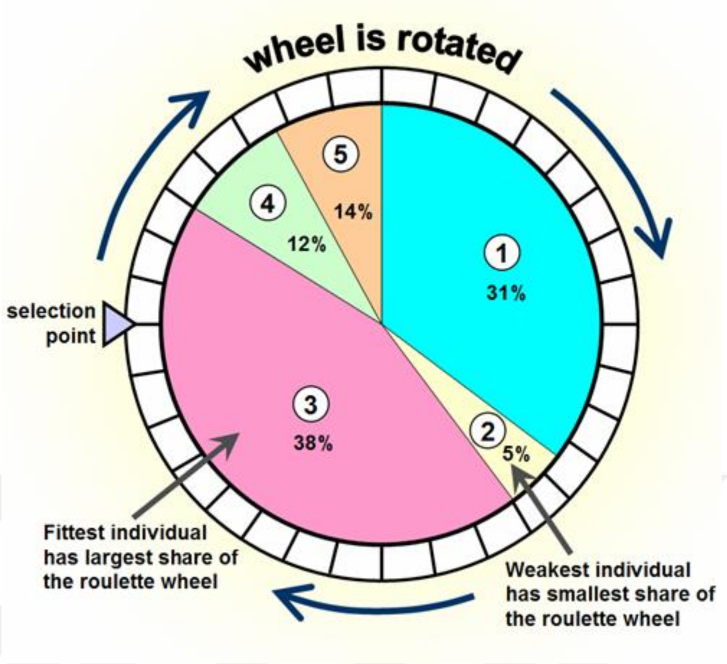


Figure 6: Roulette Wheel Selection (http://www.edc.ncl.ac.uk/highlight/rhjanuary2007g02.php/)

Elitism

The basic principle of this selection mechanism is that chromosomes are sorted according to their fitness values and that the best number is selected. For this reason, chromosomes with the best fitness values can be identified as the “parents” to form the next generation, with the dominant individuals becoming active in the identification of new generations. If a chromosome is selected from among the best chromosomes in number i, then the best order of the population using an integer p is randomly generated between 0 and i-1. The same operation can be performed by selecting the element.

In this thesis study, the best 5 values of the population were saved and transferred to the next generation. At the same time, i + 1 prevents the formation of individuals with worse conformity in the iteration.

3.1.3 Crossover

The two chromosomes obtained in the selection process are to transfer their genetic properties to their offspring in the genetic algorithm. For this purpose, these two chromosomes are treated as parents and bring the new offspring together with the crossover process. Thus, some hereditary features are transferred to offspring chromosomes. In order to carry out the crossover, it is necessary to design a discrimination point within the parent chromosomes obtained in the selection operator. If the length of the chromosome is accepted, a k point in the range of 1 <k <n-1 is randomly determined as the separation point. Then, on both chromosomes, the portion up to now is mutually displaced and thus, two new individuals, namely two "puppies," are formed.

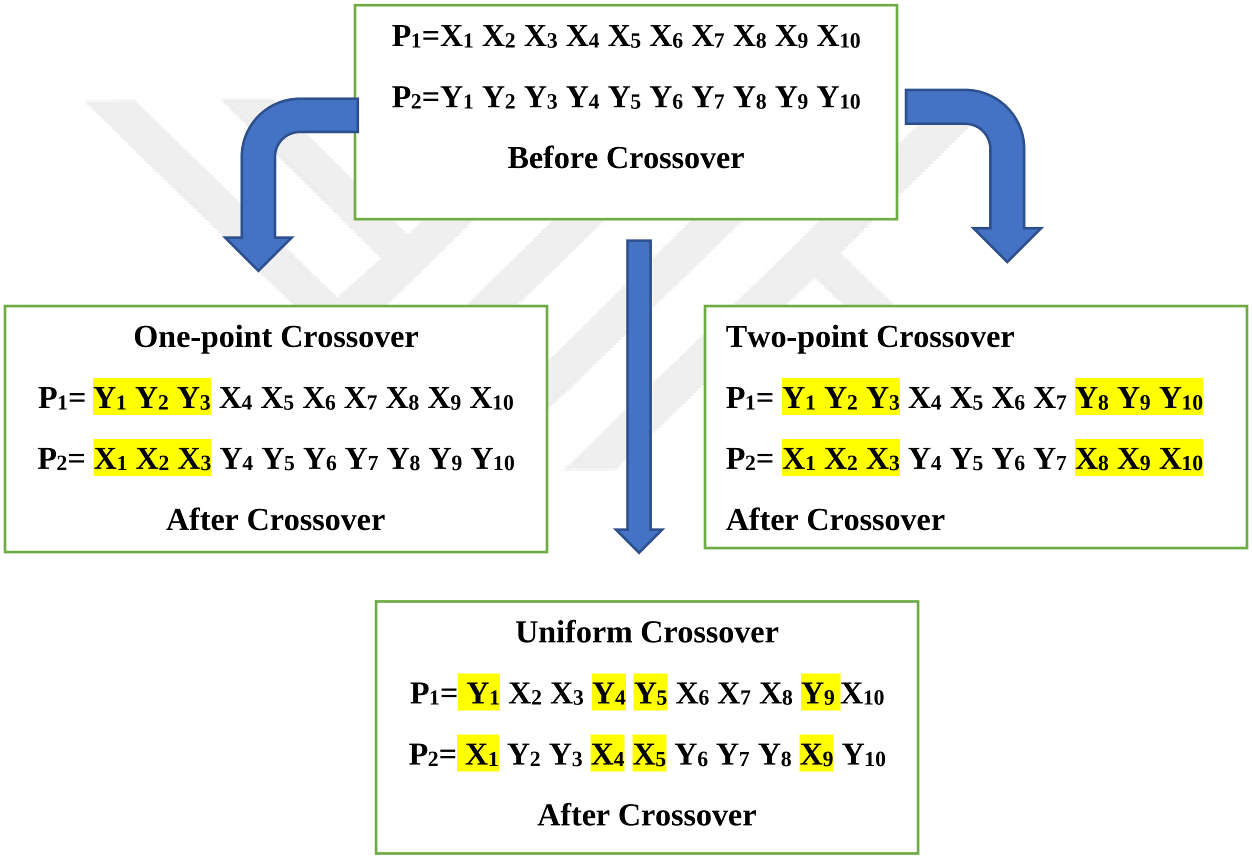


Figure 7: One-point, Two-point, and Uniform Crossover

3.1.4 Mutation

The step performed in the GA after the crossover is finished is the mutation process. The mutation process changes the value of a randomly selected gene in the chromosome, creating diversity among individuals which resemble each other in the population. Diversity in chromosome sequences generated by binary coding is achieved by selecting a random element within the chromosome sequence and changing the value of that element.

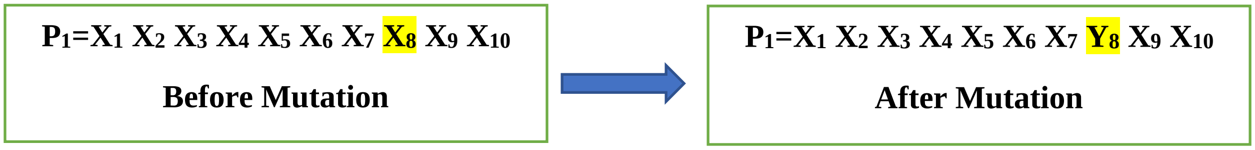


Figure 8: Mutation Operator

3.2 EPANET for Simulation

3.2.1 What is EPANET

EPANET is a software that is used worldwide to model water distribution systems. It can also be used to do an extended period of simulation of hydraulics, as well as water quality behaviour, in pressurized pipe networks (Rossman, 2000). The components of the EPANET are pipes, nodes (pipe junctions), pumps, valves, storage tanks and reservoirs. During the simulation period, to check the source and the water level of each tank, the concentration of chemical species, water age and source, and the water stream in each pipeline may be used. The purpose of EPANET is to improve the understanding of the movement, as well as the fate of the constituents of potable water throughout the distribution systems. In a network analysis, EPANET can also be used for several kinds of applications, such as “sampling program design,” “hydraulic model calibration,” “chlorine residual analysis,” and “consumer exposure assessment.” There are some alternative management strategies for improving water quality. These can cover:

- changing source usage within multiple source systems;
- changing tank & pumping filling/emptying schedules;
- satellite treatment usage, such as re-chlorination in the storage tanks;
- pipe cleaning and replacement.

When running under Windows, EPANET provides an integrated environment for editing network input data, running water quality simulations, and running hydraulic tests, while also allowing for the checking of results in a variety of formats, such as color-coded network maps, data tables, energy usage, reactions, calibrations, time series graphs, and contour plots.

In the light of these features, EPANET is going to be used in this study to simulate the system in order to easily rehabilitate the model for each try until the optimal solution can be discovered.

The following sub-sub-sections examine in detail the capabilities of EPANET, as well as the steps that the programme usually follows.

3.2.2 Hydraulic Modelling Capabilities

EPANET contains the following capabilities:

- no limitation in simulating systems based on the size of networks;
- the Hazen-Williams, Darcy-Weisbach, or Chezy-Manning formulas are used to calculate friction head loss;
- includes minor head losses for bends and fittings;
- models constant or variable speed pumps;
- calculates pumping energy and costs;
- models different kind of valves;
- storage tanks can be simulated to have any shape, diameter, or height;
- considers multiple demand categories at nodes;
- models pressure-dependent flow issuing from emitters, such as sprinkler heads;
- can base system operations on simple tank level, timer controls, or complex rule-based controls.

3.2.3 Steps in Using EPANET

While using EPANET to model a distribution system, the steps are followed:

I. Draw a network simulation of distribution systems;
II. Edit the properties of the objects;
III. Describe how the system shall be conducted;
IV. Select a set of analysis options;
V. Run a hydraulic/water quality analysis;
VI. View the results of the analysis.

3.3 Design Criteria and Formulation

The main purpose of (re)designing a water distribution system is that of finding the optimum pipe diameter for each pipe while taking into consideration the design constraints of the system, such as min & max pressure, speed, demand, and energy usage. These hydrodynamic constraints at specific nodes are obtained by using network simulations. The penalty function is used for the min pressure value when the expected pressure (10 m) is not more than the real value obtained from the simulation.

3.3.1 Objective Function

The objective function is an equation that can be optimised, minimised or maximised. There are two objective functions which aim to minimise the cost of redesigning the system and to provide the minimum water pressure requirement, which is 10 meters, while also minimising the total number of demand nodes. For this study, the rehabilitation of the system at minimum cost is possible only if the minimum possible pipe diameters are utilised.

The Cost of The Network

The total cost depends on pipe diameter and the type of the road (i.e. either minor or major). Total network costs will be calculated by using the following formula:

$$min(C) = \sum_{i}^{n} C(D_i, R_i) * L_i$$

where n is the total number of pipes; c(DiRi) is the unit cost per diameter; Di is the diameter of the pipe; Ri is the type of the road; Li is the length of each pipe; and C is the total cost.

The Total Number of Demand Nodes

$$min(DN) = \sum_{i}^{n} N_i i$$

Where Ni is the nodes which have a deficiency in pressure.

3.3.2 Penalty Function

The penalty function is provided by using the necessary node head and required head in the network. It is calculated according to the following equation:

$$C_p = \sum_1^n 10^8 \left(P_{req} - P\right), \text{if} \quad P_{req} > P$$

where C_p means the cost of the penalty as a £ and $P_{req} - P_i$ is the pressure deficit. If the pressure deficit is less than zero, this means that the pressure at that node is satisfactory and it will not be required to reduce pipe diameter. Consequently, the cost for the pipe will be equal to zero.

The EPANET is used for hydraulic simulations of water distribution networks. A GANetXL-based multi-objective algorithm, on the other hand, is used for network optimisation (Savic et al., 2011).

3.3.3 Rehabilitation Strategies

The purpose of this study is to redesign and rehabilitate water supply systems in order to meet the minimum pressure requirements for all demand nodes. There will be two scenarios. The first one is to find the minimum cost which provides the minimum pressure requirements for continuous systems. The second one is to maximise the efficiency that can be achieved by investing 1 million pounds in IWSSs, seeing as developing countries generally do not have enough money to invest in their water supply systems.

Scenario 1

Insufficient pressure results from high head losses in existing pipes. The reasons for there being high head losses include the roughness of large pipes and the diameter of small pipes. Therefore, a pipe is selected for rehabilitation when it has high head losses and short lengths. The pipes selected for rehabilitation will run and will be tested until an optimal solution is found using GANetXL for optimisation and EPANET for simulation. In order to transform an intermittent water supply system into a continuous one, the minimum pressure of the system should be at 10 meters (Ilaya-Ayza et al., 2018). Therefore, the optimal solution for this scenario is the realisation of a minimum cost where all the demand node pressures are at 10 m or more.

Scenario 2

The case in Scenario 2 is the same as that in Scenario 1, though the optimal solution will be to obtain a minimum pressure deficiency given an expenditure of 1 million pounds.

3.4 The Pathway of Optimisation

The optimisation problem was written in Microsoft Visual Basic and it is worked with GANetXL for genetic optimisation algorithm and EPANET for simulation and hydraulic analysis. The flowchart is given in Figure 9.

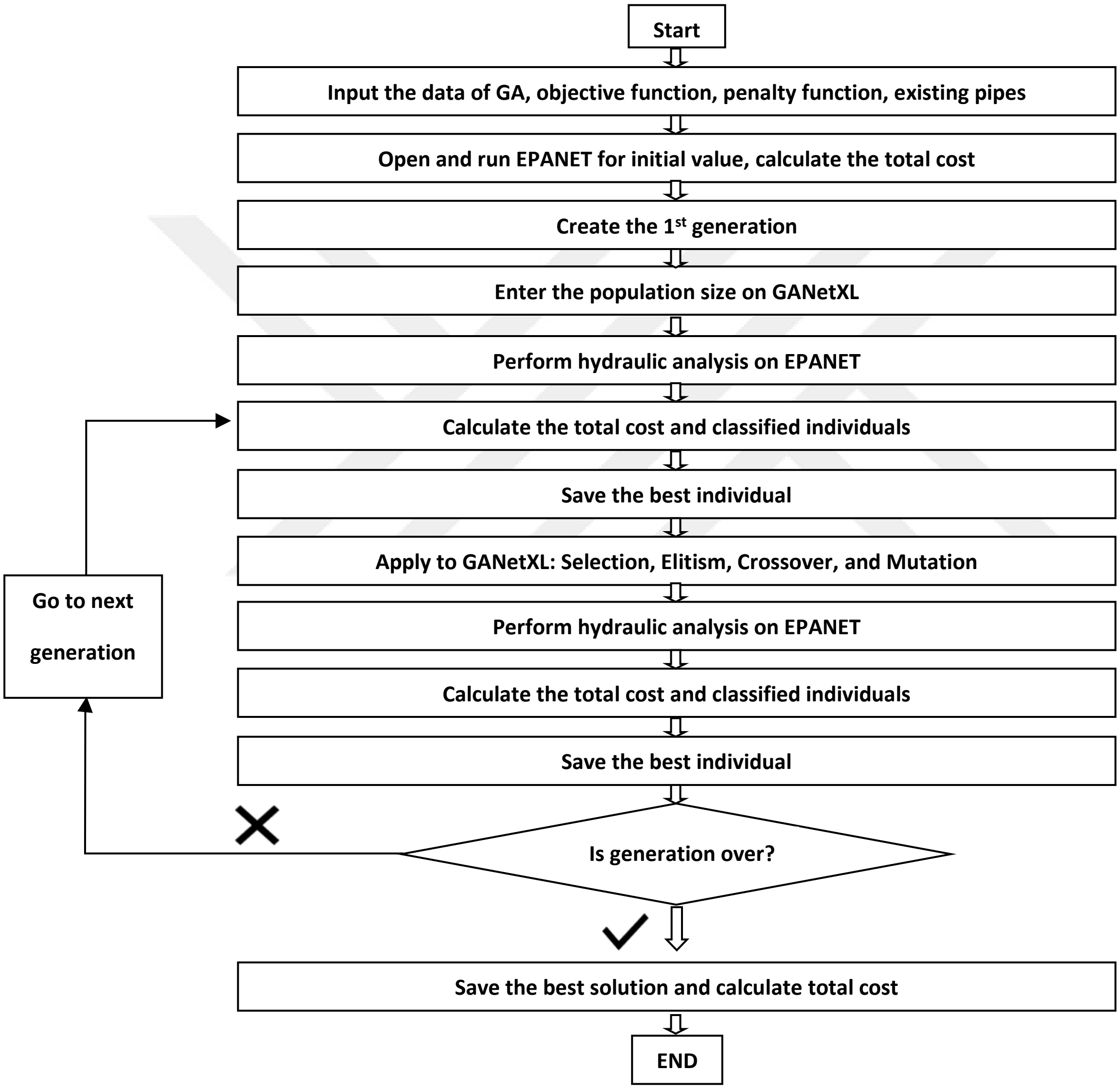


Figure 9: The flow chart of the strategy

3.5 The Case Study

The EXNET network system has been identified as being a problematic system by the Centre for Water Systems of the University of Exeter. The aim of this case study is to determine the most economically efficient design for the purpose of strengthening the existing system in order to meet the system's demands, as shown in Figure 10. The network serves a population of around 400,000 people and needs to be rehabilitated to meet the projected demand for 2020 (Karwan et al., 2017). The aim of this study is to solve the future low-pressure problems of this system which, if not resolved, will lead to intermittency. The minimum pressure requirement in order to transform the system from an intermittent one to a 24/7 one is 10 m (Ilaya-Ayza et al., 2018).

In the system, there are 1,891 nodes, 2,462 pipes, two main reservoirs (3,001 and 3,002), with five nodes (3,003, 3,004, 3,005, 3,006 and 3,007) supplying water to the system from adjacent systems.

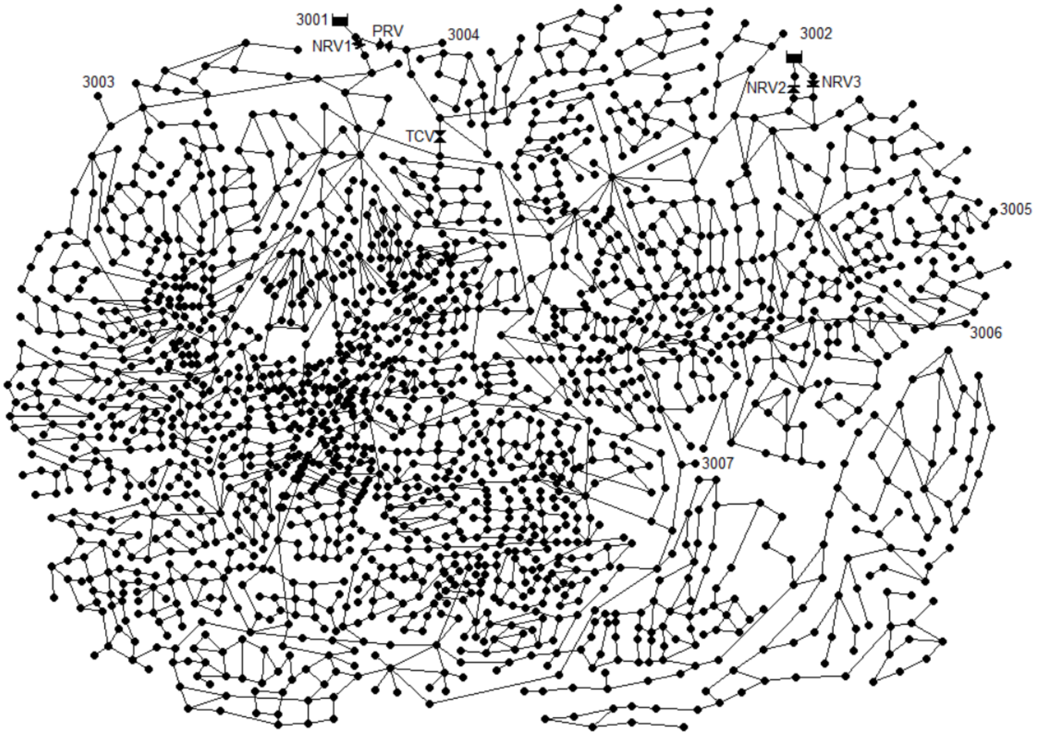


Figure 10: The Exnet Network (Wang et al., 2014)

The pressures of 1519 nodes of the system are above 10 meters. Nevertheless, the other 372 remaining nodes have a pressure deficiency. The pressures of 202 nodes of them are below 5 m, with 170 nodes' pressures being between 5 and 10 meters. As shown in Figure 11, the dark blue nodes show the nodes which have a pressure deficit or, otherwise, that their pressures are less than 10 meters. On the other hand, the light blue nodes demonstrate the nodes which do not have any pressure deficits or, equivalently, that their pressures are more than 10 meters. As shown in Figure 11, the pressure deficit is separated into two main and two small clusters.

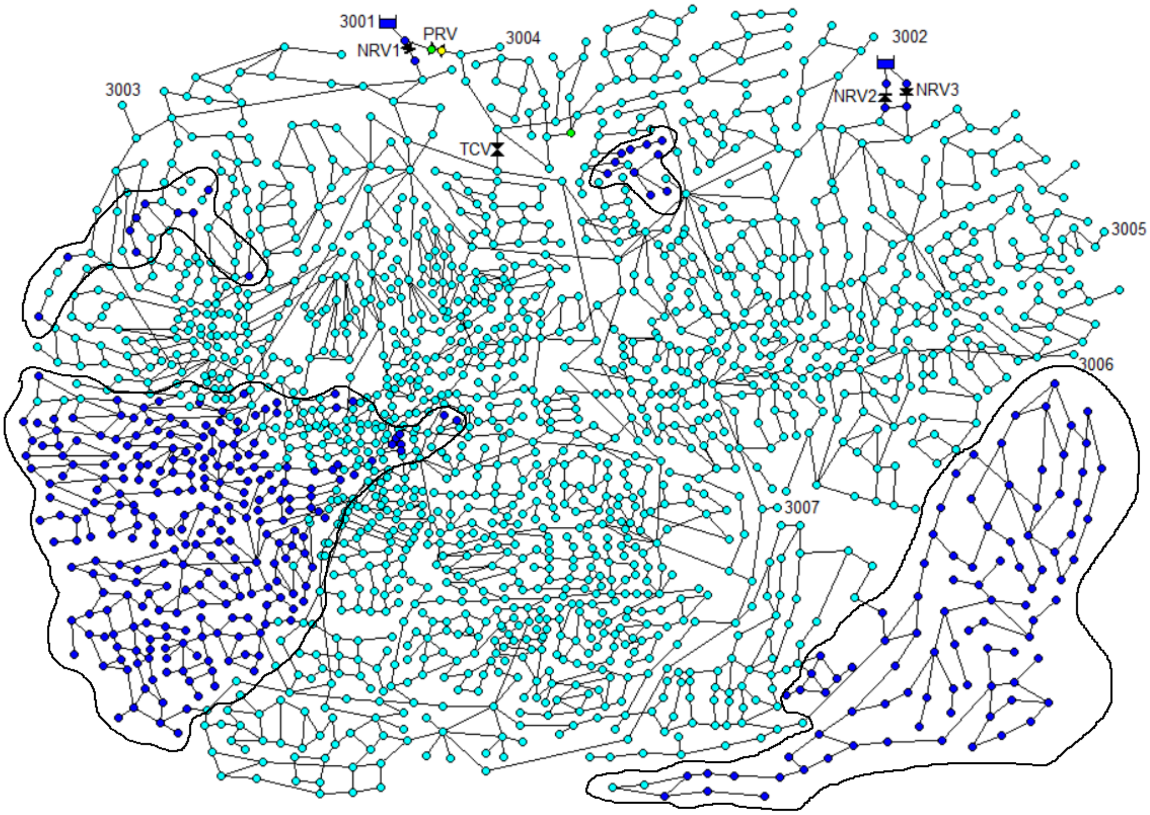


Figure 11: The nodes with pressure deficiencies

1898 pipes of the network are existing pipes which are out of rehabilitation. On the other hand, 567 of them are potential duplicate pipes, as shown in Table 3. The highlighted pipes in red show the major roads in the potential pipes for rehabilitation. Totally, there are 41 pipes in the major roads. The major roads, though, are more expensive than the minor roads because it is more difficult to excavate the main roads. The costs change based on road types and pipe diameter, as seen in Table 5. There are 11 possibilities where one does not need to rehabilitate pipe sizes, viz. 110, 159, 200, 250 300, 400, 500, 600, 750 and 900 mm (Farmani et al., 2004).

Figure 12: The potential pipes for duplication on the map

The red and yellow pipes in Figure 12 show the potential pipes for duplation on the map. They also can be seen with their original diameters in Table 3. The highlighted potential pipes in red in Table 3 show the pipes found on major roads. The other pipes are pipes found on minor roads. In addition, all of the major roads in the network are listed in Table 4. Due to the limitations of GANetXL and considering the fact that more pipes lead to hundreds of thousands of combinations, it is then necessary to decrease the number of pipes being considered. For example, if all the pipes were considered as decision variables, which is 2,462, the number of their total combinations is 11^{2462} = 8.11x10^{2563}. Furthermore, the number of potential pipes for duplication is 11^{567} = 2.95x10^{590}. Therefore, reducing the decision variables can contribute to our reaching an optimal solution more easily and quickly. In light of this information, a total of 164 pipes, consisting of all the potential pipes in a cluster, including feed pipes and pipes which have high head losses and small lengths, were selected.

Table 3: The potential pipes for duplication

Link ID	Orig. Dia. [mm]	Link ID	Orig. Dia. [mm]	Link ID	Orig. Dia. [mm]	Link ID	Orig. Dia. [mm]	Link ID	Orig. Dia. [mm]	Link ID	Orig. Dia. [mm]	Link ID	Orig. Dia. [mm]	Link ID	Orig. Dia. [mm]	Link ID	Orig. Dia. [mm]
2384	152	3974	236	3123	152	3699	102	3032	106	3035	106	2763	102	2095	102	3547	387
2334	310	3964	102	3513	540	3289	102	3253	152	2821	236	2967	106	4043	102	3538	387
2160	102	3876	152	5023	102	4998	152	3251	102	2152	229	2720	102	4088	152	4923	254
5191	918	5016	152	3131	152	3260	102	2943	152	2319	310	2736	152	4039	110	2181	152
2676	310	2294	152	2544	310	3817	106	2342	102	2451	464	2455	159	4008	229	2341	1073
3198	152	5073	106	5008	106	3535	102	2939	152	2737	310	2602	159	3639	159	2231	310
4942	152	3880	102	5120	310	5177	152	2773	106	2733	152	2133	152	3595	102	2679	310
4986	159	3849	106	2757	152	3446	540	2819	152	3652	152	2579	236	4055	127	2401	102
4911	152	2111	387	5066	552	5085	236	4024	102	2504	152	2462	229	4019	152	3127	159
2741	152	2714	152	5051	152	5074	102	2935	152	2309	152	2743	102	3068	152	4864	254
2368	229	2261	310	4875	254	2252	152	2442	102	2460	102	2052	102	3339	745	3574	229
3134	152	3940	102	4865	387	5076	102	2159	106	2591	152	2473	152	2904	152	2176	387
3896	102	4829	152	2431	159	5068	106	2320	765	3528	387	3342	319	4049	102	2288	102
2706	152	2719	500	4029	102	5113	102	2677	229	4072	319	3939	474	2765	310	2798	150
2424	159	4805	102	2712	236	5215	229	2769	236	2300	152	2512	500	3975	152	2428	102
3792	319	3282	102	2796	310	3422	765	3410	765	2292	765	5036	102	3677	1073	2154	300
4139	106	3840	152	2963	319	3124	152	2270	152	5063	540	2704	102	2568	152	4945	110
4185	152	3121	152	3834	319	4929	254	2274	102	3353	765	2656	387	3936	106	2195	159
4186	765	3902	319	3129	152	5183	102	2272	152	2727	102	2385	102	2369	765	2818	310
4904	102	4057	236	3877	106	3159	102	2782	310	2493	229	2707	159	2977	102	2203	310
5305	319	4182	159	4780	152	5038	106	2784	152	2930	152	2684	106	3585	102	3375	152
3958	691	2209	102	2412	102	4826	102	2813	152	2470	152	2651	236	4041	387	3367	1073
3960	152	4101	310	2295	102	3414	102	2962	387	2435	102	2226	106	3921	319	2349	102
3183	152	2790	300	3254	102	4950	310	2282	500	2393	310	2427	152	3412	106	4877	152
4065	106	5103	106	3236	152	2454	310	3082	229	2360	106	3922	102	3406	106	2600	310
2751	310	5079	152	3216	144	5117	629	3317	102	2465	765	3347	106	4130	97	3387	106
3963	102	3967	540	2331	144	4919	102	2314	102	2539	102	3682	152	3650	102	3637	1073
4173	765	2259	106	4834	152	4844	310	3285	102	2557	387	3457	152	3168	152	2073	745
2683	310	3388	152	2217	310	2418	229	3305	106	2376	102	4903	102	2094	229	2198	152
5262	102	3976	106	2896	152	4170	106	3672	152	2526	229	3338	474	2201	500	3352	152
5212	918	3712	918	4087	97	4165	159	2313	310	2402	102	3166	152	4070	387	4144	102
2740	102	4872	152	3505	229	2852	387	2291	102	2371	319	3506	387	3432	102	2059	102
4131	152	3909	102	5009	102	4149	102	4174	765	2474	159	2373	102	3592	102	3419	918
3750	81	3924	765	2777	387	5159	102	3445	106	2725	152	2501	102	3643	159	3847	918
5272	152	3356	152	4811	296	5139	106	3292	229	2365	229	3281	152	2108	152	3392	97
3814	917	3819	152	4827	152	4147	102	3307	152	3473	600	4080	97	4052	262	4062	310
3689	387	3269	765	4930	102	2619	522	3239	152	2590	310	2077	540	3632	102	3418	464
3436	159	4004	474	4812	102	5198	262	2199	229	4893	152	2096	890	2357	691	2409	229
5199	97	4030	159	2141	310	5084	159	2134	229	2555	540	3434	900	3625	310	2161	110
5165	540	2888	152	2883	152	4938	102	4931	152	2430	102	2051	152	2057	319	2903	102
3740	765	3235	152	3122	102	4064	319	3316	102	2297	540	3372	152	3636	152	2146	229
3713	765	4843	229	4810	102	2509	310	3256	102	2410	102	3366	97	3430	152	4112	102
5056	106	3529	310	4176	102	2532	152	3458	102	2447	387	5033	229	4160	159	2124	310
3510	102	5049	229	3687	106	5217	152	2310	387	2394	152	3393	102	3291	102	3437	106
5237	262	2155	310	3726	102	2363	152	3303	102	2856	152	3451	102	2907	152	2140	102
5235	102	2791	310	4819	152	3427	102	3200	300	2861	106	3693	152	3442	102	3474	900
4012	152	3021	310	3783	229	3178	152	2281	152	3169	152	5134	102	3565	102	3499	150
5243	387	3925	102	4985	152	2812	229	3278	152	2381	765	3579	152	3572	152	3411	152
5239	690	5018	152	4946	102	3066	152	2254	152	3004	102	3426	152	2232	152	3943	178
3932	106	2506	152	3779	152	2833	152	2311	152	2952	106	2681	236	2405	319	3920	319
4840	152	4960	152	3690	319	4158	152	3074	102	2674	387	2063	152	3524	106	3622	152
3705	102	2437	387	5155	102	3853	387	2874	102	2928	106	4816	310	3172	152	3980	102
3946	159	4970	152	4159	152	3038	106	3144	152	2575	152	4084	102	2165	254	2069	102
3988	474	4895	152	4021	152	3093	152	2330	102	2699	310	3409	918	3223	102	2599	387
2085	152	3716	765	4138	102	2271	102	3273	464	2759	310	2103	310	2186	102	2099	319
4837	152	3205	152	5248	102	2803	152	3048	1073	4982	102	3937	310	5069	159	2185	152
5047	765	2976	310	5034	288	2355	387	3047	464	3516	152	2080	319	5314	500	2446	102
3906	106	2192	310	2510	229	3787	102	3105	152	3786	319	2087	552	3440	106	4076	101
3917	319	2380	310	4995	152	4830	152	3055	236	2950	102	3186	152	2290	152	3544	310
3857	106	4899	159	2546	387	2329	106	3065	229	3624	152	2065	314	3293	102	3496	106
3982	474	2524	310	3871	106	2946	102	2824	152	2847	152	3350	152	3823	319	3487	900
3860	918	2391	106	2995	152	2902	310	3154	152	2858	152	2104	918	2139	500	3420	152
3892	102	2891	152	2416	102	2783	106	3147	152	2742	102	3471	102	2260	541	3664	102

Totally, there are 41 pipes under major roads in the system. All the pipes under major roads can be seen in detail in Table 4.

Table 4: The major roads in the system (Wang et al., 2014)

Road No.	*Pipe ID*	*Road No.*	*Pipe ID*	*Road No.*	*Pipe ID*	*Road No.*	*Pipe ID*
1	*5016*	*12*	*2681*	*23*	*5066*	*34*	*2065*
2	*4899*	*13*	*2803*	*24*	*2063*	*35*	*3917*
3	*2791*	*14*	*2784*	*25*	*5239*	*36*	*3937*
4	*3172*	*15*	*5085*	*26*	*5117*	*37*	*3823*
5	*3121*	*16*	*2579*	*27*	*3513*	*38*	*3792*
6	*3154*	*17*	*2651*	*28*	*2493*	*39*	*3834*
7	*3147*	*18*	*3055*	*29*	*2297*	*40*	*2963*
8	*2759*	*19*	*4057*	*30*	*5063*	*41*	*3690*
9	*2821*	*20*	*2790*	*31*	*5165*		
10	*2752*	*21*	*2619*	*32*	*2369*		
11	*2769*	*22*	*2087*	*33*	*4072*		

Due to several reasons which were mentioned before, the costs of rehabilitating pipes under minor roads vis-à-vis major roads are different. The numerical differences for each pipe based on diameter is demonstrated in Table 5.

Table 5: Pipe rehabilitation costs (Wang et al., 2014)

Internal Pipe Diameter (mm)	**Colebrook White Friction Factors (mm)**	**Unit cost (/m)**	
		Minor Road/Footpath	**Major Road**
110	**0.03**	**85**	**100**
159	**0.065**	**95**	**120**
200	**0.1**	**15**	**140**
250	**0.13**	**150**	**190**
300	**0.17**	**200**	**240**
400	**0.23**	**250**	**290**
500	**0.3**	**310**	**340**
600	**0.35**	**370**	**410**
750	**0.43**	**450**	**500**
900	**0.5**	**580**	**625**

Consequently, all of this data was processed into the GANetXL programme for optimisation with the following parameters for each of the scenarios:

- Population size of 70;
- Single one-point crossover type with a crossover rate of 0.95;
- Tournament selection;
- Simple by-gene mutator with a 0.04 mutation rate;
- Run for 10,000 generations.

The results of the simulations of these two scenarios are discussed in the following chapter.

CHAPTER 4 – RESULTS AND DISCUSSION

In this chapter, each scenario will be provided with a solution for rehabilitating the EXNET network based on the programmes, data, and methodology detailed in Chapter 3. When the system was redesigned, both programmes (the GANetXL for optimising the GA and EPANET for simulating the water supply system in question) were used in tandem. All of the results obtained for this study are shown and discussed in the current chapter.

Totally, there are 2462 pipes in the EXNET system. 567 of them are potential pipes for duplication, whereas the other pipes can simply be ignored during the rehabilitation process. 164 of these potential pipes were selected according to the criterions mentioned in the previous chapter and which are tabulated in Table 6 below. As a result, the 48 pipes for scenario 1 and the 11 pipes for scenario 2 were rehabilitated after the optimisation process, as may be seen in Tables 7 and 8. It must be noted that the 11 pipes are common pipes in both scenarios. The pipes highlighted in red in the following tables are the pipes to be found underneath major roads.

Table 6: The pipes selected to duplicate for scenarios 1 and 2

Pipe No	Link ID	Pipe No	Link ID	Pipe No	Link ID	Pipe No	Link ID	Pipe No	Link ID	Pipe No	Link ID	Pipe No	Link ID
1	2160	25	4805	49	3877	73	4929	97	4931	121	4982	145	3223
2	2676	26	3840	50	4780	74	3159	98	3278	122	3516	146	5069
3	3198	27	3121	51	3216	75	5038	99	2254	123	2858	147	5314
4	4942	28	2209	52	4834	76	4826	100	3074	124	2742	148	3823
5	4986	29	4101	53	4087	77	4950	101	2874	125	2763	149	4923
6	4911	30	5103	54	2777	78	4919	102	3144	126	2720	150	2679
7	3134	31	4872	55	4811	79	4844	103	3273	127	2602	151	3127
8	2424	32	4843	56	4827	80	2852	104	3105	128	2743	152	3574
9	3792	33	2791	57	4930	81	5139	105	3065	129	3166	153	2798
10	4139	34	4960	58	4812	82	5084	106	3154	130	4080	154	4945
11	5305	35	4970	59	2883	83	4938	107	3147	131	5134	155	2195
12	3183	36	4895	60	3122	84	3178	108	2152	132	4816	156	2818
13	4065	37	3205	61	4810	85	2812	109	2737	133	2103	157	4877
14	2751	38	4899	62	3687	86	3066	110	2504	134	3937	158	2600
15	3436	39	3123	63	3726	87	4158	111	2727	135	3186	159	3387
16	5056	40	3131	64	4819	88	3853	112	2930	136	2904	160	3392
17	4840	41	5051	65	4985	89	2902	113	2474	137	4049	161	4062
18	3705	42	4875	66	4946	90	2773	114	2590	138	2765	162	2903
19	4837	43	4865	67	3779	91	2819	115	4893	139	4130	163	3437
20	3906	44	2431	68	3690	92	2935	116	2856	140	3168	164	3920
21	3857	45	2796	69	4995	93	2782	117	2861	141	3430		
22	5016	46	2963	70	3817	94	3305	118	3169	142	2232		
23	2294	47	3834	71	5113	95	3445	119	2699	143	3172		
24	4829	48	3129	72	3124	96	3239	120	2759	144	2165		

Generally, Figure 13 shows some solutions and the relationship between cost and the number of nodes with deficiencies. It can be said that the number of deficit nodes increased when the total cost was decreased. A little rise in the number of nodes with deficiencies between the solution of 2 million pounds and the solution of around 3.38 million pounds are examined from scenario 1 in Figure 13, which is the minimum cost where all demand node pressures were more than 10 m, compared to scenario 2, which is the optimal solution with a minimum pressure deficiency for only 1 million pounds. On the other hand, more rise between following solutions from the solution of 2 million pound to the solution of 1 million pound which is scenario 2.

Specifically, the cost of the optimum solution obtained without pressure deficiency is £ 3,377,750.00. This means that, if this solution is applied, all demand nodes can reach a sufficient amount of water every time and that the system can transform from being an intermittent to a continuous water supply system. If scenario 2 is applied, all of the demand nodes, besides 181 nodes, will be able to supply water 24 hours a day, 7 days a week. In the simulation, however, these 181 nodes will have higher water pressures compared to their pre-rehabilitation results.

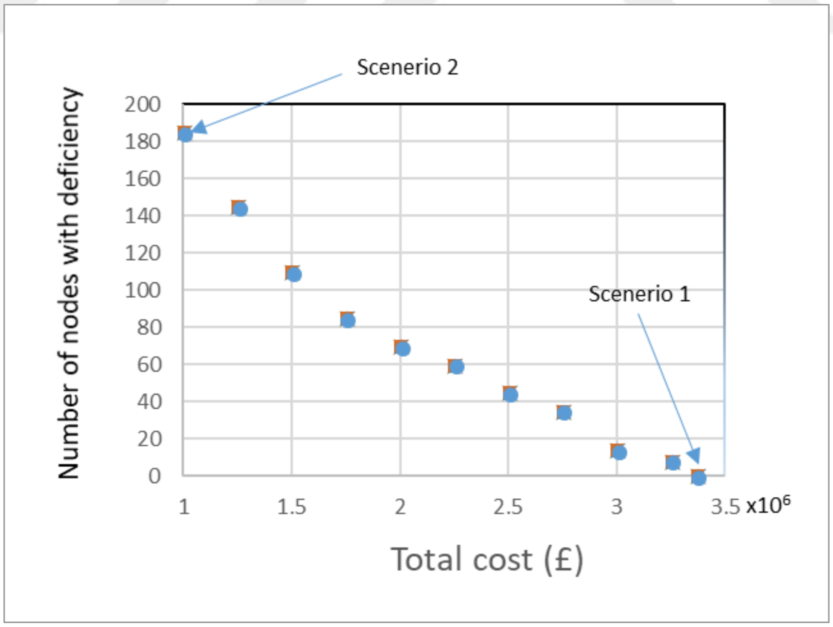


Figure 13: The relationships between cost and number of nodes with deficiency

4.1 The Result of Scenario 1

The aim of this scenario is for all demand nodes to be able to reach water continuously. For this reason, they provide the minimum pressure requirement. For this study, this pressure requirement is 10 m in order to transform the system from an intermittent to a 24/7 one. Thus, the penalty function, which is the total pressure deficit for this study, should be zero. In addition to that, the total cost should be at a minimum. In light of this information, the minimum cost solution is the one where all demand nodes can provide the minimum pressure requirement while the penalty function is zero.

As a result, the diameter of 48 out of the 164 selected pipes were upgraded. The minimum cost table obtained from this upgrade, as well as other detail, are given in Table 7. With this solution, all of the demand nodes were able to realise the minimum pressure requirement. This can be seen in Figure 14. Nevertheless, the six nodes which were the closest to the reservoir were not able to realise the minimum pressure requirement due to there being valves at the pipes following them. Thus, as seen in Table 7, the minimum total cost obtained for this solution was £ 3,377,750. During the rehabilitation process, the smallest pipe diameter selected was 159 mm and, in total, 5 pipe diameters changed in order to accord with that minimum diameter. Although there do exist 750 and 900 mm pipe diameters options, these two options were not used in order to rehabilitate the system; therefore, 600 mm pipes were used as the system's largest pipe diameter. In total, 11 600-mm pipes were used during the rehabilitation process.

10 out of the 48 pipes selected are underneath major roads. As mentioned before, the unit cost to replace pipes under major roads is more expensive than the unit cost for replacing pipes under minor roads due to several reasons which were mentioned before. Nevertheless, the cost of replacing all of the pipes under major roads (except for pipe number 2790) is £369,000.00. Even though the unit cost of replacing pipes underneath major roads is more expensive than that of replacing those under minor roads, it ended up not being more expensive because the lengths of the pipes underneath major roads were shorter than those under minor roads. Moreover, in this scenario, the most expensive 10 pipes to be rehabilitated were pipes 5305, 2790, 3690, 4844, 2812, 3853, 2902, 2782 and 3065. The total cost to replace those ten pipes was £1.7 million — in other words, 50% of the total cost of the system's rehabilitation costs.

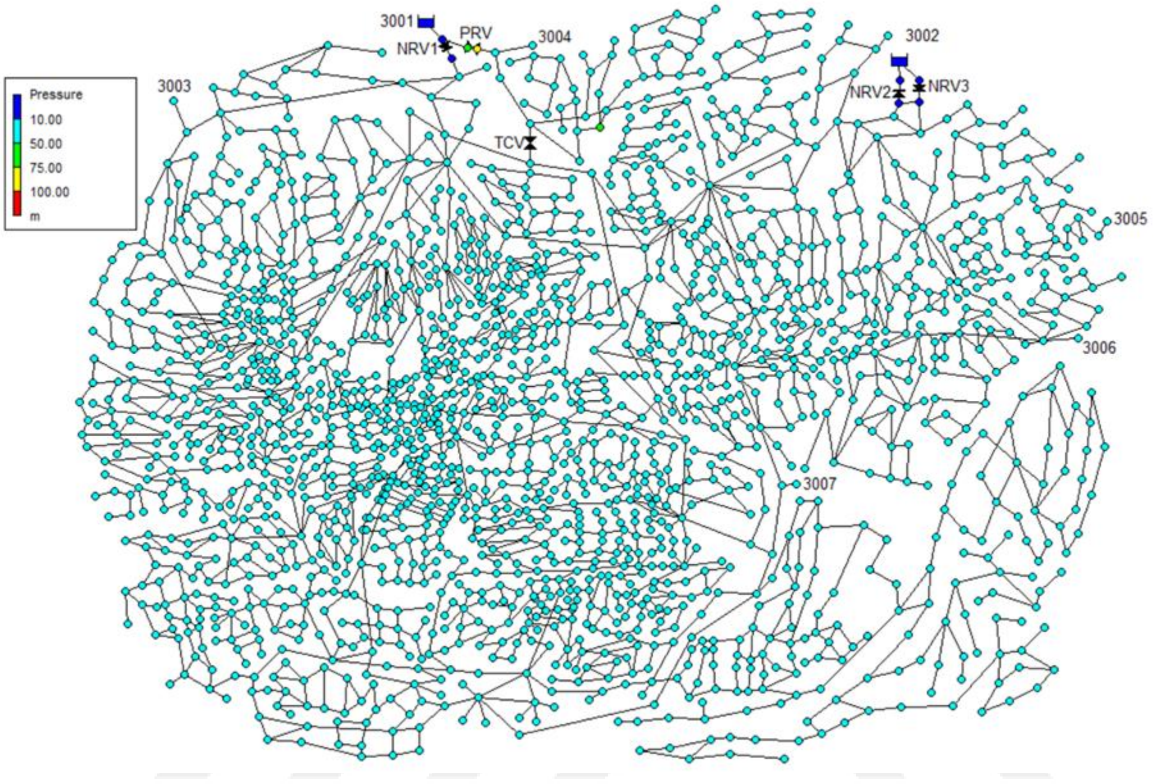


Figure 14: The solution for Scenario 1

Table 7: The results for Scenario 1

Link ID	Diameter Index	Orig. Diameter [mm]	Pipe Length [m]	New Diameter [mm]	Cost £
3792	8	319	220	500	74800
5305	8	319	330	500	102300
2790	9	300	900	600	369000
4899	7	159	320	400	92800
2431	4	159	330	200	37950
2963	7	319	280	400	81200
3877	3	106	190	159	18050
2777	8	387	710	500	220100
4811	7	296	300	400	75000
4812	3	102	150	159	14250
4946	3	102	220	159	20900
3690	9	319	290	600	118900
4844	8	310	470	500	145700
2852	9	387	240	600	88800
5139	3	106	220	159	20900
3178	4	152	160	200	18400
2812	8	229	550	500	170500
3066	5	152	80	250	12000
3853	9	387	350	600	129500
2902	9	310	540	600	199800
2782	9	310	380	600	140600
3239	7	152	310	400	77500
3074	4	102	370	200	42550
2874	3	102	290	159	27550
3144	5	152	210	250	31500
3105	5	152	190	250	28500
3065	9	229	280	600	103600
3154	5	152	160	250	30400
3147	6	152	160	300	38400
2152	8	229	120	500	37200
2737	9	310	200	600	74000
2856	4	152	260	200	29900
2861	3	106	120	159	11400
2759	9	310	100	600	41000
2858	7	152	310	400	77500
2602	7	159	120	400	30000
4816	9	310	100	600	37000
3937	9	310	190	600	77900
3186	6	152	120	300	24000
4130	4	97	190	200	21850
3172	8	152	220	500	74800
3823	8	319	200	500	68000
4923	9	254	170	600	62900
3127	5	159	140	250	21000
2798	4	150	170	200	19550
3392	5	97	200	250	30000
4062	8	310	230	500	71300
3920	9	319	100	600	37000
				Total Cost	£ 3,377,750

4.2 The Results for Scenario 2

Many developing countries suffer from having IWSSs but generally do not have enough money to invest in and rehabilitate their networks. Therefore, in scenario 2, it was assumed that there would only be one million pounds available to managers in order to rehabilitate the system. An optimum solution was attempted to be discovered given that amount of money. The solution obtained is provided in Table 8. According to the table, totally, the same 11 out of 48 pipes were selected from Scenario 1. The difference, however, is that the diameters they were upgraded to were different. The reason for these differences is that of decreasing the total rehabilitation cost to under one million pounds.

As a result, the total cost for this scenario was calculated as being £999,750. The diameters of the selected pipes are 200, 250, 300, 400 and 500 mm. In this scenario, the 3 most expensive pipes of the rehabilitation were pipes 2790, 3690 and 2812. The total cost for these three pipes was £552,000, which is 55% of the total rehabilitation cost for the system.

Table 8: The results of Scenario 2

Link ID	Diameter Index	Orig. Diameter [mm]	Pipe Length [m]	New Diameter [mm]	Cost £
2790	8	300	900	500	306000
4899	6	159	320	300	76800
3690	8	319	290	500	98600
2852	8	387	240	500	74400
2812	7	229	550	400	137500
3066	5	152	80	250	12000
3853	8	387	350	500	108500
3144	5	152	210	250	31500
3937	8	310	190	500	64600
4130	4	97	190	200	21850
3823	8	319	200	500	68000
				Total Cost	£ 999,750

This scenario is illustrated in Figure 15. According to this figure, there are totally 181 nodes with pressure deficiencies. The 50 dark blue nodes in Figure 15 show the nodes with pressures below 3 m, the 68 light blue nodes demonstrate the nodes with pressures between 3 m and 7 m, the 63 green nodes represent the nodes with pressures between 7 m and 10 m, and, finally, the other 1712 yellow nodes show the nodes with pressures above 10 m.

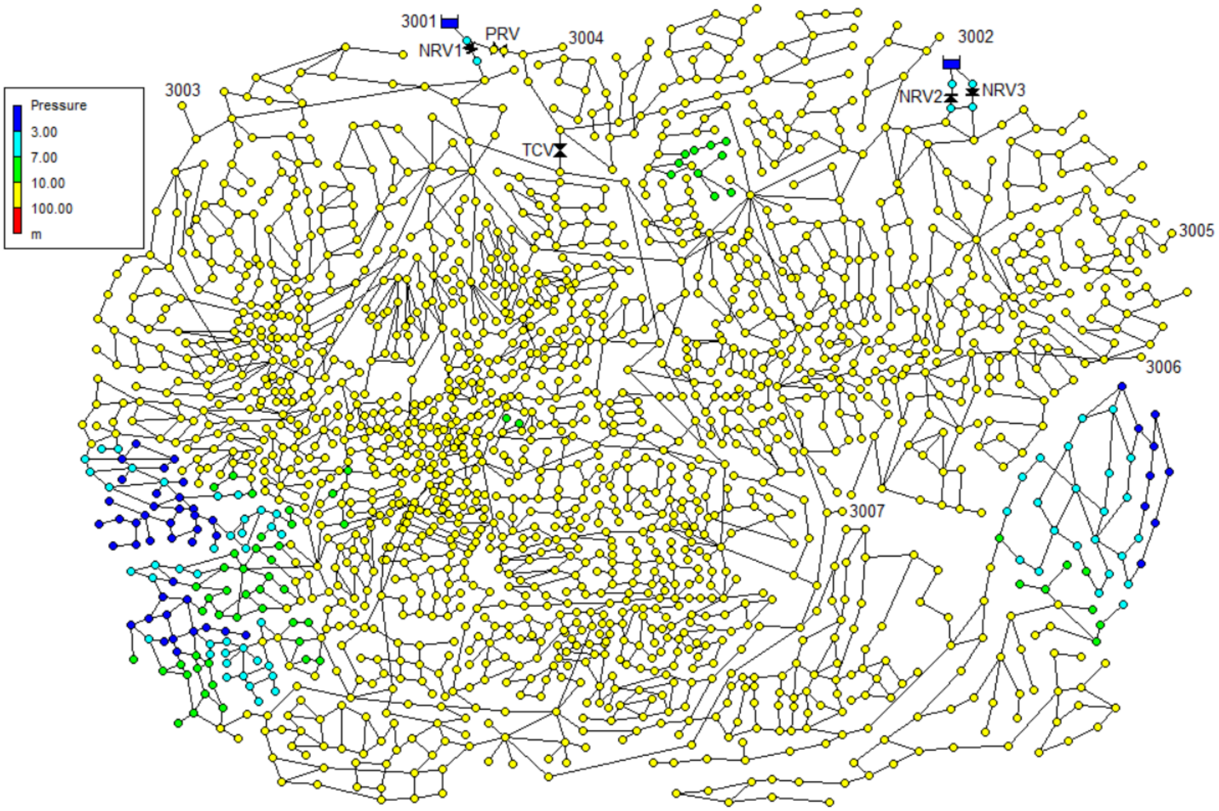


Figure 15: The solution for Scenario 2

Since the solutions for Scenarios 1 and 2 regard the exact same pipes and seeing as the rehabilitation diameters for the solutions for Scenarios 1 and 2 are different, an alternative solution was created for Scenario 2 such that the country having this network may want to rehabilitate the system in part and then, when it has gathered enough money, it can upgrade the other pipes. Thus, they will not have to rehabilitate the pipes which they have already upgraded. There are totally 173 nodes with pressure deficits at a total cost of £1,180,750.

Table 9: The alternative solution for Scenario 2

SCNERIO 2					
Link ID	**Diameter Index**	**Orig. Diameter [mm]**	**Pipe Length [m]**	**New Diameter [mm]**	**Cost £**
2790	**9**	**300**	**900**	**600**	**369000**
4899	**7**	**159**	**320**	**400**	**92800**
3690	**9**	**319**	**290**	**600**	**118900**
2852	**9**	**387**	**240**	**600**	**88800**
2812	**8**	**229**	**550**	**500**	**170500**
3066	**5**	**152**	**80**	**250**	**12000**
3853	**9**	**387**	**350**	**600**	**129500**
3144	**5**	**152**	**210**	**250**	**31500**
3937	**9**	**310**	**190**	**600**	**77900**
4130	**4**	**97**	**190**	**200**	**21850**
3823	**8**	**319**	**200**	**500**	**68000**
				Total Cost	1180750

CHAPTER 5 – CONCLUSION

Water is essential for all living creatures, not to mention humans. As important as it was in the past, it is still very important now, and will undoubtedly keep being important in the future. For this reason, it is necessary to supply and distribute water as sufficiently as possible.

In developed countries, almost all consumers can reach water and consume it 24/7. In developing or undeveloped countries, however, the opposite situation is valid. The majority of populations in both types of country either cannot reach potable water or can reach it at limited and specific hours in a day. This is called an intermittent water supply system. There are several reasons for intermittency to occur, but the lack of water resources and there being an insufficient water supply design are the most frequent reasons. In this study, it was assumed that the case study in question did not have enough water in the system and that intermittency was due to a design flaw as well as using insufficient pipe diameters. Therefore, the aim of this study was to transform the system from an intermittent to a continuous supply system by rehabilitating the pipe diameters seeing as increasing pipe diameters contributes to an increase in pipe capacity.

There are many methods for rehabilitating and transforming this kind of system, such as incorporating multi-objective criteria and clustering. The methodology applied in this study was similar to clustering methods. The Exnet Network was adopted as a case study. The aim of this case study was to provide the minimum pressure requirement for all demand nodes so as to enable the system to upgrade from an intermittent to a 24/7 system.

There were totally 2462 pipes in the system and 11 possible pipe diameter options. This was enough to show how may combinations one could try. Therefore, it was necessary to decrease the number of options. Thus, only 567 pipes in the system were considered potential pipes for duplication, with all the rest being ignored. Next, all of the pipes, except for those in clusters with pressure deficits and feed pipes which supplied the water to those clusters. As a result of this elimination, 164 pipes were selected for rehabilitation. After these pipes were examined, all the possibilities were tried using the GANetXL optimisation programme and the EPANET simulation programme in tandem. Subsequently, the optimum solution for each scenario was obtained. The results of both scenarios were given in Chapter 4. The former solution was discovered in order to find a minimum cost solution which would meet the pressure requirements for all demand nodes, with the latter solution being the most optimum solution given a maximum investment of one million pounds.

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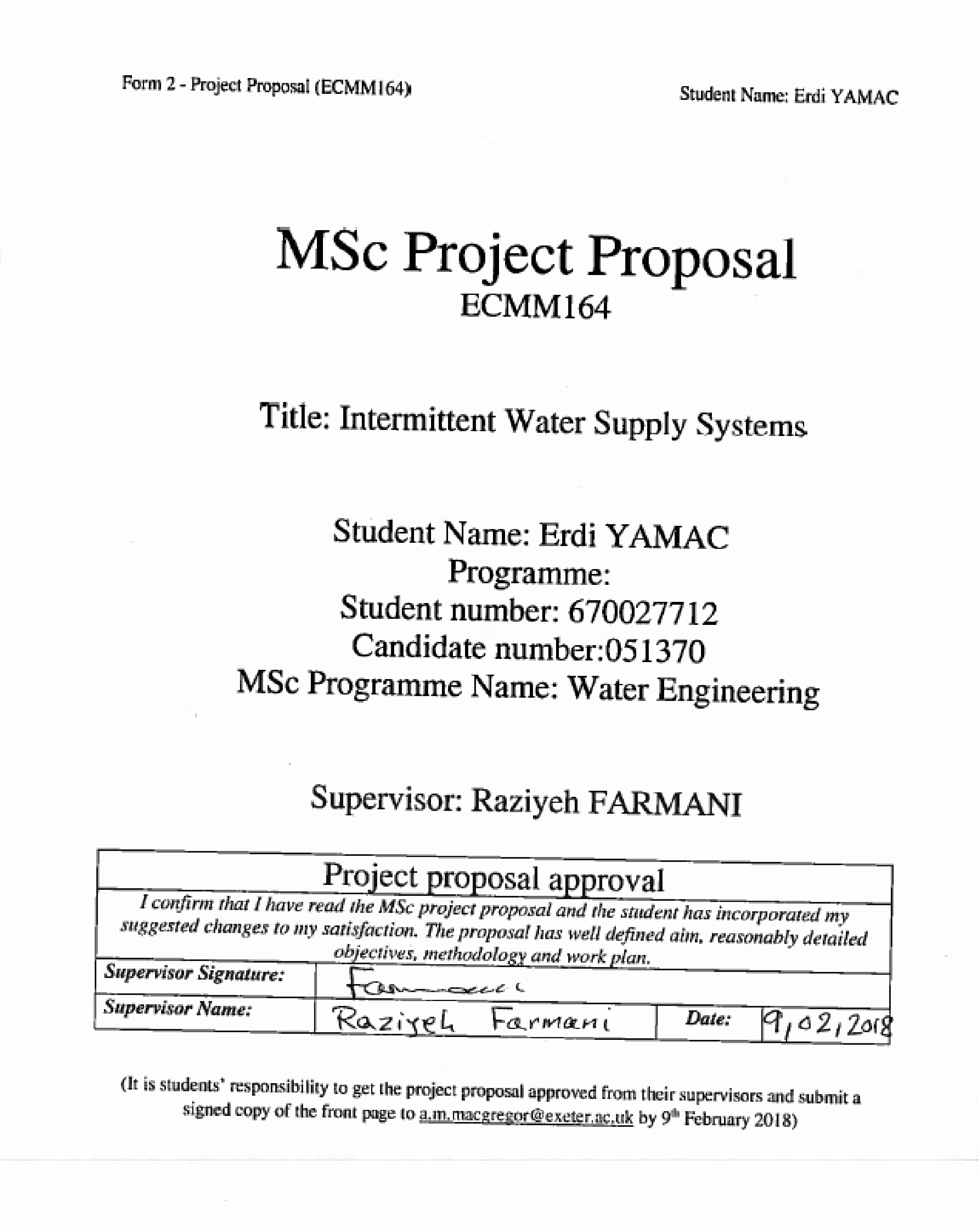
APPENDICES

Appendix-A



Form 2 - Project Proposal (ECMM164) Student Name: Erdi YAMAC

MSc Project Proposal

ECMM164

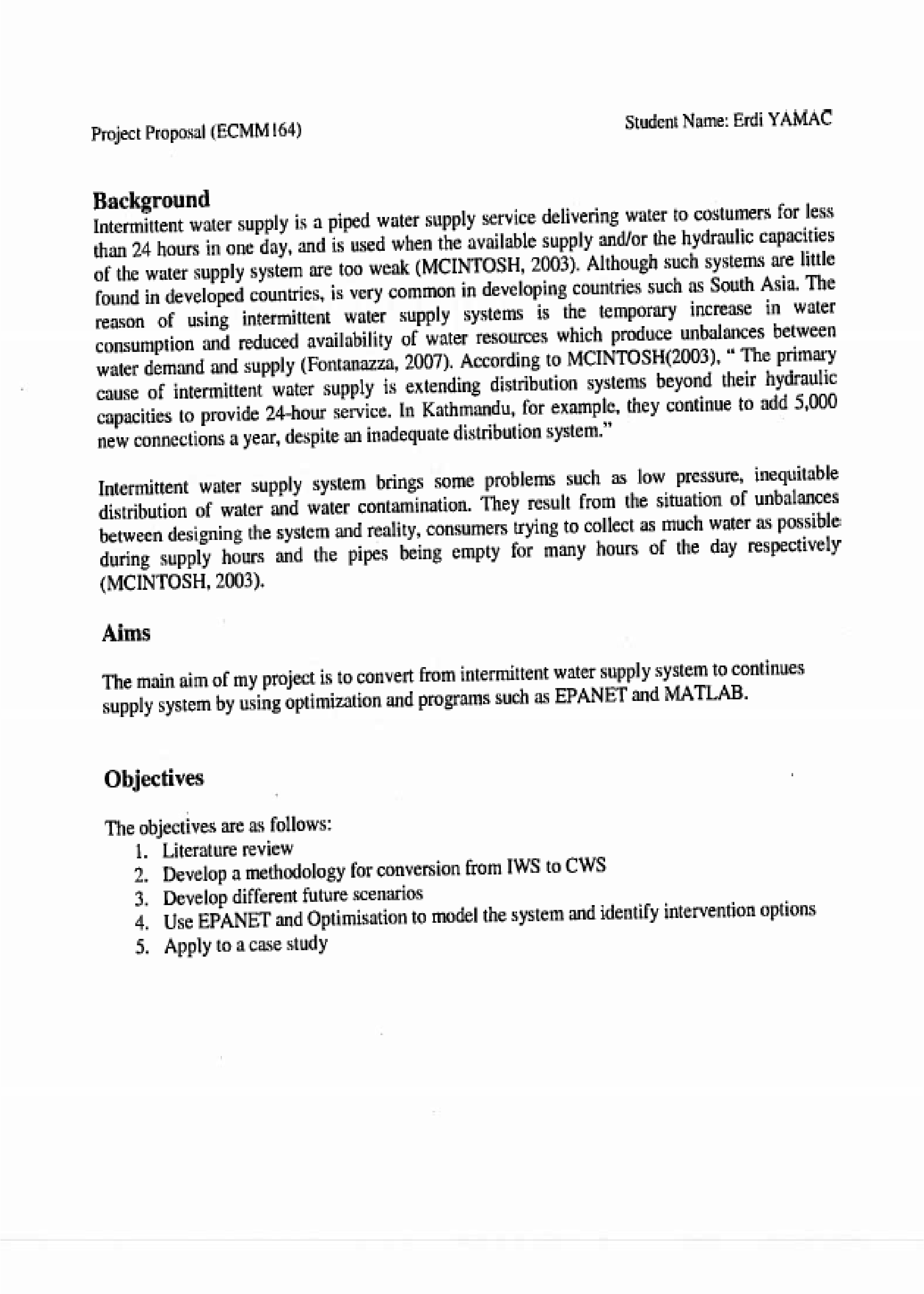
Title: Intermittent Water Supply Systems

Student Name: Erdi YAMAC
Programme:
Student number: 670027712
Candidate number:051370
MSc Programme Name: Water Engineering

Supervisor: Raziyeh FARMANI

Project proposal approval			
I confirm that I have read the MSc project proposal and the student has incorporated my suggested changes to my satisfaction. The proposal has well defined aim, reasonably detailed objectives, methodology and work plan.			
Supervisor Signature:			
Supervisor Name:	Raziyeh Farmani	***Date:***	9/02/2018

(It is students' responsibility to get the project proposal approved from their supervisors and submit a signed copy of the front page to a.m.macgregor@exeter.ac.uk by 9th February 2018)



Project Proposal (ECMM164)

Student Name: Erdi YAMAC

Background

Intermittent water supply is a piped water supply service delivering water to costumers for less than 24 hours in one day, and is used when the available supply and/or the hydraulic capacities of the water supply system are too weak (MCINTOSH, 2003). Although such systems are little found in developed countries, is very common in developing countries such as South Asia. The reason of using intermittent water supply systems is the temporary increase in water consumption and reduced availability of water resources which produce unbalances between water demand and supply (Fontanazza, 2007). According to MCINTOSH(2003), " The primary cause of intermittent water supply is extending distribution systems beyond their hydraulic capacities to provide 24-hour service. In Kathmandu, for example, they continue to add 5,000 new connections a year, despite an inadequate distribution system."

Intermittent water supply system brings some problems such as low pressure, inequitable distribution of water and water contamination. They result from the situation of unbalances between designing the system and reality, consumers trying to collect as much water as possible during supply hours and the pipes being empty for many hours of the day respectively (MCINTOSH, 2003).

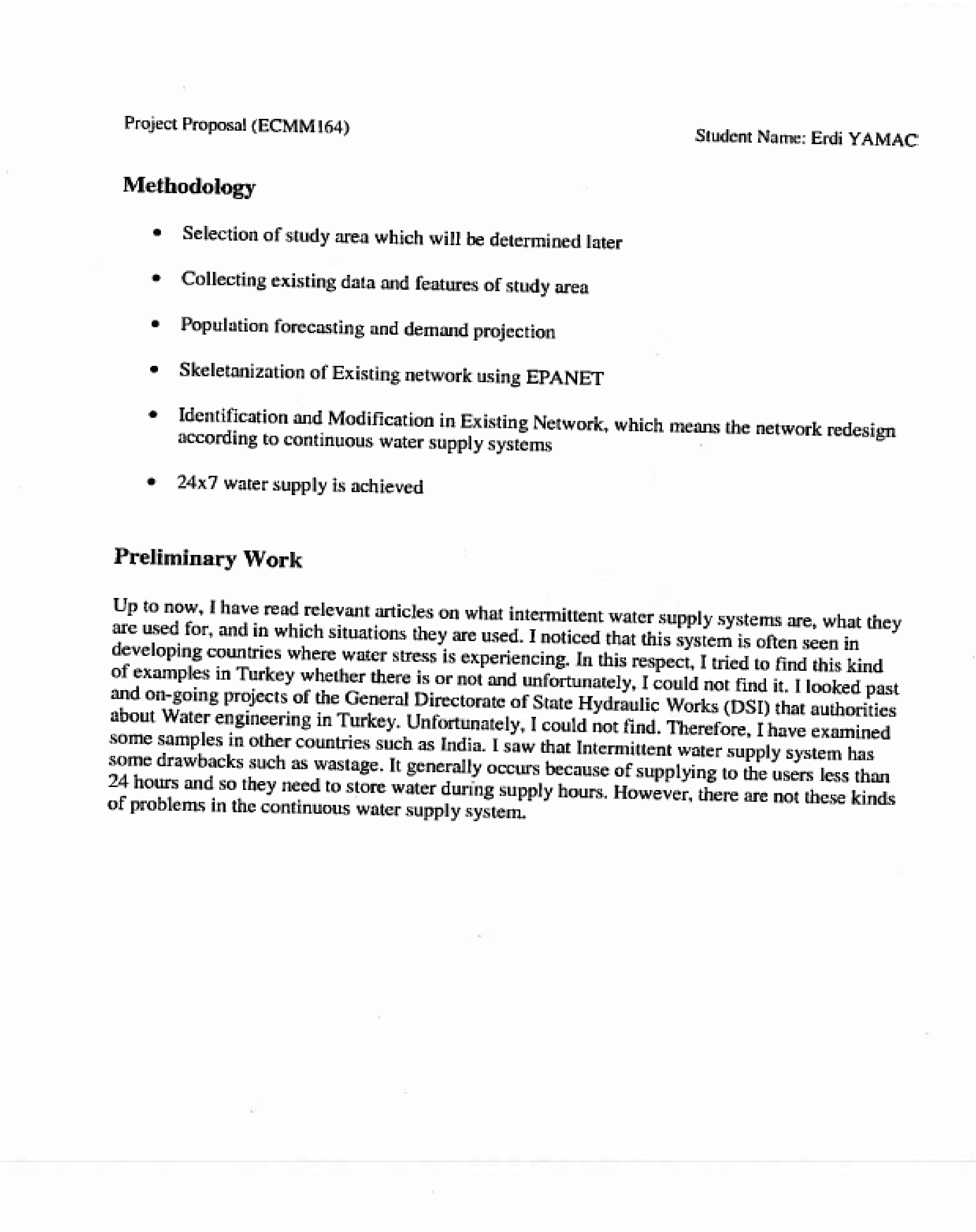
Aims

The main aim of my project is to convert from intermittent water supply system to continues supply system by using optimization and programs such as EPANET and MATLAB.

Objectives

The objectives are as follows:

1. Literature review
2. Develop a methodology for conversion from IWS to CWS
3. Develop different future scenarios
4. Use EPANET and Optimisation to model the system and identify intervention options
5. Apply to a case study



Methodology

- Selection of study area which will be determined later
- Collecting existing data and features of study area
- Population forecasting and demand projection
- Skeletanization of Existing network using EPANET
- Identification and Modification in Existing Network, which means the network redesign according to continuous water supply systems
- 24x7 water supply is achieved

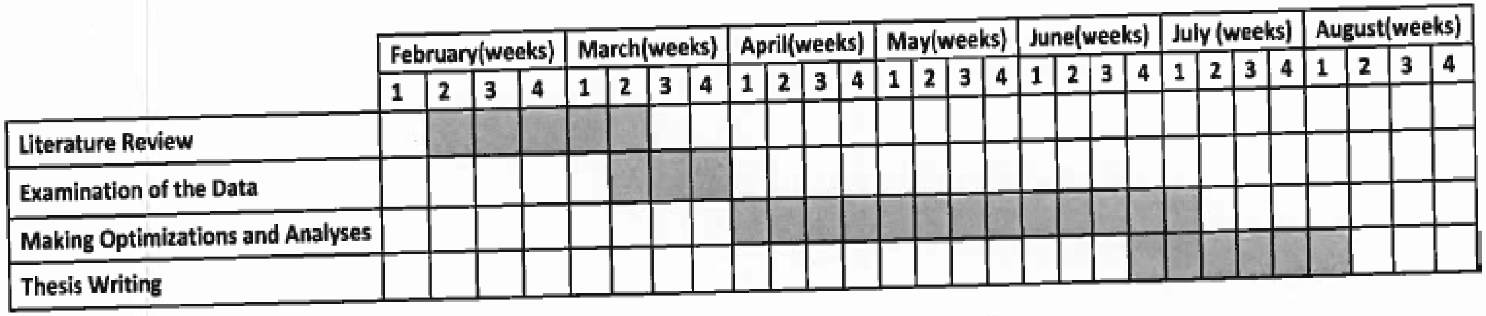
Preliminary Work

Up to now, I have read relevant articles on what intermittent water supply systems are, what they are used for, and in which situations they are used. I noticed that this system is often seen in developing countries where water stress is experiencing. In this respect, I tried to find this kind of examples in Turkey whether there is or not and unfortunately, I could not find it. I looked past and on-going projects of the General Directorate of State Hydraulic Works (DSI) that authorities about Water engineering in Turkey. Unfortunately, I could not find. Therefore, I have examined some samples in other countries such as India. I saw that Intermittent water supply system has some drawbacks such as wastage. It generally occurs because of supplying to the users less than 24 hours and so they need to store water during supply hours. However, there are not these kinds of problems in the continuous water supply system.

Form 2 - Project Proposal (ECMM164) Student Name: Erdi YAMAC

Project management

Table 1 Time management scheme is provided in the form of a Gantt chart:



	February(weeks)				March(weeks)				April(weeks)				May(weeks)				June(weeks)				July (weeks)				August(weeks)			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Literature Review		▨	▨	▨	▨	▨																						
Examination of the Data						▨	▨	▨																				
Making Optimizations and Analyses									▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨							
Thesis Writing																				▨	▨	▨	▨	▨	▨			

Table 2 Project risk assessment template

ID	Risk item	Effect	Cause	Likelihood	Severity	Importance	Action to minimise risk
	Describe the risk briefly	*What is the effect on any or all of the project deliverables if the cause actually happens?*	*What are the possible cause(s) of this risk?*			*L* S*	*What action(s) will you take (and by when) to prevent, reduce the impact of, or transfer the risk of this occurring?*
1							
2							
3							

Table 3 Ethical review

Does this project require Ethical approval?		**Yes/No**
If Yes	Estimated Date for approval	*No*

References

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