JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HYDROLOGY AND HYDRAULIC ENGINEERING CHAIR

MASTERS OF SCIENCE IN HYDRAULIC ENGINEERING

HYDRAULIC PERFORMANCE EVALUATION OF EXISTING WATER SUPPLY DISTRIBUTION NETWORK: THE CASE OF KOLFE KERANEO SUB CITY, ETHIOPIA

By: - FIKIRTE TENI MENJIYE

A THESIS SUBMITTED TO SCHOOL OF GRADUATE STUDIESOF JIMMA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN HYDRAULIC ENGINEERING

NOVEMBER, 2021

JIMMA, ETHIOPIA

JIMMA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
JIMMA INSTITUTE OF TECHNOLOGY
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
HYDROLOGY AND HYDRAULIC ENGINEERING CHAIR
MASTERS OF SCIENCE IN HYDRAULIC ENGINEERING

HYDRAULIC PERFORMANCE EVALUATION OF EXISTING WATER SUPPLY DISTRIBUTION NETWORK: THE CASE OF KOLFE KERANEO SUB CITY, ETHIOPIA

By: - FIKIRTE TENI MENJIYE

A THESIS SUBMITTED TO SCHOOL OF GRADUATE STUDIES OF JIMMA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN HYDRAULIC ENGINEERING

MAIN ADVISOR: - Dr.-Ing. FEKADU FUFA (PhD, Asso. Prof)
Co- ADVISOR: -Mr. ABDATA WAKJIRA (MSc)

NOVEMBER, 2021
JIMMA, ETHIOPIA

DECLARATION

Hereby I declare that this thesis entitled **“**Hydraulic performance evaluation of existing water supply distribution network; the case of Kolfe Keraneo sub-city**”** was composed by myself, with the guidance of my advisor, that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted, in whole or in part, for any other degree or professional qualification.

Fikirte Teni Signature ___________________Date_____________

APPROVAL SHEET

This is to certify that the thesis prepared by Miss Fikirte entitled " Hydraulic performance evaluation of existing water supply distribution network; the case of Kolfe Keraneo sub-city, Ethiopia" and submitted in fulfillment of the requirements for the Degree of Master of Science in Hydraulic Engineering complies with the regulations of the University and meets the accepted standards with respect to originality, content and quality.

BY

Fikirte Teni Menjiye

APPROVED BY BOARD OF EXAMINERS

Dr.-Ing. Fekadu Fufa	---------------------	----------------------
(Advisor)	Signature	Date
Mr. Abdata Wakjira	-------------------	---------------------
(Co-Advisor)	Signature	Date
Dr. Adane Abebe	-------------------	-------------------
(External Examiner)	Signature	Date
Mr. Mohammed Hussein	---------------------	--------------------
(Internal Examiner)	Signature	Date
Mr.	----------------------	--------------------
(Chairman)	Signature	Date

ACKNOWLEDGEMENTS

First of all I would like to thank Almighty God for providing me with good health, wisdom and strength throughout my duty and help me to complete this study. I gratefully acknowledge my Advisor, Fekadu Fufa (PhD) and co-advisor Mr. Abdata Wakjira for their extended support and guiding me on the right direction. I wants to Dilla university who wish to my upgrading knowledge's and My gratitude appreciation also goes to Jimma university Institute of technology my instructors‟ of those who gave me courses which helped me to know about so many new things of hydraulic Engineering. I am also grateful to convey my special thanks to the staffs of Addis Ababa Water and Sewerage Authority for their support in providing me the necessary data and information for the study. My thanks also extended to Engineer Tkabo Haregot who is water distribution case team coordinator at Addis Ketema water and sewerage authority, my family and friends for their encouragement and support. Furthermore, and most importantly, I would like to thank all my friends for their kind cooperation in giving the required advice and information. Finally, I would like to express my deepest gratitude to my family, for their unlimited support and encouragement that contribute great in my life.

ABSTRACT

The aim of proper design of water supply distribution network is adequate delivering of water to customers consumption nodes, Therefore the evaluation of hydraulic performance of water distribution network is important to identify the inadequacy of water transfer to a consumption nodes. Hence, the aim of this study is to evaluate the hydraulic performance of Kolfe Sub-city water supply distribution network. The existing water supply deficit and future water requirements, and junction pressure hydraulic, water velocity performance of the supply were evaluated. Water GEMS v8i, AutoCAD v2007i, ArcGIS 10.1, geographic positioning system Garmin72 and Microsoft excel sheet used. The water GEMS simulation results for both steady state and extended study period simulation of distribution network were related to pressure 44.61% *for pressure value (≤ 15 mH_2O),* 37.84% *for pressure value (15 - 60) mH_2O and* 17.55% *for pressure value (≥ 60 mH_2O) pressure head. In the same manner the velocity of pipe flow showed that* 63.25% *for velocity (≤ 0.6 m/s),* 24.94% *for velocity range (0.6 - 2 m/s) and* 11.80% *for velocity (≥ 2 m/s). The results indicated that the maximum and minimum velocity and pressure requirements was beyond maximum and minimum limit and hence, almost all junction is negative which displayed the inefficient hydraulic and the estimated total water loss is 23% for area. This problem are resulted from incorrect nodal placement and improper pipe connection during designing the system and when expanding the network to the newly established settlement area. On the other hands the existing water supply collection did not meet the average per capital water consumption rates. 20l/c/d which is 14.68l/c/d showing below standard of developing countries consumption rates. The existing water supply and demand gap of* 25329.38 *m^3/d shown a great water shortage in the area, these indicating that, the predict water demand is greater than the current supply potential of water sources or water supply deficit. The current and predicted water demands were 12127.14 m^3/day and at the end of 2046 years will be 44946.68 m^3/day, whereas the available source is 19617.3m3/d. The mitigation measures for this interruption of water supply network, water loss and supply deficits is installing proper service of reservoirs, control water loss and seeking extra sources of water supply.*

Key words: Kolfe Sub-City, pressure, velocity, water demand, Water GEMS, water loss, water supply

TABLE OF CONTENTS

Table of Contents

LIST OF TABLES

LIST OF FIGURE

LIST OF ACRONYMS

ADWD	Average Daily Water Demand
ArcGIS	Geographic Information System tool
CF	Climate Factor
CSAE	Central Statistics Agency of Ethiopia
CWD	Commercial Water Demand
EPS	Extended Period Simulation
FWD	Firefighting Water Demand
GPS	Geographical position system
GTP	General Growth and Transformation Plan
GTP II	General Growth and Transformation Plan II
HCS	House connection Service
IWD	Institutional Water Demand
MDDF	Maximum Day Demand Factor
NRWD	Non-revenue water demand
PF	Public Fountain
PHDF	Peak Hour Daily Factor
PHWD	Peak Hour Water Demand
SEF	Socio-Economic Factors
UFW	Unaccounted for Water
YOC	Yard Own Connections
YSC	Yard Shared Connections

1. INTRODUCTION

1.1. BACKGROUND OF THE STUDY

Currently, guaranteeing access to safe drinking water is one of the most problematic in the global (Desta and Befkadu, 2020, Tadesse, 2020). The access to water is crucial for life, prosperity, and all human activities and water resources must be used effectively to meet the demand of the ever-growing population, considering the limited and decreasing water availability(Fekrudin and Ababa, 2019). The provision of adequate supplies potable water for use in urban areas in developing countries is crucial for the well-being of the people. A well performing urban water supply system should provide water supply for human being and livestock consumption, for industrial and other uses taking the existing and future realities of the city in to consideration.

The distribution network is responsible for delivering water from the source or treatment facilities to its consumers at serviceable pressures and mainly consists of pipes, pumps, junctions, valves, fittings, and storage tanks. Water distribution networks play an important role in modern societies being its proper operation directly related to the population's well-being. As the demand on water increases due to the population growth rate, and the increase in per capita consumption, the defect in the performance of the water network led to the negative influence in most of the socioeconomic sectors. Leakage is one of the causes of water loss in a network distribution system that currently needs an attention.

Water supply distribution system is a complicated combination of hydraulic control parameters connected together to transmit of water from sources to consumers and network condition is defined as collectively representing the physical condition state of all water pipes in the network(Borzì, Bonaccorso and Aronica, 2018). The main purpose of design of water distribution network is to supply the required quantity of water at required time with sufficient pressure. But, in many of the developing countries, drinking water considered as probability of a node being connected to supplies are inadequate to meet consumers' piped water demands. Water Pipes with in poor condition in water distribution systems cause significant operational problems (Melese, 2020, Nikolic and Ritz, 2015, Dacombe *et al.*, 2016) and complicated site layouts which pushes up connection costs. But this cost of water is relative to low family incomes, illegal status of settlements, the transient nature of residents, and lack of political will, poor community participation, lack of competitive policies and strategies, and the susceptibility to corruption and politicization of service. Therefore, it is important to evaluate the performance of piped water distribution systems(pressure junction, water velocity and allocating demand at a junction at particular nodes of distribution should be sufficient(normal standards) (Izinyon and Anyata, 2011). Hence, adequate water distribution is one of the international goals for sustainable development (Lukubye and Andama, 2017, Anore, 2020). Thus over and below water pressure and water velocity has an improper or having deficient distribution throughout the networking system which gives low performance of the services. However, during operations of water supply systems, cases of pressure drops main challenge is the lack of a simple tool to accurately predict zones of low pressures and areas where quality is compromised(Sahilu and Chaka, 2017). Hence the study was evaluated the performance of existing water supply distribution networking system using water GEMS software for identification of efficiency of junction pressure and water velocity and flow rate in water piped.

The availability of drinking water has been one of the major global concerns in recent decades (Wannapop, Jearsiripongkul and Jiamjiroch, 2018) and particularly, developing countries face greater challenges of adequate water distribution because of their larger population growth rate, poor infrastructure, lower income levels, and less developed policy and institutional capacity(Anore, 2020). In the same way drinking water supply is challenging by increased population, climate changes and pre urbanization which causes an ever increasing demand on water supply system (Melese, 2020, Pandya, 2019,Toxicol, Imneisi and Aydin, 2016). Rising water demand as a result of population growth and urbanization has an effect on the availability and reliability of existing water distribution system. Therefore, water demands need to be assessed on the basis of considering the year and date supplying water through the distribution system. Several hydraulic modeling approaches have been proposed previously to simulate pressure deficient operating conditions in water distribution networks more realistically(Ologundudu, Odiyo and Ekosse, 2016). Thus way, water resources are limited and this requires better management of water resources and supply. The supply of water is not able to meet the demand due to several reasons like shortage of source water, high amount of leakage, poor maintenance of the system.

An urban water distribution pipe network consists of huge capacity of pumps, pipes, valves, reservoirs and tanks. It is a challenging task for the water supply board to operate the system to deliver drinking water of required quantity and quality. Consequently, water supply distribution systems in urban areas are often unable to meet existing community.

Water supply system is one of the infrastructures, where developing countries are working hard to expand. Still so many people both in rural and urban areas are suffering with the provision of adequate potable water supply and sanitation. The actual water supply coverage in towns of developing countries in general and African towns in particular is very low while compared to the demand (Desta and Befkadu, 2020). The shortage of water and frequent service interruption is not only as a consequence of the shortfall between demand and supply but also as result of unidentified leakage and complicated network systems. The existing situation of water supply system in Kolfe and other of the different developing countries, not meet the demand which is becoming the adverse effect on urban development and public health (Melese, 2020).

In many developing countries on one hand, the level of water supply coverage is very low as water demand is increasing while compared to the developed countries. In the most of developing countries; to meet water supply with increasing demand, water suppliers have relied heavily on supply management, focusing on expansion of systems which is problematic and costly as water becomes scarce(Wakuma and Fita, 2017). The system should be capable of meeting the demands placed on it at all times and at satisfactory hydraulic performance(Wannapop, Jearsiripongkul and Jiamjiroch, 2018). However, hydraulic performance is not investigated by the utility of Kolfe sub-city. Therefore, this is an attempt made to analyze and evaluate the hydraulic performance of the water supply distribution system while taking water loss into account. Consequently, water supply distribution systems in urban areas are often unable to meet existing community.

1.2. Statement of the problem

The main activities of performance evaluation for urban water supply system is to improve the water supply service level by identify the gap or to fill the gap between the demands and existing water supply system by analyzing whether the distribution system is working as per the design or not. Thus ways, the good performance distribution systems should provide safe, sufficient and affordable water supply service, with low water loss and good quality of water which fulfills national and international standards(Elsheikh, Kalthom and Zainab, 2017).One of the major challenges on reduction of the performance of towns' water supply system is the demand on water increases due to the growth of population and urbanization of the town.

In many Ethiopian urban areas, including Kolfe Keraneo sub city majority of householders total water consumption needs obtains from the town's water supply system either directly through private connections or through public taps, which pass through many temptations. Among this, due to the urbanization people are shifting to the newly developed urbanized area hence more number of people need piped water supply. The water distribution system should supply water with good quality, sufficient amount and with required pressure to fulfill system requirements to the consumer(Al-Mashagbah, 2015, Elsheikh, Kalthom and Zainab, 2017). However, the conditions of water distribution components get deteriorated with time that facilitate water losses, leakage, and improper water pressure and velocity distribution services. As a result of this, the problem such as leakage or variation in pipe roughness coefficient arises that may affect hydraulic parameter of the water distribution system. The system should be capable of meeting the demands placed on it at all times and at satisfactory hydraulic performance(Wannapop, Jearsiripongkul and Jiamjiroch, 2018). However, hydraulic performance is not investigated by the utility of Kolfe sub-city. Therefore, this study is an attempt made to analyze and evaluate the hydraulic performance of the water supply distribution system while considering water loss and consequently, water supply distribution systems in urban areas are often unable to meet existing community. This paper focused on evaluation of water distribution system behavior under leakage condition along with variation in pipe roughness coefficient and pipe diameter.

1.3. Objective

1.3.1. General objective

The general objective of the study was to evaluate the hydraulic performance of the existed water supply distribution network using water GEMS in Kale reservoir, Kolfe Keraneo Sub City.

1.3.2. Specific objective

The specific objectives of the study are;

i. to evaluate water supply deficit and predict water demand for the future,
ii. to evaluate the hydraulic performance of the existed system concerning pressure and velocity and
iii. to identify water losses in the distribution system

1.4. Research questions

In order to achieve the mentioned research objectives and to seek answers for the stated Problems, the following major research questions are formulated.

i) What is the present water supply deficit and future water demand of Kolfe Keraneo Sub city?
ii) What is the hydraulic performance of the water supply system concerning pressure and velocity?
iii) What are the main problems and water losses that exist on the distribution system?

1.5. Significance of the study

The study evaluated the situation of hydraulic performance of urban water supply distribution system for the study area. Based on findings factors that are negatively contributing for satisfaction level of the service was listed out and alternative system operation, maintenance and management should be recommended. In addition, hopefully, the insights that have drawn from this study that initiate further research on similar sites and will contribute to solving the existing problems of rural water distribution system. The research findings can strongly assist decision / policy makers in planning urban water supply and other development activities in a way to achieve the sustainability of urban water supply and the distribution system.

1.6. Scope and Limitations of the study

The primary goal of the study is to evaluate the performance of the existing distribution system of the City of Addis Ababa, Kolfe Keraneo, which is aimed to help the City of Addis Ababa understand its distribution system needs and assist them in long-term planning of water assets. Thus, the scope of this study is to evaluate the performance of the existing drinking water distribution system using water GEMs and recommend changes, if any, in the existing system.

The scope of this study is limited to the stated objectives above over the study area. This may provide an approximation of the overall position of the utility which may assist to make an overall conclusion on the performance of water loss and hydraulics in the utility. The detailed design of the proposed changes to the current distribution system and cost analysis is not within the scope of the project. The performance assessment of urban water supply includes a number of aspects such as technical, financial, social and institutional, however, this research did not cover all aspects because of financial and time scarcity. In this research only population projection is made it does not cover population prediction.

1.7. Organization of the Thesis

The thesis is organized in five chapters. Chapter One deals with introduction that covers the general background of the study area, the problem statement, objectives of the research, the research question, scope of the study, significance of the study, and organization of the study. Chapter Two deals with an overview of literature with regards to urban water supply distribution networks, method of population estimation, water demand and water total water analysis and model simulation for hydraulic parameters. Chapter Three covers materials and methods of the study, data collection, covers data analysis and study design. Chapter Four covers the result of the study and discussion of the study material. Chapter Five, it deals with conclusion and recommendations.

2. LITERATURE REVIEW

2.1. General of Urban Water Supply

Water is one of the necessities for human being and for all living things. It is used in many ways as example for dirking, bathing, flushing of sewers, firefighting etc. Without food we can survive for some days but can't survive without water. Provision of clean water supply is one of the major factors that greatly contribute to the socioeconomic, transformation of a country by improving the health thereby increasing the productivity of the society. But, however most of the developing countries like Ethiopia have still have very little coverage of potable water supply and sanitation that has resulted the citizens to be suffered with water born and water related diseases.

water supply distribution system is complex systems which have to fulfill the customer's needs for a domestic and non-domestic water demand services(Bhaskar *et al.*, 2017, Salunke *et al.*, 2018; Mehta and Joshi, 2019). These are meet public health and environmental constraints, considering the ever increasing needs for fresh water and other essential non-potable water. According to (Anisha *et al.*, 2016) water supply distribution system consists of several components such as pipes, pumps, reservoir tanks and hydraulic control elements that collectively supply the required quantities of water with adequate pressure from sources to all customers. Urban water supply coverage provides a representation of the water supply situation one specific region or town and helps to compare the standard of the town with others and the inter and interact town distribution within a specificity. One of the indicators to compare the coverage of water supply in urban areas are the percentage of the population with or without piped water connection (Genetie, Beyene and Befekadu, 2019).

2.2. Urban water supply in Ethiopia content

The World Bank Group (Institute, 2005) stated that though Ethiopia is often referred to as the "water tower" of Africa, only a quarter of the country's population has improved access to water sources. A number of factors are indicated for marginal urban water supply and distribution in different literatures (YitayhLeul, 2012). Assessing the current situation of urban water supply helps to know the supply and distribution networking system, and challenges against the distribution system and to set directions aimed at adequate water supply to the target urban community on sustainable basis. Accordingly, data on water supply and distribution status and accessibility, causes of water supply distribution interruptions and existing urban water supply and distribution in the town.

2.3. Source of water supply

Water source is the critical part of any water supply scheme and it's an important source of supply which can be capable of providing service for both the short term and long-term demands being expected (Temesgen Mekuriaw, 2018). Water for drinking purpose can be found from natural sources like surface water, ground water and rainwater that are used for various household purposes, like drinking, food preparation, hygiene related purposes, washing cloths and body, as well as for livestock drinking. Accordingly, the researcher suggestion there are mainly two of aspects on which the success of a water supply scheme depends (Temesgen Mekuriaw, 2018; Ethiopia, 2017). These aspects are amount of available water from the source and the amount of water actually needed by the town. Availability of water from a source which may be surface and ground ultimately depends upon rainfall. According to (Temesgen Mekuriaw, 2018), and (Minwuye, 2015) water sources fall in to three categories as the follow described.

2.4. Challenge of urban water supply in Ethiopia

Access to water supply is a fundamental human right (Organization, 2010). However, water supply and distribution is constrained by multiple factors related to socioeconomic (population growth, lack of technological capacity and financial problems) (Doe, 2015), institutional (lack of institutional capacity and weak sector coordination) (UNICEF, 2008) and environmental (topography of the area and insufficient water resource). Ethiopia has plenty of water resources but the available water is not distributed evenly across the country and the amount varies with seasons and years. The challenge in any situation is to maintain a year-round supply that is adequate to meet people's needs. To ensure that supply meets demand the source of the water must be carefully chosen, taking into account present and future demand for water, and the costs. The cost of water supplies is heavily influenced by the distance of reliable water sources from towns.

The challenge for many towns is finding nearby water sources planning for present and future demand has to consider population growth. The demand for water is increasing in cities and towns due to an ever-growing population and the migration of people from rural areas to towns in search of jobs and a better life. There are also increasing demands from industrial and commercial development. The quantity of water required for domestic use depends not only on the number of people but also on their habits and culture, and on how accessible the water is. As water supply systems improve and access increases, the consumption of water will also increase.

The performance of water supply facilities mainly depends on a timely and regular maintenance and operation of the system. However, in most developing countries, including Ethiopia, it has been found out that operation and maintenance of water supply facilities is in a poor state of condition and the sustainability of the scheme is at stake.

2.5. Components of water distribution network

Water distribution systems are one of the major infrastructure assets of the society, with new systems being continually developed reflecting the population growth, and existing systems being upgraded and extended due to raising water demands. Designing economically effective Water distribution systems is a complex task, which involves solving a large number of simultaneous nonlinear network equations, and at the same time, optimizing sizes, locations, and operational statuses of network components such as pipes, pumps, tanks and valves (Mays, 1999). Water distribution networks are very important lifeline infrastructure systems, where failures are inevitable. Typical water distribution networks consist of network of pipes, nodes linking the pipes, storage tanks, reservoirs, pumps, additional appurtenances like valves. This distribution system represents a major portion of the investment in urban infrastructure and a critical component of public works. The main goal is to design water distribution systems to deliver potable water over spatially extensive areas in required quantities and under satisfactory pressures. Therefore, hydraulic models for water distribution networks have become indispensable tools for understanding system behavior by simulating pressures and flows at different locations and times in the networks (ASSFAW, 2016; Bhatt, 2017). The purpose of water supply distribution network system is to deliver water to consumer with appropriate quality, quantity and pressure. Water distribution system is used to describe collectively the facilities used to supply water from its source to the point of usage.

2.6. Methods of water supply system

Water can be delivered to customer in continuous supply system or intermittent supply system (African Ministers' Council on Water, 2010). The continuous water supply system is the best system and water is supplied for 24 hours and 7 days in a week and in this system it's possible when there is adequate quantity of water for supply (African Ministers' Council on Water, 2010). This system of supply water is always available for firefighting and continuous due to circulation of water always remains fresh. The system uses fewer diameters of pipes and rusting of pipes will be less, but there will be more water losses if there are leakages in the system (Reforms, 2008).

In the intermittent water supply system adequate quantity of water is not available, the supply of water is dividing into zones and each zone is supply with water for fixed hours in a day or on alternate days (African Ministers' Council on Water, 2010). In this system, the high-elevated area, get adequate pressure by dividing the city in zones term by terms due to different factors like insufficiency of water quantity for supplying, lack of distribution power systems, poor operation and maintenance. For efficient distribution it is required that, the water should reach to every consumer with required rate of flow. Therefore, some pressure in pipe line is necessary, which should force the water to reach at every place. The methods of distribution system classified as gravity system, pumping system and combined system (Adeyemo A.M and Afolabi, 2005).

a. Gravity system

Gravity system water distribution is suitable when the ground elevation is sufficiently high above the city area is available, this can be best utilized for distribution system in maintaining pressure in water mains (Anon., 2004). This method is also much suitable when the source of supply such as lake, river or impounding reservoir is at sufficiently higher than city and water flows in the mains due to gravitational forces.

b. **Pumping system**

In the methods of pumping water distribution system, a constant pressure can be maintained in the system by direct pumping into mains (Ministry of Water Resource, 2016). Rate of flow cannot be varied easily according to demand unless numbers of pumps are operated in addition to stand by ones. Supply can be affected during power failure and breakdown of pumps. Hence diesel pumps also in addition to electrical pumps as stand by to be maintained. This method is suitable for distributing when the source water supply is from ground water or borehole and when surface elevation and ground elevation is flat.

c. Combined pumping and gravity system

This is also known as dual system whereas the pump is connected to the mains as well as elevated reservoir. In the beginning when demand is small the water is stored in the elevated reservoir, but when demand increases the rate of pumping, the flow in the distribution system comes from the both the pumping station as well as elevated reservoir. As in this system water comes from two sources one from reservoir and second from pumping station, is a dual system. This system is more reliable and economical, because it requires uniform rate of pumping but meets low as well as maximum demand. The water stored in the elevated reservoir meets the requirements of demand during breakdown of pumps and for firefighting.

2.7. Layout of distribution system

According to (A.G.Chaudhari, 2017), the water distribution networks can classify as explained below; there are mainly four types of systems adapted for the layout of pipelines to distribute water.

i) **Dead end or tree system**:

In this system a main starting from the reservoir is laid along the main road and sub mains are taken off from it along roads joining the main road. Branches and distributors are taken off from the sub main along streets and lanes joining the road service connections are made from these branches. This system is suitable for towns develops in irregular manner and has the advantages of cheap initial cost, simple design calculation and easy extension of the system when desired. The main disadvantages of this system are: the supply will be cut off if repair work is carried on the main or sub mains, there are dead ends which may contaminate the supply and it is difficult to meet the fire demand during repair (Authority, 2011; Eshetu, 2015).

ii) Grid-iron system:

This system is most convenient for towns having rectangular layout of roads. Actually, this system is an improvement over dead-end system. All the dead ends are interconnected with each other and water circulated freely throughout the system (Abebaw, 2015) (Desalegn, 2015). In this system mainline is laid along the main road. Sub-mains are taken in both directions along other minor roads and streets. From these sub-mains branches are taken out and are interconnected to each other and water circulates freely throughout the system. This system removes all the disadvantages of dead-end system (Frank, 2010). From the above systems Grid iron system is most suitable for towns that have a rectangular lag out of roads & for newly developed cities.

iii) **Circular or ring system**:

This system is adopted only in well planned locality of cities. In this system each locality is divided into square and the water main are laid around all the four sides of the square. All the sub-mains and branches are taken off from the boundary mains and are interconnected (Ilesenim, 2006). This system is the best of the other system but, it requires many valves and more pipe length. The ring system is most suitable for towns and cities having well planned road access.

iv) **Radial system**:

Actually, this is the reverse of ring system and water flows towards outer periphery from one point. The entire district is divided in to various zones and one reservoir is placed for each zone which is placed at the center of the zone (Damgir, 2017).

2.8. Challenges of water distribution network system

Water distribution network can be defined as its ability to deliver a required quantity of water under sufficient pressure and an acceptable level of quality during different normal and abnormal operational situations (Authority, 2011). A good distribution system should be a capable of supplying water at all intended place within the city with reasonably sufficient pressure head and the requisite amount of water for various types of demand (Liu, 2010).Therefore, water distribution system is a function of several things, including the size and shape of the opening, and the pressure at the opening (Minwuye, 2015). Typically, city water supplies are at 40 to 70m, (static pressure) (Frank, 2010). Older private systems are set to maintain water pressure between 20m and 40m, which is too low for some lifestyles; plumbers can set systems higher if the pump is capable of delivering higher pressure (Minster of Water Resource, 2006).The other challenges of water distribution system is water pressure drops due to corrosion (Management, 2000).This can be happened when the water pressure is poor in the distribution system, the most common cause is corroded galvanized steel piping. It is wise to replace with a larger diameter pipe on the main feeds at least to improve pressure. When galvanized steel pipe is present, and pressure is low, it is common for accessible pipes running across the basement ceiling to be replace first (Health, 2005).

Water pressure drops due to distance from the source and poor water pressure other causes of the sustainable distribution systems (Resource, 2009). The water supply distribution line from the street to the house may be undersized, damaged or leaking which result in the poor distribution system. Long runs of relatively small pipe within a house will result in considerable pressure drop and clogged pipe within the house will adversely affect pressure (Kebede, 2010).

2.9. Population projection and urban water demand analysis

Prior to design any water supply projects either for urban water supply or rural water supply population projection is mandatory in order to forecasting the future water demand of the town water supply.

2.9.1. Method of population projection

In order to determine the sustainable of the current water supply distribution networking system and the future prediction of water demands, population of the town in various periods has to be estimate. Hence, as population of the area increases in the future, the correct present and past population data have to be taken form census office to determine design population of the area. The average percentage of the last few decades (years) is determined and the forecasting has been done on the basis that percentage increase per decade is same (Alemayehu, 2010) . There are more than eight (8) methods of population forecasting. Among this method the study was select four methods of projection in order to minimum the error of estimation as describe considering the study area existing of population data indication. Those are arithmetic increase method, geometric increase method, incremental increase method and Ethiopian static authority methods are the most preferable used for population projection of Kolfe sub-city.

a) Arithmetic increase method

This method is based on the assumption that the population is increasing at constant rate, that is the rate of change of population with a time is constant. Generally, the method is applicable to large and old cities.

$$\frac{dp}{dt} = k \quad , \qquad \int_{po}^{pn} dp = K \int_{0}^{n} dt = Pn = Po + Kn$$

Pn=Po+Kn ………………………………………………………………………………...2.1

Where; Pn = population at n decade, k = arithmetic increase and

n = decade or year

b) Geometric increase method

The method is based on the assumption that the percentage increase in population remains constant. It also known as uniform increase method. The increase is compounded over the existing population. This method is mostly applicable for growing towns and cities having vast scope of expansion.

$P_1 = P_0 + K * P_0 = P\,(1 + K)$

Pn=Po (1+k) ^n……………………………………………………………..……...2.2

Where Po = initial population, Pn = Population at n decades or year,

n = decade or year and K = percentage or geometric increase

c) Incremental increase method

In this method the population in each successive future decade is first worked out by the arithmetical increase method and to these values the incremental average per decade is added. Since the method combines both arithmetic as well as geometric increase method, it improves the few results that are obtained by arithmetic increase method. Hence it gives satisfactory results.

Pn=$\boldsymbol{p + nI + (n(n+1)r)/2}$…………………………………………………………..2.3

Where Po = present population, Pn = population at n^{th} decade or year,

n = number of decades, I = average increase per decade And

r = average incremental increase

d) Method used by Ethiopian statistics authority

The Ethiopian statistic authority uses the formula $Pn = Poe^{kn}$ for most water supply project in the country to project population at the end of required decade or year.

Pn=Poe^kn……………………………....……………………………………….....2.4

Where Pn = population at n decades or year, P = initial population (from census),

K = growth rate and n = decade or year

2.9.2. Analysis of water demand

Water demand in water supply system is an accurate estimation of water demand helps to determine the quantities of water and moments when the water will be used for both the domestic water demand and non-domestic water demand as described below.

i) Domestic water demand projection

Domestic water demand is the quantity of water required in the houses for drinking, bathing, cooking, washing etc., which mainly depends upon the habits, social status, climatic conditions and customs of the people. This may vary between 80 l/c/d to 140 l/c/d for major Ethiopian cities (Alemayehu, 2010). Western industrialized countries extend this amount to as high as 350 l/c/d (G. Anisha, 2016). The total domestic water consumption shall be equal to the per capita demand multiplied by the total population at the end of the design period (A.G.Chaudhari, 2017). Usually this amounts to 50-60% of the total water consumption.

ii) Analysis of Domestic water demand by mode of services

Per capita demand of the town was projected by mode of services using Addis Ababa water supply and sewerage authority design criteria. The percentage of population to be served by each mode of service will vary with time. The variation is caused by changes in living standards, improvement of the service level, changes in building standards and capacity of the water supply service to expand (Resources, 2012-2016; Solomon, 2011; Ilesenim, 2006). Accordingly, the present and projected percentage of population served by each demand category is estimated by taking the above stated conditions and by assuming that the percentage for the house, tap and yard tap users will increase gradually during the project service as shown in below Table 2.1.

Table 2. 1: Projection % by mode of services (Ministry of water resources, 2006)

Mode of Service	2014	2015	2020	2025	2030	2035
House connections	0.57	0.57	2.93	6.49	9.12	10
Yard connections private	43.96	43.63	50.47	60.24	67.56	70
Yard connections shared	14.63	14.63	13.47	11.74	10.43	10
Public taps	40.84	40.84	33.13	21.57	12.89	10
Total	100	100	100	100	100	100

An average per capita consumption has been derived from the annual and monthly consumption of each woreda which aggregated from customers' water meters. Also distribution of domestic connection per family has been evaluated using number of connections and population of each woreda. In this, analysis was considered these expressions level of connection per family(G, A and N, 2016).

Level of connection per family = $\frac{\textit{No of connection of each kebeles}}{\textit{Population of each kebeles per mean faily size}}$…………… 2.5

Per Capita Demand: It's the total quantity of water required by various purposes for a town per year to the population (Mersha, 2007). In community, water is used for various purposes as described above. For the purpose of estimation of total requirement of water, the demand is calculated on the average basis, which is expressed in per capita demand (l /c /d) (WHO, 2010), mathematical,

Per Capital Demand = $\frac{Q}{P*365}$……………………………………………………….2.6

Where Q: is the total quantity of water required by a town per year in liter and

P: The population of the town

iii) Projection of per capita water demand by mode of services

Per capita demand of the town was projected by mode of services using Addis Ababa water supply and sewerage authority design criteria. The percentage of population to be served by each mode of service for Kolfe Keraneo sub city is shown in the table below as described in below Table 2.2 source (Ministry of Water Resource, 2016).

Table 2.2: Per capita water consumption by mode of services (Ministry of water resources, 2006)

Purpose	Mode of Service			
	HC	YCP	YCS	PT
Total (l/c/day)	50	30	25	20

iv) Non - Domestic water demand

Water demand is the volume of water requested by users to satisfy their needs. Design of water systems require estimation of expected water demands applicable to size the pumping equipment, transmission and distribution pipe lines and storage facilities (Suraj Kumar Bhagat, 2019; Bhatt, 2017; A.G.Chaudhari, 2017; Alemayehu, 2010). Estimating water demands for a particular town depends on the size of the population to be served, their standard of living and activities, the cost of water supplied, the availability of wastewater service and the purpose of demand (Taha, et al., 2019; Ministry of Water Resource, 2016; Report & Holeta urban planning office, 2009,2010). However, water demand can vary according to the requirement (domestic, institutional, industrial and residential) institution and that water demand can be described briefly as follows.

Residential Water Demand: Residential water demand includes the water required in residential buildings for drinking, cooking, bathing, lawn sprinkling, gardening, and sanitary purposes. In most countries, the residential demand constitutes 50 to 60% of the total demand (Belay, 2012; Berihun, 2017; Kebeto, 2016; Walski., 2003; Welday, 2005; Alemayehu, 2010).

Institution and Commercial Demand: Universities, Institution, commercial buildings and commercial centers including office buildings, ware houses, stores, hotels, shopping centers, health centers, schools, temple, cinema houses, and railway and bus stations comes under this category. Commercial use of water amounts to about 10 to 30% of total consumption (Temesgen Mekuriaw, 2018; ohammed Ali I. Al-Hashim, 2014; G.P, 2017; Shinstine, 2015; Belay, 2012).

Industrial Water Demand: The quantity of water demand for industrial purpose is around 20 to 25% of the total demand of the city (Neufville, 2000; Vidhi N. Mehta, 2019; Kahalekar, 2017).

Fire Fighting Demand: A volume equivalent 5-10 % of the maximum day demand is included in sizing the service reservoirs as stipulated in the design criteria. The fire demand reserve was assumed to include for other emergency needs. The quantity of water required for firefighting purpose is a function of population, but within minimum limit (Berihun, 2017). Because the greater the population, the greater will be the number of buildings and hence greater risk of fire.

The required amount of water for firefighting will not be more than the amount of water distributed during the maximum day water demand (Berihun, 2017). Thus, way the quantity of water needed to extinguish fire depends upon population, contents of Buildings, density of buildings and their resistance to life. Therefore, the water required for firefighting shall be meeting by stopping supply to consumer for required time and directly it for firefighting purposes.

Public water Demand: It is for parks, public buildings, and streets contribute to the total amount of water consumed per capita is about 5 to 10% of all water used is for public uses (Pieter, 2013; Delesho, 2004; Rahmato, 1999-2000; Ms. P. S. Salunke, 2018).

v) Variation of Water Demand

Average daily demand: - The average daily demand is typically computed using historical water usage. The average daily water demand is the sum of the domestic, non-domestic and unaccounted for water which is used to estimate the maximum day & the peak hour demand. The average day demand is used in economic calculations over the project's lifetime. For this analysis, the projected average Daily Demand was determined using the most current average per capital consumption of water (Anon., 2008) described as the following formula.

ADD= Popn * average per capita consumption of water…….…………………………...2.7

Where $\text{ADD} = \text{average daily demand}, \text{popn} = \text{design population}$

Maximum daily demand: it's the highest demand of any one 24-hour period over any specified year and its represents the changes in demand with season and some special events happening in any specified year (Amdework, 2012) .This is the amount of water required to meet water consumption change with seasons and days of the week.

The maximum day demand is obtained by multiplying the average day demand with the maximum day peak as described in below Table 2.2.

Peak hour demand: It's the highest demand of any one-hour over the maximum day which represents the diurnal variations in water demand resulting from the behavioral patterns of the local population. This occurs when particularly all the water taps are opened at particular rush hour. The rush hours are in morning between 6-8 A.M and 4-6 P.M in the afternoon and peak hour demand factor is 1.6 (Ministry of water resources, 2006). In order to sufficiently supply the required volume of water during these particular hours the distribution lines are designed to convey the water demanded by the beneficiaries with adequate allow. The peak hour demand is obtained by multiplying the maximum day demand with the peak our factor.

Table 2.3: recommended water demand peak factors (Bank, 2003)

Population size	**Maximum day factor**	**Peak hour factor**
<2,000	1.3-1.5	2.6
2,000-10,000		2.4-2.2
10,000-50,000		2.2-1.8
50,000-80,000	1.2	1.8-1.7
>80,000		<1.7

vi) Water Demand Adjustment multiplicity factor

a) Adjustment for climate

The climatic condition of project area has an impact for the quantities of water consumption. Those who are living in hot area consume extra water and people who live in normal temperature area consume less water. In order to account for changes of average per capita domestic demand, the water demand is multiplied by climatic factor.

Table 2.4: climatic factor (Design Guideline for WSP, 2008)

Group	Altitude	Factor
A	>3300	0.8
B	2300-3300	0.9
C	1500-2300	1.0
D	500-1500	1.3
E	<500	1.5

b) Socio-Economic Adjustment Factor

Socio-economic activities have a role in determining the degree of development of the town under study which in turn determines water consumption.

Table 2.5: Socio-economic Adjustment Factors (Towns, 2006)

Group	Description	Factor
A	Towns enjoying high living standards and with high potential for development	1.10
B	Towns having a very high potential for development, but lower living standards at present	1.05
C	Towns under normal Ethiopian conditions	1.00
D	Advanced rural towns	0.90

2.10. Hydraulic Performance of water supply system

The purpose of water distribution systems was to convey water of appropriate quality to individual users in a sufficient amount and at an acceptable pressure. It should be capable of delivering the maximum instantaneous design flow at a satisfactory pressure. The water distribution networks should meet demands for drinkable water. If designed correctly, the network of interconnected pipes, storage tanks, pumps, and regulating valves provides sufficient pressures, adequate supply, and good water quality throughout the system. If incorrectly designed, some areas may have low pressures, poor fire protection, and even health risks(Pandya, 2019).

The water distribution network, which is typically the most expensive component of a water supply system, which was continuously subject to environmental and operational, stresses which lead to its deterioration. Increased operation and maintenance costs, water losses, reduction in the quality of service and reduction in the quality of water are typical outcomes of this deterioration(Pandya, 2019, Jalal, Science and Engineering, 2008). This study used to evaluate the Kolfe sub-city distribution system was, first to establish the existing and projected hydraulic requirements of the system, and secondly to evaluate the adequacy and limitations of the system under the existing and projected demand conditions finally to optimize the resources without changing the existing structure. The system was evaluated against a number of key operating and engineering principles and industry standards. These include: system pressure, the velocity of water in the pipelines, head loss pipe looping, and several stress conditions were simulated in order to evaluate the adequacy of the system under existing and projected demand conditions. Stress conditions used for this analysis include: Minimum pressures at peak hour demand: sufficient to serve the highest supply point in the network. Typically a mains pressure of not less than 15 to 20 m would be required to serve buildings up to three stories high. Higher pressures may be necessary for some areas where there are significant numbers of dwellings exceeding three-story height; but high rise buildings are normally required to have their own boosted supply.

Maximum day in the year 2025 Plus Fire Flow Requirements under maximum-day plus fire flow demand conditions, a system must be capable of providing the needed fire flow during maximum day demands, while maintaining a minimum residual pressure of 15m coincidental throughout the distribution system. Each of these conditions was evaluated under varying demands, and where the system does not meet the criteria set forth, alternative improvements will be modeled and recommendations are made based on the hydraulic effectiveness.

2.11. Flow hydraulics and network analysis

The flow hydraulics covers the basic principles of flow such as continuity equation, equations of motion, and Bernoulli's equation for close conduit. Another important area of pipe flow was to understand and calculate resistance losses and minor losses due to pipe fitting (i.e., bends, elbows, valves, enlargers, and reducers), which has to be essential parts of a pipe network. Suitable equations for form-losses calculations were required for total head loss computation as fitting can contribute significant head loss to the system(Ganjidoost, 2016).

The known parameters in a system are the pipe sizes and the nodal withdrawals. The system has to be analyzed to obtain input point discharges, pipe discharges, and nodal pressure heads. In the case of a branched system, starting from a dead-end node and successively applying the node flow continuity relationship, all pipe discharges can be easily estimated. Once the pipe discharges are known, the nodal pressure heads can be calculated by applying the pipe head-loss relationship starting from an input source node with known input head.

In a looped network, the pipe discharges were derived using loop head-loss relationship for known pipe sizes and nodal continuity equations for known nodal withdrawals.(Chaudhari *et al.*, 2017, Damgir and Patil, 2017, Ganjidoost, 2016) , briefly describes that the water distribution network analysis over 100 years and also included the chronology of pipe network analysis methods. A number of methods have been used to compute the flow in pipe networks ranging from graphical methods to the use of physical analogies and finally the use of mathematical/numerical methods.

Darcy Welsbach and Hazen Williams: - Provided the equations for the head loss computation through pipes (Liou, 1998). Brown (2002) examined the historical development of the Darcy Welsbach equation for pipe flow resistance and stated that the most notable advance in the application of this equation was the publication of an explicit equation for friction factor by(Damgir and Patil, 2017). Based on the application of an analysis method for water distribution system analysis, the information about pipes forming primary loops can be an essential part of the data.

The pipe flow patterns will vary. Hence, combining flow paths, the flow pattern map of a water distribution network can also be generated, which were important information from operator/manager of a water system for its efficient operation and maintenance. The analysis of a network was also important to make decisions about the network augmentation requirements due to increasing in water demand or expansion of a water servicing area. The understanding of pipe network flow and pressures was important for making such decisions for a water supply system (Pandya, 2019). Generally, the water service connections (withdrawals) were made at a random spacing from a pipeline of a water supply network. Such a network was difficult to analyze until simplified assumptions were made regarding the withdrawal spacing. The current practice was to lump the withdrawals at the nodal points; however, a distributed approach for withdrawals can also be considered. A methodology was required to calculate flow and head losses in the pipeline due to lumped and distributed withdrawals.

2.12. Hydraulic design parameters

The main hydraulic parameters in water distribution networks were the pressure and the flow rate, other relevant design factors were the pipe diameters, velocities, and the hydraulic gradients. The pressure at nodes depends on the adopted minimum and maximum pressures within the network, topographic circumstances, and the size of the network(Capt *et al.,* 2021) .The minimum pressure should be maintained to avoid water column separation and to ensure that consumer’s demands are provided at all times. The maximum pressure constraints result from service performance requirements such fire needs or the pressure bearing capacity of the pipes, also limit the leakage in the distribution system, especially that there was a direct relationship between the high pressure and the increasing of leakage value in the system (Ganjidoost, 2016).

The flow rate was water passes within a certain time through a certain section. Velocity was directly proportional to the flow rate. For a known pipe diameter and a known velocity, the flow rate through a section can be estimated. Low velocities affect the proper supply and will be undesirable for hygienic reasons (sediment formation may cause due to a long time of retention).

The building code requires that sanitary fixtures and appliances have an adequate water supply at an adequate flow rate. As with water pressure, flow rates are crucial. A flow rate that is too high will result in water being wasted, whereas a flow rate that is too low mean that sanitary fixtures and appliances don't work properly. Design and Layout of water distribution networks in building code compliance document G12/ASI set out acceptable minimum flow rates in pipes at 0.6l/s while the velocity must not exceed 2.5/3l/s (Design and Enterprise, 2019).

Water GEMS Vi8 was used to investigate the current flow and velocity situations in the pipes under the current demand conditions over the study area. The effect of the velocity on the diameters of pipe system can be observed from the following equation:

$V = 4Q/(\pi D^2)$ ………………………………….………..…………………………..….2.8

$D = \sqrt{4Q/\pi v}$ ……………………………………………….……………..……..…...2.9

Where D: diameter of the pipe (m), Q: discharge (m3/sec), V: velocity (m/sec). From the above equation, it is clear that the velocity increasing should decrease the diameter value.

2.13. Water distribution network sizing

The selection of the design period of a water supply system, projection of water demand, per capita rate of water consumption, design peak factors, minimum prescribed pressure head in distribution system, maximum allowable pressure head, minimum and maximum pipe sizes, and reliability considerations were some of the important parameters required to be selected before designing any water system.

The minimum design nodal pressures are prescribed to discharge design flows on to the properties. Generally, it was based on population served, types of dwellings in the area, and firefighting requirements. The information can be found in local design guidelines the minimum pressure in distribution system was 15m while the maximum was 100m World Bank Water Supply guideline (2006) and 3m to 70m according to water supply design manual. As it was not economic to maintain high pressure in the whole system just to provide the need of few high-rise buildings in the area, the provision of booster pumps was specified. Moreover, water leakage losses increase with the increase in system pressure in a water distribution system.

The minimum size of pipes in a water distribution system was specified to ensure acceptable flow rates and terminal pressures. It works as a factor of safety against assumed population load on a pipe link and also provides an assurance to basic firefighting capability. The minimum pipe sizes were normally specified based on total population of a town. Generally, a minimum size pipe of 100mm for residential areas and 150mm for commercial/industrial areas was specified. Local design guidelines should be referred to for minimum size specifications. The maximum size of a distribution main depends upon the commercially available pipe sizes for different pipe material, which can be obtained from local manufacturers. The mains are duplicated where the design diameters are larger than the commercially available sizes.

The main hydraulic parameters in water distribution networks are the pressure and the flow rate, other relevant design factors are the pipe diameters, velocities, and the hydraulic gradients.

i) Pressure

The pressure at nodes depends on the adopted minimum and maximum pressures within the network, topographic circumstances, and the size of the network. The minimum pressure should be maintained to avoid water column separation and to ensure that consumers' demands are provided at all times. The maximum pressure constraints results from service performance requirements such fire needs or the pressure bearing capacity of the pipes, also limit the leakage in the distribution system, especially that there is a direct relationship between the high pressure and the increasing of leakage value in the system.

ii) Flow rate

It is the quantity of water passes within a certain time through a certain section. Velocity is directly proportional to the flow rate. For a known pipe diameter and a known velocity, the flow rate through a section can be estimated. Low velocities affect the proper supply and will be undesirable for hygienic reasons (sediment formation may cause due to the longtime of retention).

2.14. Water distribution simulation

Simulation refers to the process of imitating the behavior of one system through the functions another. In our case, the term simulation refers to the process of using a mathematical representation or real system, called a model. Simulation can be used to predict system responses to under a wide range of conditions without disrupting the actual system, and solutions can be evaluated before time, money, and materials are invested in a real-world project. There are two most basic types of simulations that a model may perform, depending on what the modeler is trying to observe or predict. These are steady state simulation and extended period simulation (EPS).

i) Steady State Simulation

It computes the state of the system (flows, pressures, pump operating attributes, valve position, and so on) assuming that hydraulic demands and boundary conditions do not change with respect to time. A steady-state simulation provides information regarding the equilibrium flows, pressures, and other variables defining the state of the network for a unique set of hydraulic demands and boundary conditions. Steady-state models are generally used to analyze specific worst-case conditions such as peak demand times, fire protection usage, and system component failures in which the effects of time are not particularly significant.

ii) Extended Period Simulation

Extended period simulation tracks a system over time, and it is a serious of linked steady state run. The need to run extended period simulation is because the system operations change over time. Demands vary over the course of the day, Pumps and wells go on and off, Valves open and close and Tanks fill and draw.

Simulation Duration: An extended-period simulation can be run for any length of time, depending on the purpose of the analysis. The most common simulation duration is typically a multiple of 24 hours, because the most recognizable pattern for demands and operations is a daily one.

Hydraulic Time Step**:** An important decision when running an extended-period simulation is the selection of the hydraulic time step. The time step is the length of time for one steady state portion of an EPS, and it should be selected such that changes in system hydraulics from one increment to the next are gradual. A time step, too large may cause abrupt hydraulic changes to occur, making it difficult for the model to give good results. Using an EPS model we can simulate based on the peak, minimum and average day demands.

2.15. Hydraulic model: water GEMSv8i

A computer model is composed of two parts a database and a computer program. The database contains information that describes the infrastructure, demands, and operational characteristics of the system. The computer program solves a set of energy, continuity, transport, or optimization equations to solve for pressure flows, tank levels, valve position, pump status, water age or water chemical concentrations. The computer program also aids in creating and maintaining the database and presents model results in graphical and tabular forms. In networks of interconnected hydraulic elements, every element is influenced by each of its neighbors; the entire system is interrelated in such a way that the condition of one element must be consistent with the condition of all other element (Walski et al., 2003). According to Swamee and Sharma (2008) interconnections of hydraulic elements are defined in concepts of conservation of mass and energy. Thus, way hydraulic performance in the distribution network is defined by water flow and pressure in the water distribution system and take sensitivity analysis is performed to analyses how the water distribution system model under different network configurations using water gems v8i. The software helps improve your knowledge of how infrastructure behaves as a system, how it reacts to operational strategies, and how it should grow as population and demands increase (Rossman, 2000), whereas water distribution system is a pipe network which delivers water from single or multiple supply sources to consumers. The demand usually reaches a peak in the morning when people are at home and preparing their meal and its second peak in the evening maximum water use and minimum water use, usually related to average water use by multiplication of peaking factors (Maina, 2015). Additionally, the size and complexity of water distribution systems vary dramatically; they all have the same basic purpose to deliver water from the source to the customer. For efficient distribution it is required that the water should reach to every consumer with required rate of flow. The other challenging goals for the water supply systems are: reliable delivery of water even in case of emergencies like pipe failures, power outages, efficient and economic operation of the system, and, meeting water quality standards.

2.16. Water losses in distribution system

Water losses in an urban water supply can exist in each component of water distribution networks due to varies factors. This water loss may occur along main path, from source to treatment plant, from plants to reservoir and from reservoir to the junction within reticulation system, within treatment plant, within the distribution system and within consumer's premises.

Water loss is the difference between the system input volumes and authorized consumption volumes, or system input volume equals to the sum of authorized consumption volume and water loss volume (Eshetu, 2015; Berihun, 2017). The volume of water lost between the point of supply and the customer meter due to various reasons (Mutikanga, 2012; Melaku, 2015; Oljira, 2015). It can be express as the difference between system inputs volume, and authorized consumption, and consists of apparent and real losses.

Apparent losses can be sub divided into unauthorized consumption, meter inaccuracies and data handling errors. Real losses are made up of leakage from transmission and distribution pipes, leakage from service connections and losses from storage tanks (Zewdu, 2014). Water losses occur in every water distribution network in the world. For economic and technical reasons, it has to be accepted that real water losses cannot be eliminated. Nevertheless, there has been a large increase in the knowledge and development of state of the art equipment, allowing us to manage water losses with in economic limits; (Stevens, 2004; Cunlifffe, 2014). According to (Welday, 2005); quantifying and characterizing water loss and leakage in a city water supply is by its nature a complex task. Beside this Leakage identification needs detailed field investigation sometimes using sophisticated equipment. The annual water loss in the town water supply distribution system was evaluated using top- down water balance method. Performance indicator assessment Non- Revenue Water: as % of system input volume Percentage by volume was crucial as a basic financial PI for non-revenue water but a basic PI for real loss from a water resources point of view, it should not be used for assessing any aspect of operational performance management of water losses (Liemberger & Farley, 2004). It was given by:

NRW (%) = (Qin –Qreverence)/Qin * 100 ………………………...………………2.10

Where; Qin = annual system input volume, Q revenue = annual billed volume Non-Revenue Water: as % of the cost of the running system. The analysis of the financial PI for non- revenue water was based on the percentage of the value of the water, rather than the percentage by volume (Salazar, 2004) and generally expressed by:

NRW (%) = (Cost of Non –QReverence water)/ (Cost of operation system)*100…..2.11

The infrastructure leakage index: is the ratio of the current annual real losses to the unavoidable (technical minimum) annual real losses

a) Causes of water losses in distribution system

Leakage is usually the major component of water loss in developed countries, but this is not always the case in developing or partially developed countries, where illegal connections, meter error, or an accounting error are often more significant. The other components of total water loss are non-physical losses, e.g., meter under registration, illegal connections and illegal and unknown use. Unaccounted for water represents the difference between "net production" (the volume of water delivered into a network) and “consumption” (the volume of water that can be accounted for by legitimate consumption, whether metered or not (Abebaw, 2015; Belay, 2012).

b) Controlling and monitoring water loss and leakage

According to (Welday, 2005); in order to control water loss methods like leak detection in the field and repair, rehabilitation and replacement program, corrosion control, pressure reduction and public education program legal provisions such as, water pricing policies encouraging conservation, human resources development and information system development also need to be employed. The losses and leakage of water are inevitable in the process of water distribution network as well as starting from the reservoirs at the treatment plant, through a complex network to the individual customers. According to Mulwafu .et al., 2003; suggest that leakage monitoring and control in pipe reticulation systems is critical in ensuring the efficiency performance of the system. Pipe systems are commonly used for distributing water to areas of consumption. If pipes are worn-out, large volumes of treated water may be lost through leakage as a result of high pressure of flow. Leakage control is possibly one of the most difficult tasks for water engineers. Even in developed countries, about 15-20% of the distributed water is lost through pipe leakage. It is therefore important to ensure that leakage monitoring and control given the attention it deserves by all water supply authorities and consumers.

3. MATERIALS AND METHODS

3.1. The Study Area

3.1.1. Location

The study area is located in the Kolfe Keraneo Sub city which is located in the western edge of, Addis Ababa. The Sub city is one of the semi-peripheral parts of the city recognized for its informal business activities. According to the former administrative structure of Addis Ababa; the Kolfe area encompasses Kebele 9, 10 and 11 from district 24 and Kebele 3, 4, 5, 6, 7 and 8 from district 25. Recently Kebeles changes to woredas and the Sub city holds 15 (fifteen) Woredas.

3.1.2. Topography

The district is located in the western sub urban of the city, near the Gefersa Reservoir and hence, its borders with the districts of Gullele, Addis Ketema, Lideta, Nifas Silk-Lafto and with Oromiya special zone of Burayu. Geographically, the Kolfe area covers locations stretching from the Dutch Embassy to the General Wingate High School area. The general Wingate area in the north, the Mesalemiya area in the east and the Torr-Hayloch area in the south border Kolfe, in generally this sub-city of Administration has about 61.25 Km^2 of area. Addis Ababa at the moment covers 540 square kilometer land area and it lies between 8°55” north and 9° 05” north latitude and 38° 40” east and 38° 50” east longitude and Topography of Kolfe sub-city varies from ground elevations of 2300 masl to 2500masl (AAWSA and AAU, 2003) as indicates in Figure 3.1.

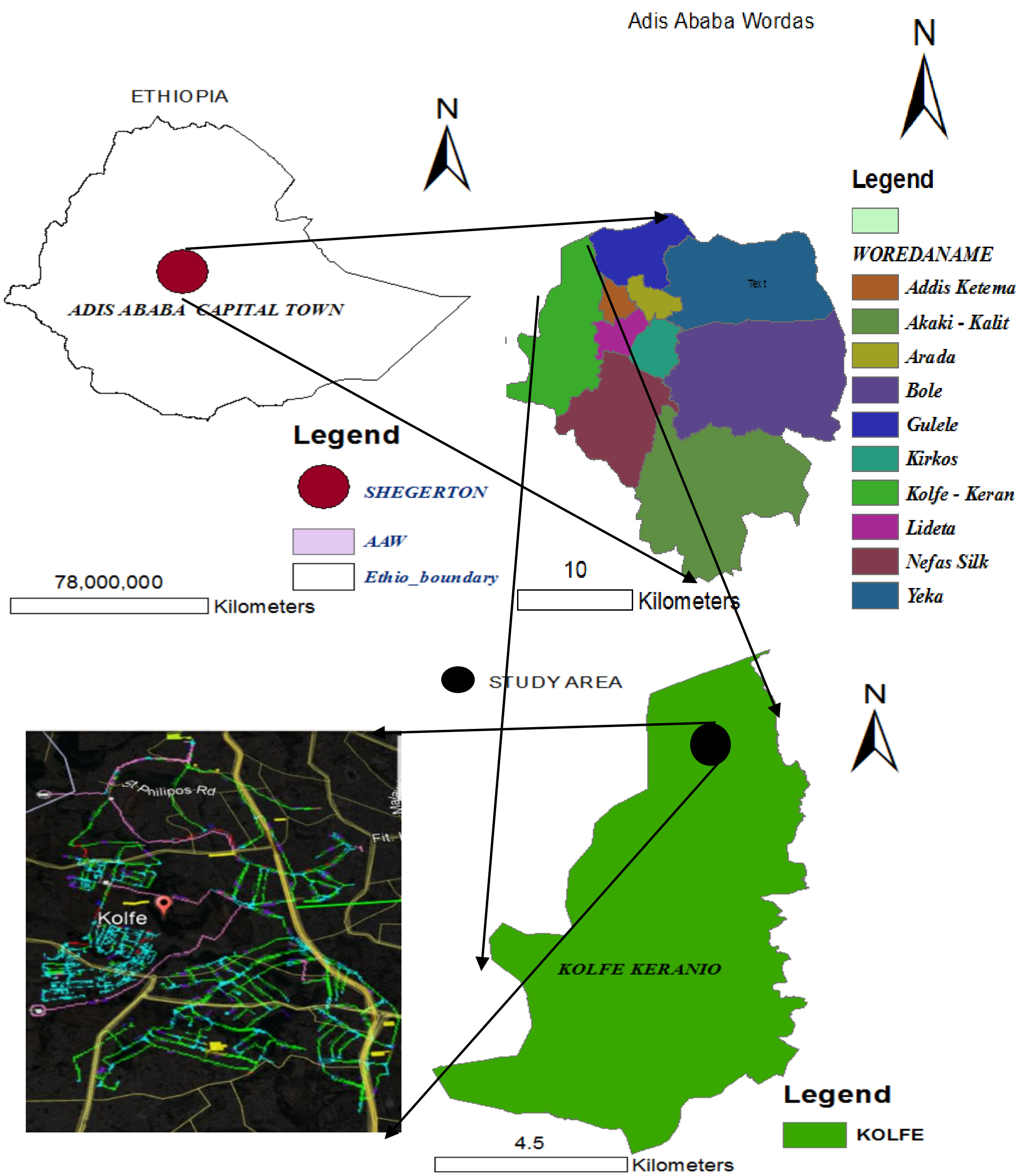

Figure 3 1: The location map

3.1.3. Climate and effects of seasonality

Like many parts of the country, Kolfe enjoys all the four seasons (summer, winter, spring and autumn) of the year. With the exception of the summer season, which is rainy and lasts from mid-June until mid-September, the other seasons do not have a direct negative impact on livelihoods. During summer, the area is cold and there is much rainfall. This often causes flooding and destroys the shanty houses and some squatter settlements constructed along the edges of the small streets. In any given year, a number of houses are partially or fully destroyed by rainfall, forcing households to vacate their poorly constructed houses.

The rainy season is particularly bad for destitute social groups such as the street children, spring and elderly people as the rainfall impedes their mobility in the neighborhoods and threatens their daily lives. Similarly, petty traders and local food peddlers are forced to interrupt their daily business under the open-air market. During the rest of the year, sales and exchange activities are considered safer and smooth.

3.2. Materials and tool used for the study

In order to react the specific objectives of the study, researcher was used to different tools and software's in additional same instrument like scientific calculator, pressure gage meters to measures water pressure in the distribution network, and GPS Garmin72 tool which was used to collect the required elevation data, northing and easting of junction, tank, pump and air release valve. The other tools used since they were like Water Gems v8i software to determine velocity and nodal pressure, hydraulic grade lines, Arc GIS for delineation of the study area, excel package SPSS V20, and Auto CAD were used.

3.3 Research analysis / Study design

Water supply status of the town was first evaluated before analyzing the water loss. In this the focus was on; the level of connection and the volume of water consumption as these are highly related to the issue of water loss. After evaluating water supply coverage, the total water loss was analyzed for the area that covers Kale reservoir. Then, water demand for present and future was estimated, lastly, performance of water distribution network and status of pressure was evaluated, then simple distribution network was modeled. The working methodology and tool used in this study are as followed.

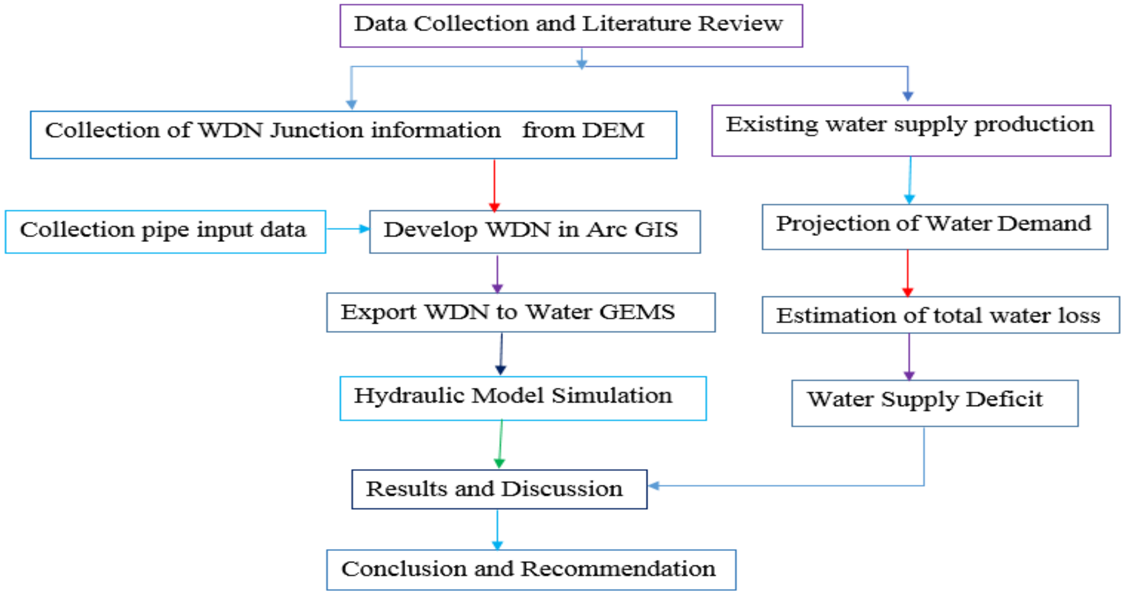

Figure 3 2: Research process flow diagram

3.4. Data source and data collection

Both primary and secondary data were used to process the study in the realistic situation and techniques to get the required information.

a) Primary data collection

Primary data were collected from customers through household survey, face-to-face interview with local administrative and field observations. The data was collected on field surveying, at the pressure junction in the water distribution network of pipes at coordinates (x, y) and water pressures at each junction from starting node to stop node of pipe connectivity survey. From pressure junction and its coordinate system were collects for 10 nodes as a sample for validation the study result (J-89, J-192, J-11, J-134, J-105, J-110, J-54, J-176, J-208, and J-226) measured near the corresponding location using pressure gauge. During this collection of data pressure gage meter and GPS Garmin 72 tools used were which to use in locating the latitude and longitude of the selected main node of the system.

b) Secondary data collection

Secondary data were collected from reviewing of documents from archives of Kolfe sub-city water supply and sewerage enterprise, journals, internet, literature review of any documents, article, and report. The secondary data which was collected were the water supply and pumping data, daily and monthly water production and consumption data, water supply network data. The data can be included, pipe length, size of pipe, elevation of each node, unit demand of each node and number of users at each mode of service (house, tap, yard and shared connection users).

The existing available data as described have been gathered from different concerned organization, mainly from Addis Ketema water supply and sewerage office the gathered data were water production, water consumption and water supply distribution network drawing, bill out rate. Each of this data collection contains numerous elements, for instance water supply distribution data (elevation of the distribution system, map of water distribution network, water distribution network layout, pipe data like material type, size and length, tanks and valves in the network). From last population and housing census report (CSA, 2007), the growth rates and population for Kolfe sub-city has been collected in order to forecast the future population.

3.5. Estimation existing water supply

The source of water supply was collected from Gefersa water treatment plant to Kale reservoir which store 500 cubic meters and one deep borehole then distributed to woreda 13 and 14 fully and to woreda 15 partially namely Tero, Mikiland and Asko respectively as shown in Figure 3.2 in this distribution layout systems. The total existing of water supply for Kolfe Keraneo sub-city from two sources of water was for about 213 l/s totally collects per day (BCP, 2015).

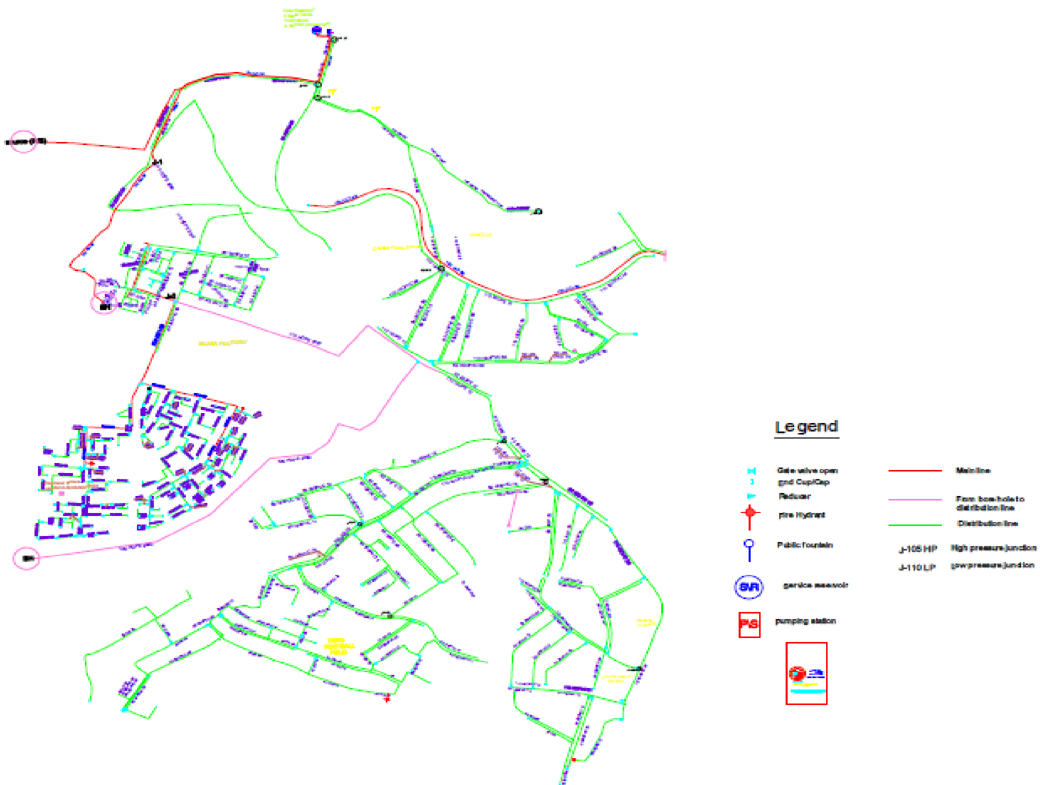

Figure 3 3: Existing water distribution networks

3.6. Population Projection

According to the records of the sub-city, the total population of Kolfe Keraneo sub-city was estimated at 546,219, Male: 220,859; Female: 235,360 in 2013. Population projection provides information on the future size, configuration of the study area and hence, this information is a fundamental for development plans where target is to satisfy the future need of population in the area of water demand. Therefore, as discussed under 2.9.1 point were different populations forecasting methods available as described in the literature of equation numbers (#2.1, #2.2, #2.3 and #2.4) which are used for population projection. But their result varies from one method to another, so its preference appropriate for particular sub-city needs to consider overall current situations of the targeted town having the minimum error calculation among each method. Hence by considering the standard level of sub-city, in addition to the existing census results the population projection methods for the current status were done as in Table 3.1 with considering minimum error among preferable. This population projection can also be determined by population growth rate and this growth rate was different from time to time and hence the Central Statistics Agency of Ethiopia calculated this population growth rate from 2008 to 2035 as justified in Table 3.1.

Table 3.1: Population growth rate (Central Statistics Agency of Ethiopia, 2014)

Year	2008	2010	2015	2020	2025	2030	2035
Growth rate	4.6	4.6	4.4	4.2	4.0	3.8	3.6

Table 3. 2: Methods population projection

Year	n	Arithmetic	Geometric	ECSA	Calculating error in each method
		$P_n = P_o + kn$	$P_n = P_o(1+k)^n$	$P_n = P_o e^{kn}$	$\frac{\text{Actual popn} - \text{proj.popn}}{\text{Actual population}} x100$
2046	25				

Accordingly, the growth rate and equation (Table 3.2) forecasting for the future projection of coming design period of, 25 surveillance the designed population using the Central Statically Agency of Ethiopia is for about 546,219 populations can service from the existing sources.

3.7. Estimation of present and future water demand deficit

The design and execution of any water supply scheme requires an estimate of the total amount of water required by community and designing the water supply scheme for any area is necessary to determine the total quantity of water required for various purposes. The water demand of Kolfe sub-city has the following categories: Domestic demand, small scale industrial demand and institutional and commercial demand. The water demand for actual household activity is known as domestic water demand and this demand may depend on many factors, the most important of which are economic, social and climatic factors. The water demand projection was calculated for domestic water demand, per capita domestic water demand, non-domestic water demand, and institutional water demand, commercial water demand, Industrial water demand, commercial water demand, average daily water demand (total sum of domestic, non-domestic, unaccounted for water demand), and maximum daily water demand. As justified under section 2.9.2 the estimation of maximum daily demand and peak hourly demands, depends on the design population projection as they listed in the literature ranging from 1.2 to 1.3 values. For both cause the research used to 1.2 and 1.7 for obtaining the daily maximum and peak hourly water demand for the study area. The annual consumption data was converted to average daily per capital consumption using the number of populations.

a) Projection of per capita water demand by mode of services

Per capita demand of the town was projected by mode of services using Addis Ababa water supply and sewerage authority design criteria. The percentage of population to be served by each mode of service for Kolfe sub-city is as per described under 2.9.2.section. Based up on this mode of service (domestic water demand) determination techniques the rest of other non- domestic water demand depends on and calculated from this domestic water demand by percentages. Accordingly, estimated domestic water demand is 10% for institutional and commercial demand, 10% for industrial water demand and 5% for firefighting water demand were added to get the average daily water demand.

b) Analysis of domestic water supply coverage

The water supply coverage of the city has been evaluated based on the average per capita consumption and level of connection per family. Beside to the average per capita water consumption, the distribution number of domestic's connection per family has been also evaluated based on mode of services for Kolfe sub-city as indicated in Table 3.3.

Table 3.3: Projection by mode of services (Ministry of water resources, 2006)

Mode of Service	2014	2015	2020	2025	2030	2035
House connections	0.57	0.57	2.93	6.49	9.12	10
Yard connections private	43.96	43.63	50.47	60.24	67.56	70
Yard connections shared	14.63	14.63	13.47	11.74	10.43	10
Public taps	40.84	40.84	33.13	21.57	12.89	10
Total	100	100	100	100	100	100

c) Analysis of non-domestic water supply coverage

Based up on the above population mode of service (domestic water demand) determination techniques the rest of other non- domestic water demand depends on and calculated from this domestic water demand by percentages. Thus, way as per 2.9.2 sections from estimated domestic water demand is 10% for institutional and commercial demand, 10% for industrial water demand and 5% for firefighting water demand were added to get the average daily water demand.

3.8. Analysis distribution network

Water GEMS V8i software were used for the purpose of understanding pressure regime, demand, velocity, head loss and overall, systematically studying and better understand network operation. Hydraulic performance analysis was carried out for both steady state and extended period simulation by using Water GEMS. In addition to this software Arc GIS 10.1 were used to locate the map of the town water sources, reservoirs and boost stations is produced by taking GPS readings of the existing water sources, reservoirs and pumping stations. The analysis is beginning by feeding the diameter of distribution pipes in to software and the pressure, velocity and head loss are in the distribution system. By using the land use map, the area that was supplied for each node is marked, measured, and tabulated under each category. The total water demand for each category is computed and the demand area ratio for each category is computed assuming the population distribution is uniform.

a) Pressure in the Distribution

Main Gravity supply from the service reservoir at lowest water level condition. As a rule, a minimum pressure gauge head of 15m is considered as adequate during Peak Hour Demands. However, in exceptional cases, depending on the topography of the area, lower pressure levels may be permitted, but not less than 10 m. A maximum of 80m manometer head, to avoid risking leaks and bursts in the distribution system, particularly during minimum flow conditions and when the static pressure would be dominant. Pipe pressure classes are chosen for the maximum pressure head that may occur under no or minimum consumption condition which is set at nil or 10 percent of the average day demand and the service reservoir at maximum water level. The operating pressures in the distribution network shall be as follows:

Table 3.4: recommended operating pressure in the distribution network

Condition	Normal condition	Exceptional condition
Minimum	15m water head	10m water head
Maximum	60m water head	70m water head

b) Velocity and Head loss

According to MoWR Urban Water Supply Design Criterion Water velocities shall be maintained at less than 2 m/sec, except in short sections & for pumps. Velocities in small diameter pipes (<DN100) may need even lower limiting velocities. A minimum velocity of 0.3 m/sec can be taken, but for looped systems there are also pipelines with sections having velocity <0.1m/sec.

Head loss is related to velocity and pipe roughness hence, the maximum head loss with therefore be governed by the maximum velocity criterion. Experience shows that a pipe designed to flow at a velocity between 0.6 and 2 m/sec, depending on diameter, is usually at optimum condition (head loss versus cost). The shortest sections, particularly at special cases, at inlet and outlet of pumps, may be designed for higher velocities. Minimum static head is 20 m, which can supply a 4-storey building from the distribution system. Maximum static head within a pressure zone was limited to 80 m. Minimum dynamic head was established at 10 m at maximum velocities of major transmission mains < 2.5 m/s. Maximum velocities of distribution mains < 2 m/s at the minimum velocities range 0.1-0.3 m/s within the system.

3.9. Hydraulic Model: Water GEMS

To assess the hydraulic performance of the distribution network some parameters were required like flow velocity and pressure. The analysis is beginning by feeding the diameter of distribution pipes in to software and the pressure, velocity and head loss are in the distribution system. Pressures were measured throughout the water distribution system to monitor the level of service and to collect data for use in calibration. Pressure readings are commonly taken at water distribution mains also at hose bibs, and home faucets (Bentley, 2008). The method of pressure readings was done using pressure gauge. According to Benyam, (2016) and Tomas, *et al.*, (2003); in water distribution networks the most basic type of mode simulations is either steady-state or extended-period simulation.

Steady-state simulations: represent a particular view of point in time and are used to determine the operating behavior of a system under static conditions.

It computes the hydraulic parameters such as flows, pressures, pump operating characteristics and others by assuming that demands and boundary conditions were not change with respect to time. In general, this type of analysis was used to determining the short-term effect of demand conditions on the system (Tomas, *et al*., 2003 and Benyam, 2016). Hence, this study was used the steady state simulation for the work in order to accomplish the study. For this study Water GEMS V8i is used because: it modifies the flex table, analyze pipe and valve criticality, identify leakage and water loss from the network, prioritize pipe renewal, build and manage hydraulic models, manage energy use can effectively identify potential problem areas.

3.10. Modeling process of water GEMS v8i

i Model Setup and Data Entering Procedures

The main purpose of modeling is to assessing the existing system and to evaluate the levels of pressures at critical points within the system and to develop efficient model. The existing data, procedure of evaluating and model building ware as follow. First step synchronizing the distribution network system by conversion of the original existing water network of the town which available in auto CAD to water GEMS V8i; used directly within the Water GEMS tools for hydraulic model. Second, the other important elements such as junctions or nodes, pipe, tanks and reservoirs, pumps, etc. were located.

ii Data entering procedure

In modeling procedure the below step were considered; All the existing data collected and generated data have been entered into the built model. The system has been simulated for steady state and extended period simulation. Hydraulic models are often used to validate the design of water distribution systems (Bentley, 2008) as indicated in Figure 3.4.

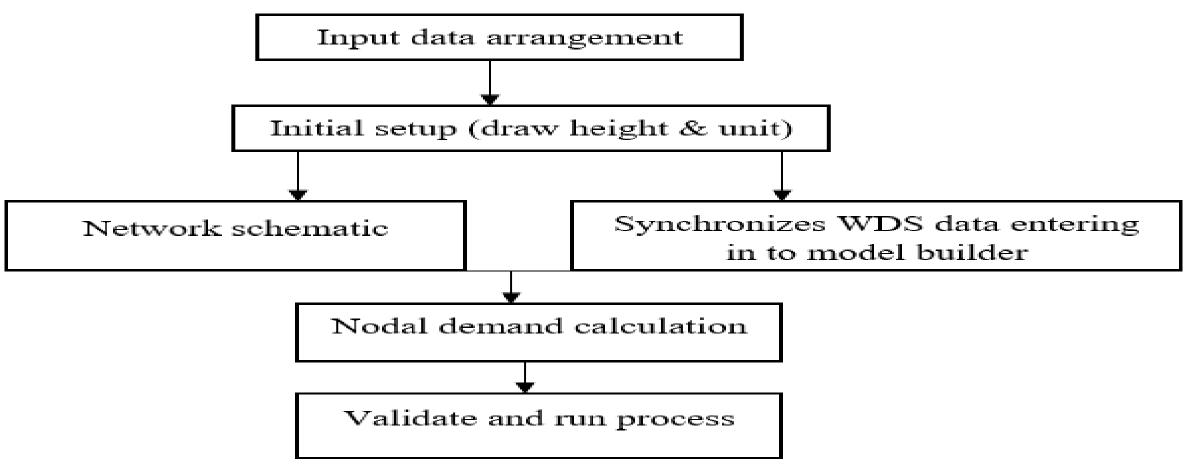

Figure 3 4: Hydraulic model flows in Water GEMS for water distribution systems

3.11. Model calibration approach

The trial and error process that usually goes into model calibration or manual approach was used for calibration. This generally carried out by supplying to the model estimated of pipe diameter, length, roughness as well as nodal demands and elevation, conducting the simulation, and comparing predicted performance to observed performance. If the agreement is unacceptable, then the cause of the problem must be hypothesized and modifications to the different model parameter must be made. The process is repeated again until the predicted and observed values are within a reason.

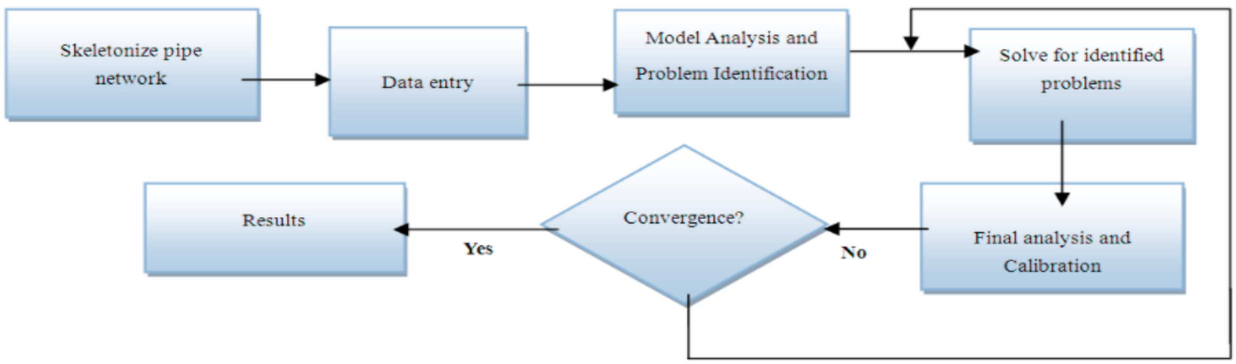

Figure 3 5: Model calibration approach

3.12. Model calibration and validation

It is a fact that the computed parameters of the model and real field measurement are not usually having the same result. Hence, calibration was carried out i.e. is a process of adjusting the model input data until its results become closely approximate to the measured field data. In order to calibrate and validate the hydraulic network and for comparison purposes, some quantitative information is required to measure model performance. In this study, the pressure data measured was used to evaluate the model performance.

The method of pressure readings was done from April 24, 2020 to May 01, 2021 using pressure gauge meters commonly taken both at higher and lower zone of the selected points in distribution network; such as raw water pump stations, service reservoir, public fountains and different end user taps. In this way, the perceived pressure data was taken a total of 10 samples for peak demand time analysis five samples were taken from lower zone and five samples from higher zone. All sampling points were selected after the computed model was simulated and knowing the pressure variation area (pressure zone) in the town water distribution network.

The model validation work was taken by comparing the measured pressure and computed values. Therefore, correlation (R^2) was used to check that the model is validated by using Microsoft excel sheet. According to Benyam, (2016) and Tomas, *et al*., (2003), the calibration process was performed by adjusting sensitive parameters related with flow; like pipe roughness coefficient and water demand until it become within the acceptable limit of 85% of field test measurements (it should be within $\pm$0.5 m or $\pm$5% of the maximum head loss across the system, whichever is greater). Hence, as per pressure criteria 85% of the computed model results should become within ±0.5m head of the observed field conditions. To assure the acceptable level of calibration, the two most commonly used model inputs parameters; pipe roughness coefficients and junction demand data were adjusted. Hence, during model calibration; C-factor was used 150 for PVC, 120 for HDPE and average value of 130 for DCI pipe.

3.13. Water losses in distribution networking system

Water losses in an urban water supply can exist in each component of water distribution networks due to varies factors as described in the literature review. These water losses may occur along main path, from source to treatment plant, from plants to reservoir and from reservoir to the junction within reticulation system, within treatment plant, within the distribution system and within consumer's premises. Apparent losses can be sub divided into unauthorized consumption, meter inaccuracies and data handling errors whereas the real losses are made up of leakage from transmission and distribution pipes, leakage from service connections and losses from storage tanks (Zewdu, 2014; Stevens, 2004; Cunlifffe, 2014).This loss can occur main at the pressure junction point, at the treatment plant, at services reservoirs, and entrance or exited pipe diameter variation as some of it described as below.

i) Water losses at junction pressure/fittings

Input data of junction are elevation and base demand, which were obtained by operating GPS at every junction in the water distribution network. GPS readings of elevation and coordinates of a reservoir, pumps at the boreholes and pipe junctions were collected. In water distribution system, baseline demand comprises customer demand and unaccounted for water loss. Nodal demand allocation was carried out by a method called simple unit loading. This method involves counting the number of customers at a given specified area or number of dwelling units/housing units which use water at a given node and multiplying that number by the unit demand (per capita per day). After consumption rates are determined, the water uses is spatially distributed as demands or assigned to nodes or allocate average day demands to nodes, and nodal demand is calculated by using (Amdework, 2012):

$Qi\ t = \sum Bij\ Pij\ t$……………………………………………………………………...…….3.1

Where, $Q_{i,\ t}$, = Total demand at junction i at time t (m^3/s), $B_{i,\ j}$ = Baseline demand for demand type j at junction i (m^3/s), and $P_{i,\ j,\ t}$ = Pattern multiplier for demand type j at junction i at time t.

Whereas the junction pressure at this nodal water demand of the hydraulic performance indicator and with its standard level were justified in the below Table 3.5.

Table 3. 5: water performance indicators

Performance indicator	Description	Selected target
Pressure	Minimum and maximum pressure in pipes,	15 to 70m (Ministry of water resources, 2006)
unit head loss	Head loss in the water pipes	≤15m/km (TAHAL Consulting Engineering, 2003)
Water loss	Volume of water lost as percentage of water supplied.	20%, (Tynan, 2002; Mwanza, 2004)

Water loss is expressed as a percentage of net water production (delivered to the distribution system), as m^3/day/km of water distribution pipe system network (specific water loss) and others like m^3/day/connection, m^3/day/connection/m pressure and water loss as % of net water production is the most common (Welday, 2005).This be can occurs in networking system due to size of pipe material , elevation ,internal wall frictional and coefficients are some of the main factors of water losses in distribution system.

ii) Water losses in through Pipes line

Pipes are links that convey water from one point in the network to another. The pipe has length, inside diameter, roughness coefficient and minor loss coefficient. Pipe coefficient is related with the pipe material and age, whereas minor loss coefficient is related to pipe fittings. As the water flows in the pipe, hydraulic energy is lost because of the friction between the water and pipe surface. Flow direction is from the end at higher hydraulic head (internal energy per weight of water) to that at lower head.

The principal hydraulic input parameters for pipes are: start and end nodes, diameter, length, roughness coefficient (for determining head loss), status (open, closed, or contains a check valve). Head loss in the pipe was analyzed by water GEMS software; the final outputs for pipes were flow, velocity, and head loss and junction pressure.

The hydraulic head loss by water flowing in a pipe due to friction with the pipe walls was calculated by Hazen-Williams formula (Walski., 2003) which is the most commonly, used head loss equation for drinking water flowing in distribution system as described in the literature.

Frictional loss = (10.68*L*Q^1.825)/(C^1.852*D^4.87)…………………………….…...3.2

The frictional loss (H_f) is a function of the diameter of the pipe (D) in mm, length of the pipe (L) in m, flow rate (Q) in m^3/s and pipe roughness (C).

iii) Unaccounted Water loss

Unaccounted for water often constitutes a major problem in water supply, representing considerable loss in revenues, creating excessive production and reducing the available water to customers. According (Welday, 2005), high levels of unaccounted for water indicate inefficiency on the side of a water utility as unaccounted for water is a basic measure of the utility's performance. Another factor to be considered to assess the performance of urban water supply systems is amount and causes of water loss.

Water losses not only represent economic loss and wastage of a precious scarce resource but also pose public health risks and every leak is a potential intrusion point for contaminants in case of a drop-in network pressures. Hence, the total water loss throughout the distribution networking embodies the difference of water production to water consumption and water unbilled to the ratio of water production which summarized in equation (3.2).

Total water loss (%) = (W tot. Prod-W tot. Cons-W tot. Unbilled)/ (W tot. Prod)*100..3.3

$$\text{Where, W tot. prod} = \text{total water produced, W tot. cons} = \text{total water consumed and W tot. unbilled} = \text{total water unbilled}$$

3.14. Controlling water loss

In order to control water loss methods like leak detection in the field and repair, rehabilitation and replacement program, corrosion control, pressure reduction and public education program. The legal provisions such as, water pricing policies encouraging conservation, human resources development and information system development also need to be employed (Welday, 2005).

3.15. Acceptable level of water loss

It is a compromise between the cost of reducing water loss and maintenance of distribution system and the cost of the water are saved (Desalegn, 2015). Addis Ababa water authority leak detection and accountability Committee recommended 10% as a benchmark for UFW. Regarding UFW levels and action needed, < 10% Acceptable, monitoring and control, 10-25% Intermediate, could be reduced and > 25% matter of concern, reduction needed (Sharma, 2008).

3.16. Input data collection for water GEMS

As described under *3.4 section* the input data required for hydraulic network modeling were associated with to the component of distribution network system. This data can collect in each node of pipe link are, pipe label, pipe material, pipe length, pipe diameter, starting node, stopping node, and pipe roughness are some of the pipe input data requires for the modeling and simulation of water distribution network sustainability. The other input data associated are, pressure junction at node/link which includes junction label, junction elevation, and junction demand. Tank data requires are base elevation, minimum elevation, maximum elevation, initial elevation and tank diameters. The pump input data collection is, design flow, maximum operation flow, design head, maximum operating head, maximum operating head, shut off design and coordinate system (x, y). Lastly the source of water supply data with properly elevation and coordinate in x and y axis. In addition to the network pipe and node data, physical data must be obtained to that describe all valves and categories of water demand situation either in fixed or pattern distribution networking.

3.17. Data analysis

In order to estimate total water demand that quantities of water produced to meet all water needs (residential, Institution and commercial, industrial, public use, firefighting and losses) and total number of populations needed to know barrier between production capacity of the scheme and consumption of water in the town. The official records for production and water consumption (water billing) data were used in this research to undertake water balance analysis and subsequently to quantify losses. Additional data collected includes reservoir data, Borehole data and pump data. The distribution system was designed to adequately handle the peak hourly demand or maximum day demand and fire flows, whichever is greater, during peak hourly flows; storage reservoirs supply the demand in excess of the maximum day demand. Then evaluating demand variation based on population size was key element to determine the whole capacity of distribution system. The collected data was analyzed in qualitative analysis. The qualitative data collected from customer using key informants' interview and personal observation was also analyzed through description, narrating and interpreting the situation contextually so that the town's water supply situation has been properly revealed

4. RESULT AND DISCUSSION

4.1 Population projected for Kolfe Keraneo Sub city

The base population of Kolfe Keraneo sub-city is currently 595,343 and this society gets water from the existing of water supply schemes. Among different method of population forecasting techniques available the Central Statically Agency was used since the estimation of error were very small relative to the other methods up 2046 as describe in the Figure 4.1. Thus way by using this method the study was forecasted for 25 years of study period as per-described in Figure 4.1 and hence the designed population projected was for about 1,336,029 of population. This implies that for about 740,686 of population numbers were added on the existing water supply service, which highly increases water supply consumption rates and facilitates to low performance of piped water supply for the study area. For each consecutive years the growth rate of the population was increased which seeks for additional water source for different purpose of their water consumption rates.

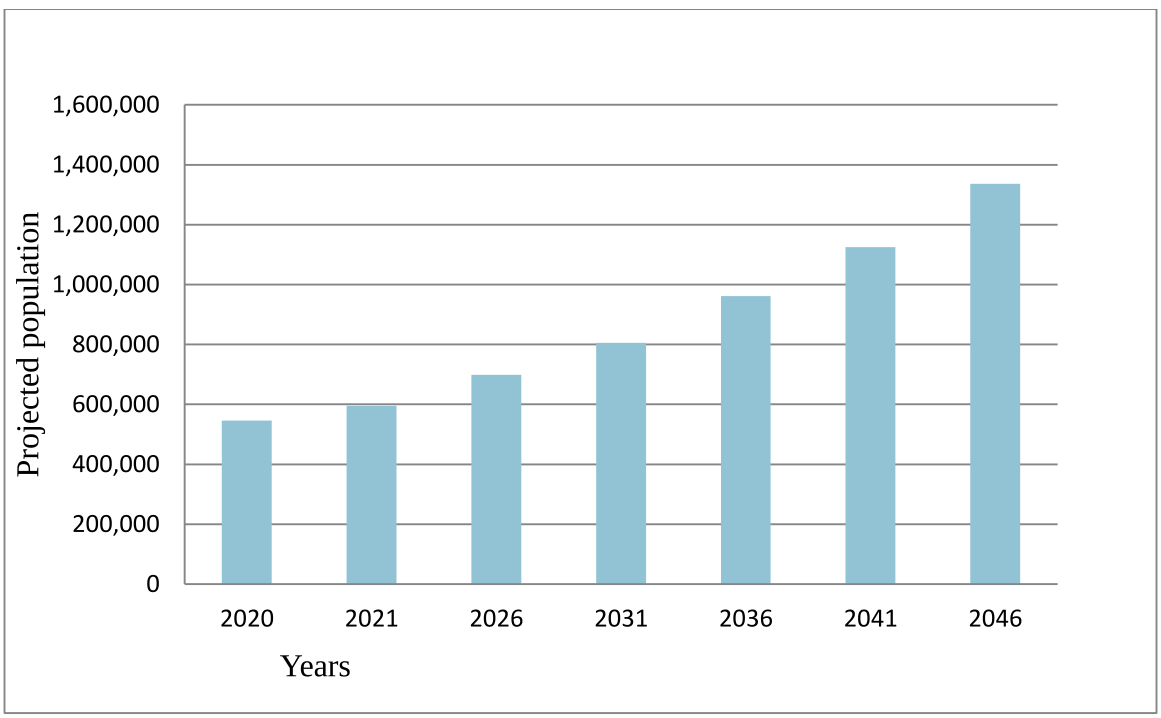

Figure 4 1: Population projection of Kolfe Keraneo Sub city for 25 years

4.2. Projected domestic water demand by mode of service

Domestic water demand is the daily water requirement for use by human being for different domestic purposes like drinking, cooking, bathing, gardening. The design period (2046) population of Kolfe Keraneo Sub-city will be 1,336,029, which is categorized under catogry-1, town with population number greater than 100000. The percentage of population using HC and YC were increased from time to time while YSC were decreased from time to time.

Table 4.1: estimation of domestic water demand by mode of service and per capital demand

Years	No	2021	2026	2031	2036	2041	2046
projected Popn		595343	699154	805979	961884	1124900	1336029
Popn distribution by mode of Service %							
HC	%	0.05	0.075	0.09	0.1	0.125	0.15
YTS	%	0.2	0.25	0.26	0.275	0.3	0.325
YTP	%	0.175	0.225	0.25	0.25	0.275	0.295
PT	%	0.575	0.45	0.4	0.375	0.35	0.32
Popn- distribution service							
HC	No	29767	52437	72538	96188	140613	200404
YTS	No	119069	174789	209555	264518	337470	434209
YTP	No	104185	157310	201495	240471	309348	394129
PT	No	342322	314619	322392	360707	393715	427529
Per capita demand							
HC	l/c/d	50	60	70	70	70	70
YTS	l/c/d	25	27.5	30	30	30	30
YTP	l/c/d	30	35	40	40	40	40
PT	l/c/d	20	22.5	25	25	25	25
Domestic Water Demand	l/d	14437068	20537649	27483884	33305234	42183750	53507961
	m3/d	14437.1	20537.6	27483.9	33305.2	42183.8	53508.0

4.2.1. Adjustment of water for domestic demand

Kolfe Keraneo Sub-city is located at average altitude of 2300 and 3300 m amsl, climatic factor 0.9 was considered. Kolfe Keraneo was high potential town for development, but lower living standard at present, therefore take socio-economic factor 1. As described on Table 4.2, the current (2021) adjusted domestic water demand of Kolfe has been 12993.36m^3/d while design period (2046) water demands of study area were 48157.16 m3/d this indicates the water demand of the down is increased by 35163.8037m^3/d. This is why domestic water demand of the community was increased from time to time. From the Table 4.2, suggested that domestic water demand (DWD) was adjusted by climate (CF) and socio-economic factors (SEF) and this means that water is more used at hot area than cold ones.

Table 4.2: Adjusted domestic water demand

items	units	2021	2026	2031	2036	2041	2046
Domestic WD	l/d	14437068	20537649	27483884	33305234	42183750	53507961
	m3/d	14437.1	20537.6	27483.9	33305.2	42183.8	53508
Multiplier factor for domestic water demand adjustment							
Climate condition		0.9	0.9	0.9	0.9	0.9	0.9
	l/d	12993361	18483884	24735496	29974711	37965375	48157165
	m3/d	12993.4	18483.9	24735.5	29974.7	37965.4	48157.2
Socio-economic		1	1	1	1	1	1
	l/d	12993361	18483884	24735496	29974711	37965375	48157165
	m3/d	12993.36	18483.88	24735.5	29974.71	37965.38	48157.16
Ave. Adjusted DWD	l/d	12993361	18483884	24735496	29974711	37965375	48157165
	m3/d	12993.36	18483.88	24735.5	29974.71	37965.38	48157.16

4.3. Non-domestic water demand projection

This refers to the water demand required for non- domestic water (NDWD) area like public and institutions water demand (IWD), commercial water demand (CWD), firefighting water demand (FFWD) and industrial area (IWD). The total water demands for both case in the domestic water demand and non-water demand were estimated as the following Table 4.3 based on the above Table 4.2 of demand estimation

Table 4.3: Projected non - domestic water demand (2021-2046)

Years	Unit	Adjusted DWD	CWD10%	IWD5%	FFWD 5%	NRWD 20%	Ave. NWD
2021	l/d	14437068	1443707	721853.4	721853.4	2887413.6	5774827.2
	m3/d	14437.068	1443.7	721.9	721.9	2887.4	5774.8
2026	l/d	20537649	2053765	1026882	1026882	4107529.8	8215059.6
	m3/d	20537.649	2053.8	1026.9	1026.9	4107.5	8215.1
2031	l/d	27483884	2748388	1374194	1374194	5496776.8	10993553.6
	m3/d	27483.884	2748.4	1374.2	1374.2	5496.8	10993.6
2036	l/d	33305234	3330523	1665262	1665262	6661046.8	13322093.6
	m3/d	33305.234	3330.5	1665.3	1665.3	6661.0	13322.1
2041	l/d	42183750	4218375	2109188	2109188	8436750	16873500
	m3/d	42183.75	4218.4	2109.2	2109.2	8436.8	16873.5
2046	l/d	53507961	5350796	2675398	2675398	10701592	21403184.4
	m3/d	53507.961	5350.8	2675.4	2675.4	10701.6	21403.2

From this Table water demand for public and commercial area were more than water demand for other non-domestic area, this indicates the area covered by public and commercial were greater than other areas. The design period for non-domestic water demand were increased by 15628.4 m^3/d as compared to 2021 non-domestic water demand, this can indicates the amount of water supplied for non-domestic area was increasing from year to year. Additionally as described in Table 4.4 and Figure 4.3, domestic water demand and the percentage contribution of all water demand on the design period were analyzed. Among those categories domestic demand is higher than all other consumption categories. This demand category is followed by public and commercial activities whereas industrial, livestock and fire demand have a lower contribution to total water demand

4.4. Water demand variation

Water demand is a summation of all consumption given in the preceding sections and it would determine the capacity needed from the sources. As described in Table 4.1 and 4.2, the domestic demand throughout the year is higher than non-domestic demands. Non-domestic demand are found to have a lower to total water demand as described in Figure

4.2 indicates. Since 2021 the water supplied for domestic was 8662.2 m^3/d greater than water supplied for non-domestic area. The reason behind the current water supplied for domestic consumption was greater than non-domestic was, the community of study area were more commonly consumed water for domestic purpose rather than non-domestic purpose. As per described in the above Table 4.1, 4.2 and 4.3 domestic water demand for the study area was more than the required for non- domestic water demands area.

The averagely domestic water demand to be 32104.8 m^3/d greater than the non-domestic water demand at end of design period. Whereas the current water demands for the domestic water demands were 8662.25m^3/d more than the non-domestic water demands required in 2021 year which implies that there were highly expansion urban area and immigration to the study area. The design period for non-domestic water demand was increased by 15628.4 m^3/d as compared to 2021 at the end of design period water demand projections.

Table 4.4: Variation of water demand estimated for 2021-2046 to Kolfe Keraneo sub-city

Water Demand	Unit	Year					
		2021	2026	2031	2036	2041	2046
ADWD	l/d	14437068	20537649	27483884	33305234	42183750	53507961
	m3/d	14437.07	20537.65	27483.88	33305.23	42183.75	53507.96
ANDWD	l/d	5774827	8215060	10993554	13322094	16873500	21403184
	m3/d	5774.827	8215.06	10993.55	13322.09	16873.5	21403.18
ADWD	l/d	10105948	14376354	19238719	23313664	29528625	37455573
	m3/d	10105.9	14376.4	19238.7	23313.7	29528.6	37455.6
MDDF	-	1.2	1.2	1.2	1.2	1.2	1.2
MDWD	l/s	12127137	17251625	23086463	27976397	35434350	44946687
	m3/d	12127.14	17251.63	23086.46	27976.4	35434.35	44946.69
PHDF	-	1.6	1.6	1.6	1.6	1.6	1.6
PHWD	l/s	16169516	23002167	30781950	37301862	47245800	59928916
	m3/d	16169.52	23002.17	30781.95	37301.86	47245.8	59928.92

Maximum daily demand factor, 1.2, was selected based on the population number of design period. And also the value of peak hourly demand factor, 1.6, was selected based on the population number of design period.

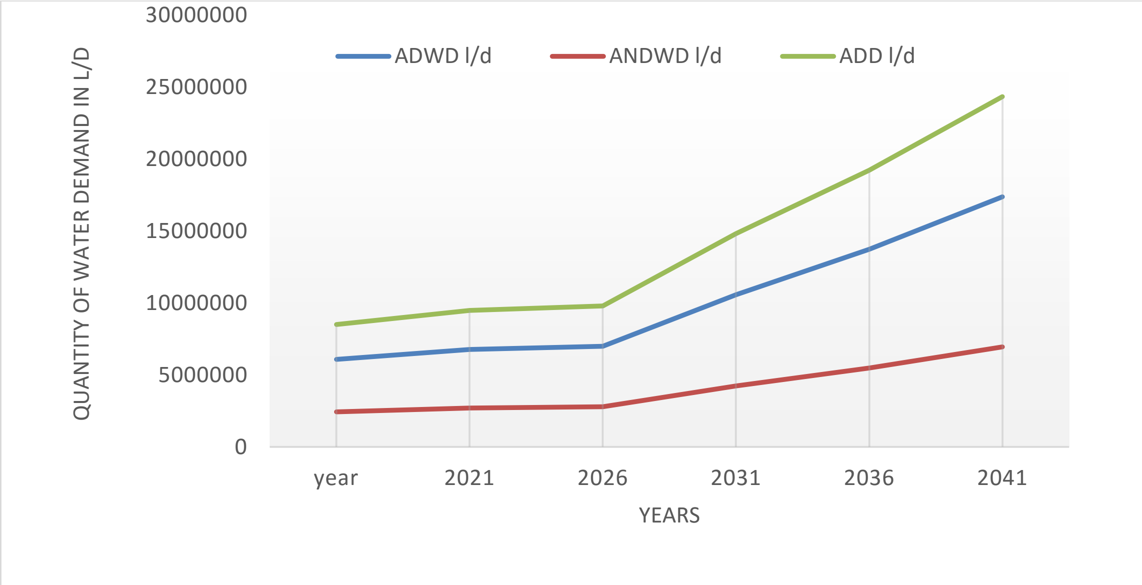

Figure 4 2: Water demand variation

As described in Figure 4-2, Average daily demands (ADD), Maximum daily demand and Peak hour demand of the study area for 2026, 2031,2036 and 2041 were increased by 36.47, 73.49, 117.39 and 168.96 %, respectively as compared to 2021 average daily water demand. Maximum daily demand factor, 1.2, was selected based on the population number of design period. And also the value of peak hourly demand factor, 1.6, was selected based on the population number of design period.

4.5. Projection of water demand and water supply deficit

According to the information obtained during discussion with the experts of water supply office the other problem of water supply is the source of power for pump motor or shortage of power supply. That means, the supply of water to the town was dependent on electric power. When electric power was available, the sources produce a total volume of discharge 19,617,358 l/d (227.052 l/s), and also by using pump operation hours which is equal to 7410865l/d (85.78 l/s) in 24 hours. Therefore the total volume of water entered to storage tank within 24 hours is 308,786.04 m^3. However, the maximum day demand and peak hourly water demand for the area were 44946.68 and 59928.92 m^3/d of water consumption were requiring which implies unbalanced water production and water demand for current projected population and 12127.14 and 16169.52 m^3/d to the forecasted period with respectively. The collected water supply was insufficient and the consumption rate were less than 2 l/c/d from 2021- 2031 years and beyond to this year's water supply requirements was greater than the water supply collected for this area. This indicate the amount of water which is supplied for town is less than amount of water demand required at the design period required. This shows that there were huge gaps between water production and water demand for the study area, since the source of water was fixed whereas the water demand can vary from time to time. The gaps between the current actual water supply with current water demand is crucial to know the gap and strive to investigate the problems causes the gap and hence search solution for the problem. Mainly the determination of peak hourly water demand was used to estimate the services reservoir capacity, which implies 1/3 of peak hour demand. Accordingly, the current reservoirs capacity of the study area was 500 meter cubic which was limited storage, but for the study period the reservoir capacity were requires 832.5 let's consider safety factor and hence take 1000 cubic meters of reservoirs was requires. In order to minimizes the load for constructing one reservoir it too better using two service reservoirs of 500 cubic meters for each.

4.6. Hydraulic performance in distribution system

The study area of water distribution system starts from Kale reservoir to woreda 13, 14 fully and woreda 15 partially. The distribution system consists of pipes of various sizes, valves, meters, pumps, distribution reservoirs; hydrants; stand posts and this pipeline carry the water to every street and road. Pumps are provided to pump the water to the water mains to obtain the required pressure in the pipelines.

4.6.1. Pump and capacity curve

As described graphically the pump efficiency of the modeling running results were ranges 75 - 80% by delivering the 40-60 l/s discharge for the pumping head of 25-30 m. However, design data of the for Kolfe Keraneo Sub-city, indicates, by using 149.2 kW pump power delivers water at the 200 m^3 pioneer reservoir at the inlet of reservoir for pump head 95.5m for a head 100m to collection 120 l/s flow. This shows that power of pumping did not delivers water for 95.5 or 100 m at the required pump heads for collecting water, but it efficiently collects water to a less than 30 m heads. Accordingly, the pump efficiency was 50.1%, which complies with ISO 9906; 2012 (Benyam, 2016). However, pumps that perform in good condition have efficiency in the rank of 60-80% (ISO 9906; 2012). Hence, a lot of factors like damages of pumps and frequent failure, the pump was not replaced for a long time are occurring, thus the pumps did not perform within the required efficiency range. Therefore, 50.1% of the pump efficiency shows that currently those pumps were not operating in good performance and did not deliver sufficient water to treatment plant continuously. The pressure in the distribution systems may occur staring from source /borehole to the final distribution distinction area special woreda thirteen. The cause and its consequences are drop of elevation, size of the pipe material, wall friction and water pressure as below Figure 4.4 indicates. Therefore, capacities of the pump reflection of water for the study area were determined from on the topographical location of the borehole.

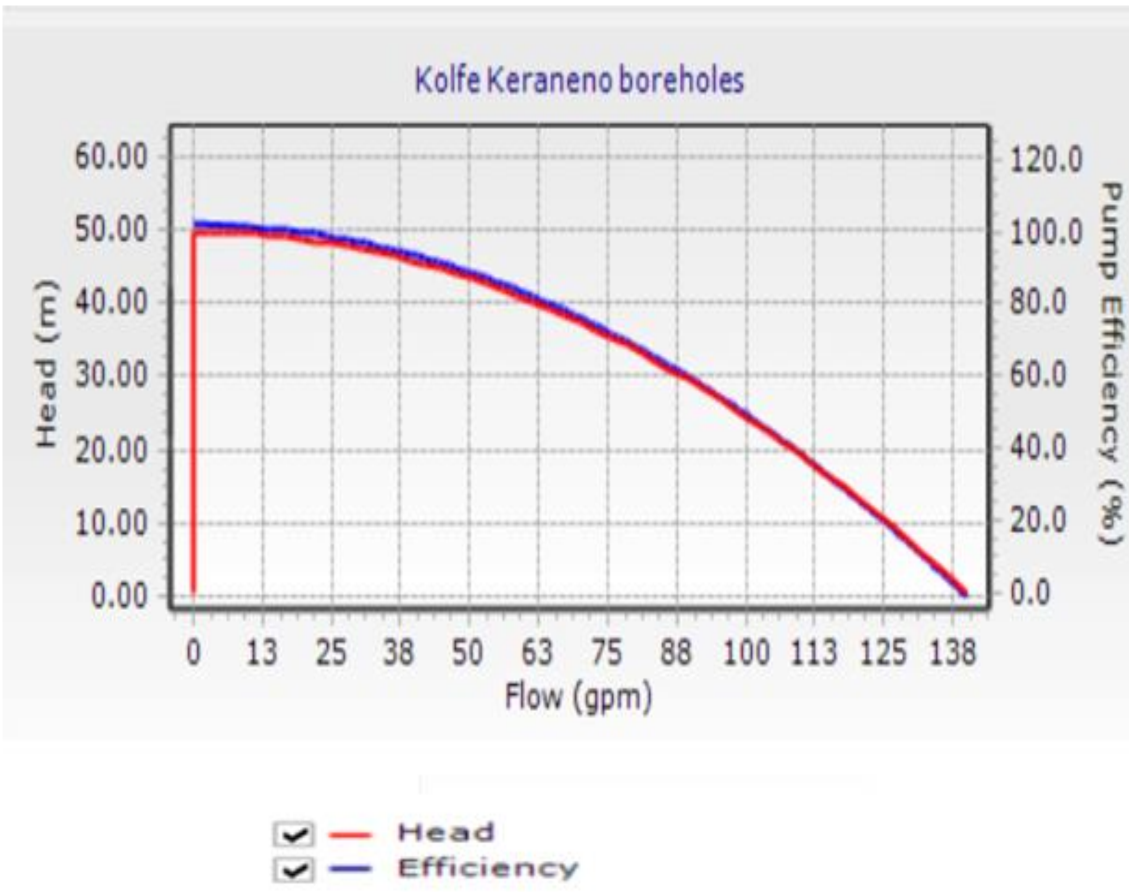

Figure 4 3: Pump head and pump efficiency for Kolfe Keraneo borehole

4.7. Pressure in existing water supply distribution network

As shown in Figure 4.4; the water pressures in the water distribution system were a function of factor maximum day demand and peak hour. Additional variation of elevation difference in most part of the town has also an impact for the rising and reduction of water pressure in the network. Therefore, during peak demand time most part of the network was disconnected from the system and wide commercial area of the town were not getting water and most of the commercial were get and collect water at night flow during low demand time. The following figure of pressure simulation in the water distribution systems are start from tank to the customer tap as shown Figure 4.4 below.

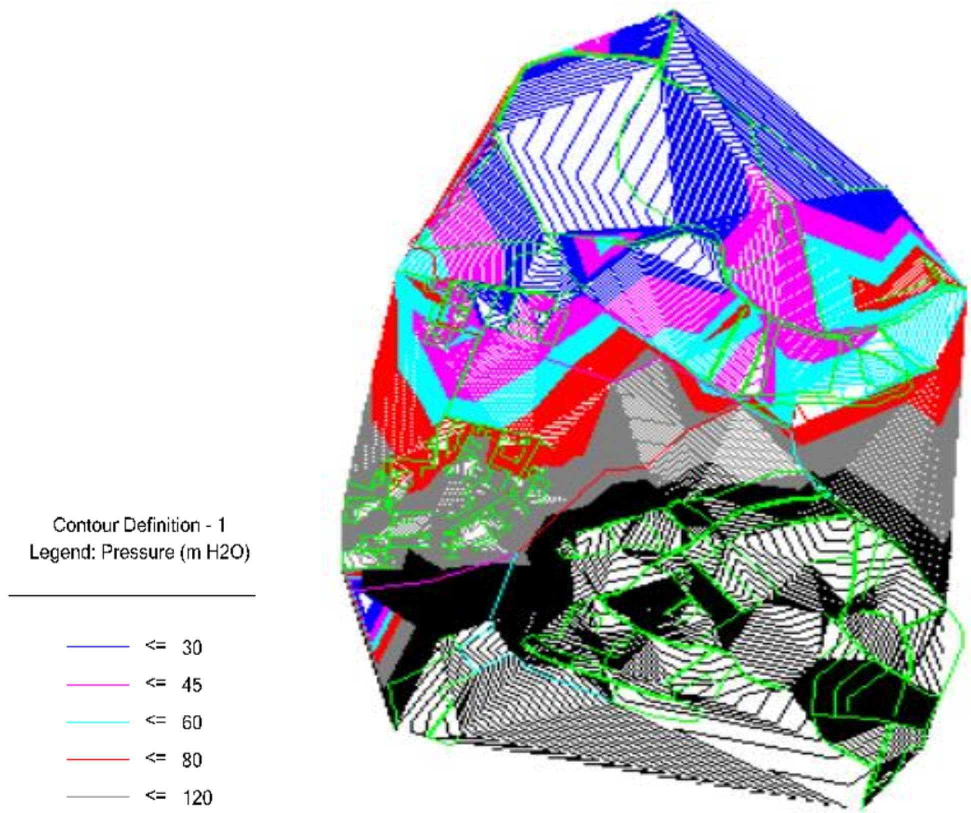

Figure 4 4: Pressure of existing water supply distribution netwok

As the result where distribution pipes are close to reservoirs in terms of perhaps both location and elevation, in small sections of the distribution system that would require a PRV or BPT for rising pressures general to achieve a 15 minimum pressure. The sky blue color presented indicates pressure less than 15 mH_2O, which implies that the water distribution networks below ≤ 30 and ≤ 15 mH_2O, which was below permissible range.

The violet, aqua green and pink color was describes the normal range of water pressure in the distribution systems, were as light brown color indicates pressure above permissible range indicated.

Table 4.5: Pressure distributions at peak hour time

Pressure range value	≤ 15 mH_2O	15-70 mH_2O	≥ 70 mH_2O
Number of nodes	244	207	96
percentage	44.61%	37.84%	17.55%

As per described above Table 4.5 of the pressure in the distribution indicates the result of simulation run was obtained after model restrained the input of existing data, which have the total pressure node of 547 which was reported by water Gems v8i in the dialog box software since simulation. From this table, as the results of simulation indicates 62 % of the pressure junction have been observed out of the recommended functional pressure (≤15 mH_2O and ≥ 80 mH_2O), due to the elevation of town and water pressure and limitation of hydraulic design. This implies that in the design of water distribution systems only 38% were delivered proper to ends of the consumer's needs.

4.8. Velocity of water in the existing water distribution network

Table 4.6 and Figure 4.5 below summarize the velocity of water in distribution network at high water consumption, morning.

Table 4.6: Number of velocities of water in distribution systems from modeling and simulation

Velocity ranges (m/s)	Counted pipes	Count %	Remarks
≤ 0.6	284	63.25%	Sedimentation problem
≥ 0.6 ≤ 2	112	24.94%	Normal status
≥ 2	53	11.80%	High head loss occurred

As shown from the above Table 4.6 of velocity of in the water distribution systems as indicated from the water GEMS software running since the simulation and modeling of the existing water supply for the areas that is covered by Kale reservoir. This result indicated 63.25 and 11.80% of the pipes are below and above the permissible range (0.6 up to 2 m/s) of velocity respectively. This is due to, improper design of hydraulic parameters and insufficient of discharge in each pipes distributed to three woredas water supply and distribution network was not satisfactory for effective flow of water and also pump power, which deliver water from source to customer, was not effective. As the previous studies result indicates only 26.55 % of the pipes of existing Kolfe sub-city water supply distribution system are within the permissible range of velocity (Mesfine, 2017), Desta and Befkadu, 2020) and for Bole sub-city 31.43% (Tadesse, 2020, Fekrudin and Ababa, 2019). And hence, by comparing the permissible velocity value of Bole sub-city with Kolfe Keraneo, the velocity value was less permissible.

Figure 4 5: velocity in the existing distribution network

Demand pattern is one of critical component at the system, from which is identified how much capitals consume to describe in Figure 4.6. The system condition have been computed over 24 hours with a specified time increment of an hour and starting model run at time 12:00 am (Mid night). The model has capacity to run 24 hours but to indicate the real performance pattern the simulation of this model was adjusted. The model has been performed 12:00 am (mid night) to 5:00 am minimum hour consumption while 6:00 am (Morning) to 9:00 am for the peak hour consumption. It is noted that minimum hour model run has been made at extended hour.

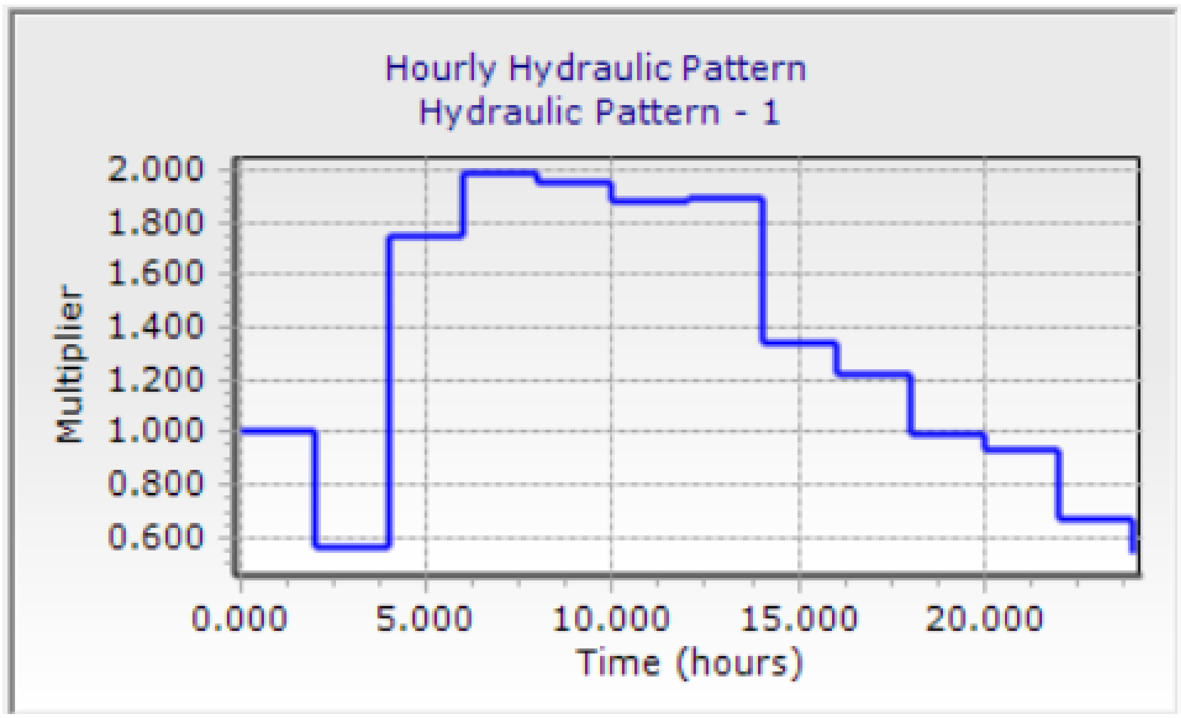

Figure 4 6: Demand pattern in water distribution with in 24h

4.9. Behavior of storage tank at different consumption hours of a day

Dynamic (EPS) simulation result future water demand for newly designed was used to show the fluctuating storage volume with time increments during high and low consumption. Moreover, in low demand hours when the water consumption of consumer are almost zero, amount of pumped water is higher than system demand so that extra water coming from pumps are stored at storage tank and equilibrium of water distribution system satisfied again. The time varying simulation indicates that storage service reservoir starts to decrease its volume at 6:00 hour that means up to 6:00 hour the volume in the tank was full.

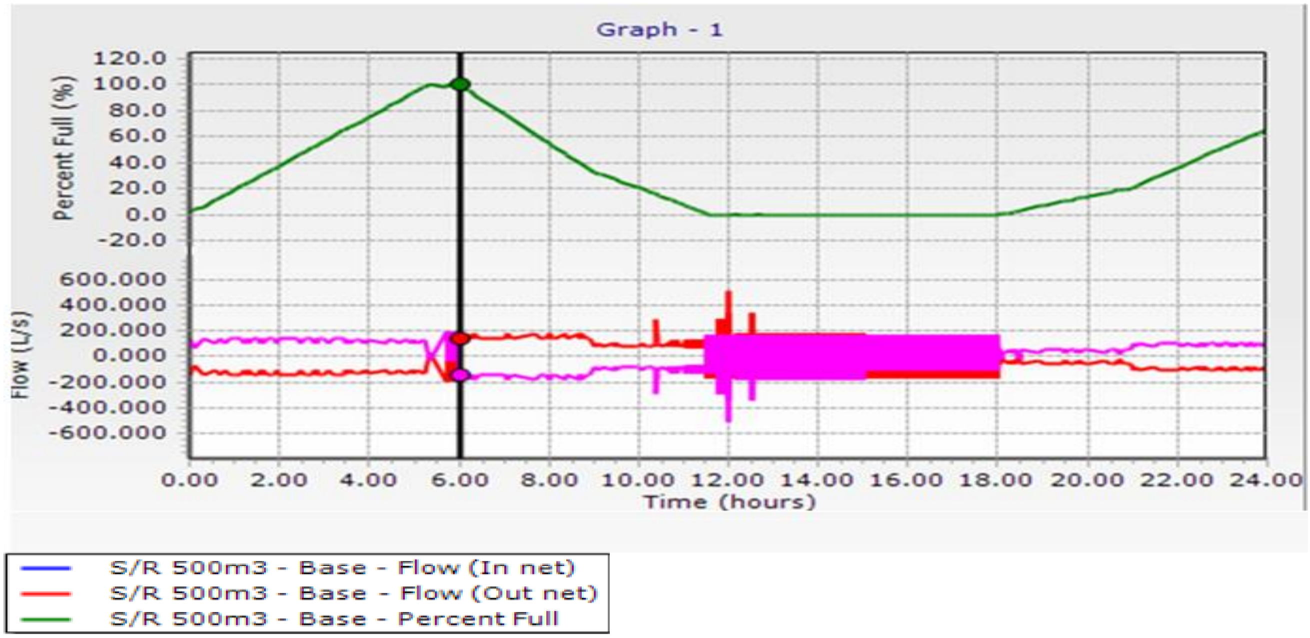

Figure 4 7: Service reservoir water volume fluctuation over 24 h period

Figure 4.7 shows during the extended period simulation the storage level of the tank fluctuate for 24 hour period which shows the change in percent of full in different time interval. When the simulation run begins the tank was not full and then the volume starts to decrease form 6:00 am, so that the pumps should have to operate to replenish the volume of the tank starting from 6:00 am hours. The maximum day demand at the end of the 25 years design period of Kolfe Keraneo water supply capacity is 44946.7 m^3 and the maximum day demand of study area in 2021 was 12127.14 m^3; therefore additionally 32819.55m^3 water is required.

4.10. Water loss analysis

The total annual water produced and distributed to the distribution system and the water billed that was aggregated from the individual customer meter reading were used to quantify the total water loss for the city. According to this study, the average water loss in the study area is 23 % this shows that water supply loss in the city was needs concern and the loss must be controlled and monitored. The water loss trend of the city showing that loss was fluctuated from year to year. This could be due to road, hotels construction and breakage of pipes. An interview result showing that, once a leak identified repairs are made after 74 hour on the average. This implies that, leak was not a timely response and it maximized water loss. However, both water loss increased and decreased depending on time of construction and awareness creation between people.

Table 4.7: Water loss trend of the study area

Year (E.C)	Total production (m^3/yr.)	Total Billed data (m^3/yr.)	Total unbilled Data(m^3/yr)	Total loss (m3/yr.)	% of losses
2007	20394790	16747127	2039479	1608184	0.08
2008	18823623	14240639	1882362.3	2700621.7	0.14
2009	11024325	8110745	1102432.5	1811147.5	0.16
2010	15325638	9811104	1532563.8	3981970.2	0.26
2011	18070764	9886969	1807076.4	6376718.6	0.35
2012	11111029	5471023	1111102.9	4528903.1	0.41
Average water loss (%)					0.23

4.11 Major factors contributing to water loss in the study area

Water losses are a major problem for water utilities, as they affect environmental and financial sustainability of the town water services. There are several reasons for the high level of water loss in the water distribution networks.

I) Age and size of pipes

The pipe age of material is the major factors that contributes to the burst of pipes which a result for causes a of water loss. It has been observed that small size and aged pipes were laid in Kolfe water distribution network. As per surveying since data collection the information obtained from Addis Ketema water supply service office nearly 48% of the pipe were served without any replacement for the last 32 years. These pipe materials were grieved due to its long service time, and environmental conditions which response for frequent pipe bursting and real losses through the distribution network.

II) Metering error

As per Adiss Ketema water supply and sewerage Bureau under registration of customer meters is one of the causes of water loss in the town which have the same contribution on water loss with pipe size and material ages. For the study area the customer errors in the town happens due to accounting procedure and errors due to under or over registration of the meters. As per interviewed of the water service office of sub-city, these occurrences happened due to under registration which is the main technical problems of customer water meter, and it was found as the main source of apparent loss in Kolfe sub-city water supply system under registration is the main.

III) Data handling errors

As per the water authority of the Sub city data handling error in the meter reading and billing process was contributed for apparent losses. Customer meter reading practice; especially unbilled metered trends were the common problem of Addis Ketema water service office. Whereby, recording of overestimated number lead the water utility to improper collection of revenue, and at the end of the month the authority was lost money.

IV) Illegal connections

According to the water authority of the Sub city, it is such difficult to identify the illegal users of water within town water distribution network. There by the illegal connection is inevitable in the town that contributes to loss enormous amount of water tariff. Hence, as the information obtained, it is possible to say that illegal connection is one of the major factors that contributes to large volume of water loss in the town.

V) Poor maintenance practices

In many water utilities there is less attention for water loss as a result of their poor maintenance capacities. In Kolfe sub-city water service it was observed that; there are no enough budget, proper weak supervision, instrument, accessories, carelessness of the technicians and strong policies for suitable leakage management. However, these have a considerable impact for physical losses in the town water distribution system so that it needs a hot concern to handle the problem.

Figure 4 8: Breakage of pipe material and maintenance (9/2/2013E.C.)

4.12. Hydraulic calibration and validation

As shown in Figure 4.9 and Figure 4.10 the computed pressure for both upper and lower pressure zone value was calibrated until the result was approach to the observed pressure value.

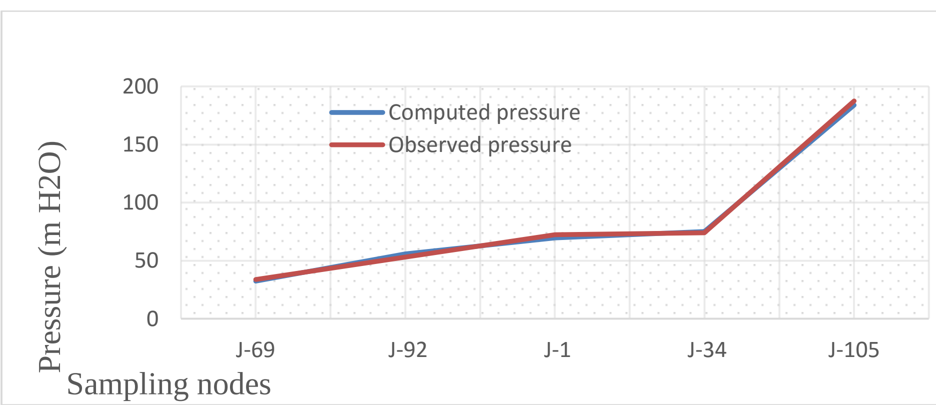

Figure 4 9: Graphical representation of the computed and observed pressure value (upper pressure zone)

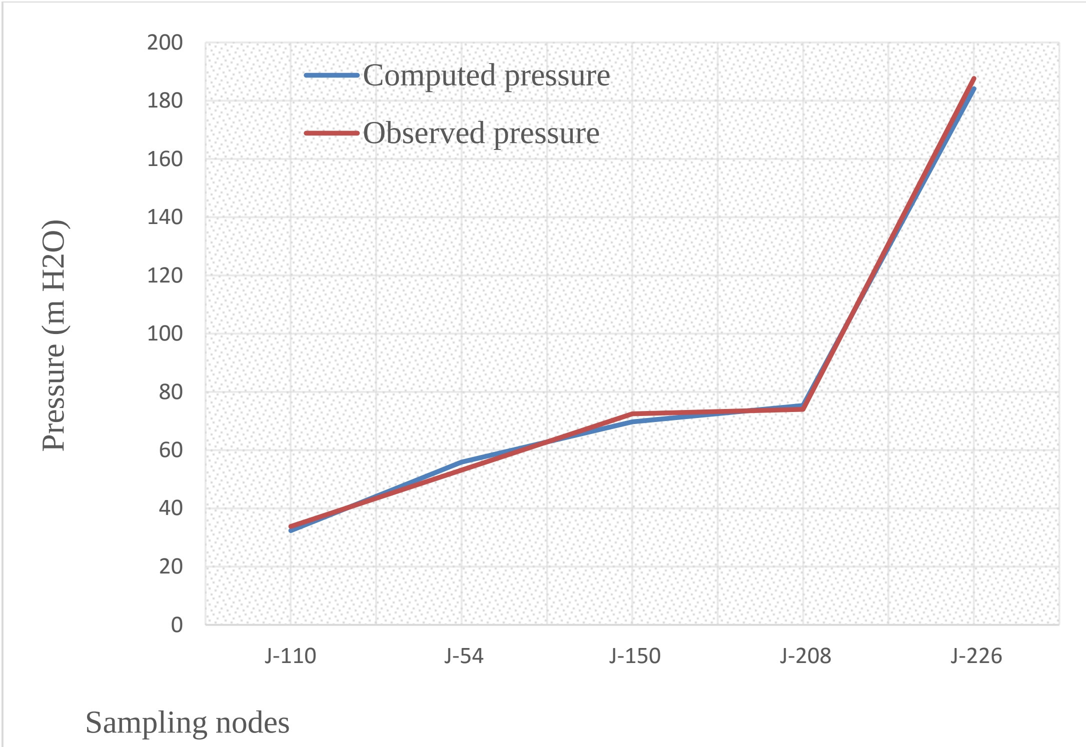

Figure 4 10: Graphical representation of the computed and observed pressure value (lower pressure zone)

While, as per discussion with the water utility manager, in Kolfe sub-city the maximum hour water demand is happen during morning and evening time, when most people use water for bathing, washing and cooking purpose so that in case of higher and lower pressure zone the computed pressure and observed pressure are almost close to each other.

4.13. Model validation

The model validation work was taken manually using the correlation coefficient equation (R^2) method and it were described and represent graphically in figures below. As shown in Figure 4.11 and Figure 4.12; it explains the results of correlation value (R^2) for both high and Low pressure zone was representing as 99.99% and 99.97%, respectively. Thereby, the calibrated Pressure value was validated within the recommended standard.

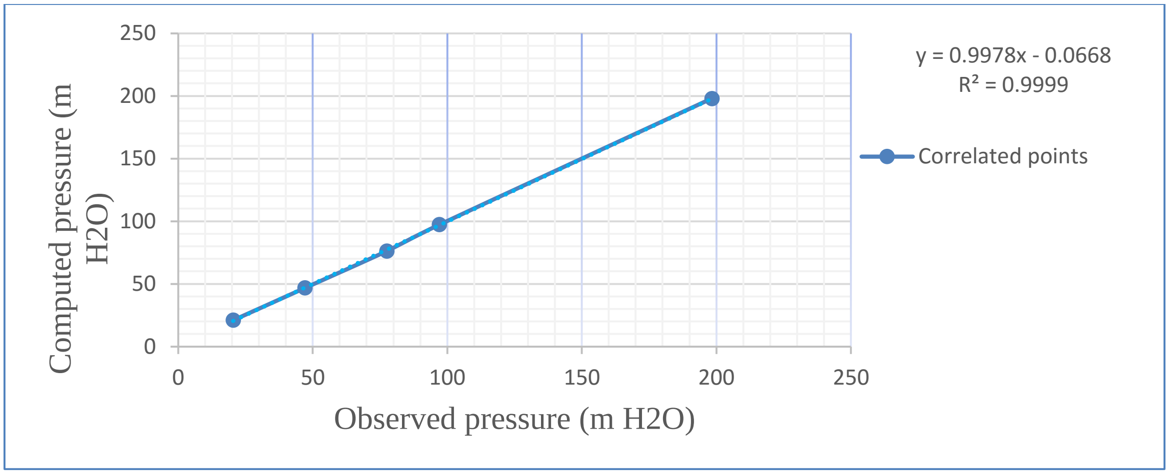

Figure 4 11: Correlated polt during pressure calibration (upper pressure zone)

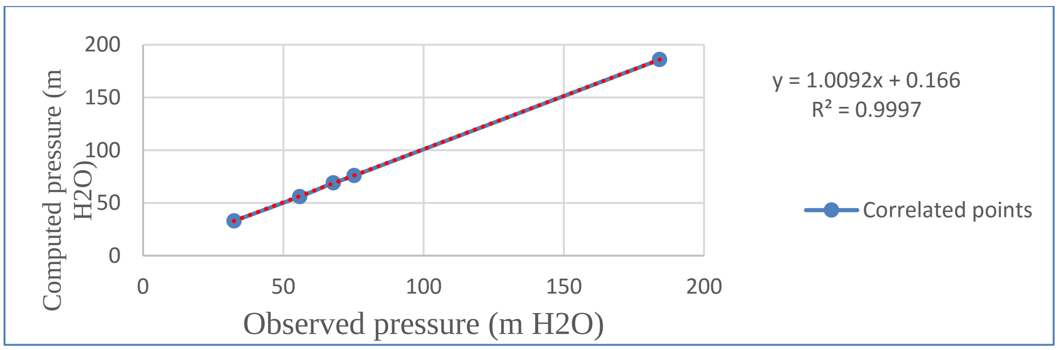

Figure 4 12: Correlated plot during pressure calibration (lower pressure zone)

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusions

For the study area the existing water source from Kale Reservoir and borehole doesn't meet the projected population, since water production for the sub city is fixed and the wish of water consumption rate is daily increase with population growth rate. So that the current water demand is 12127.14 m^3/day and the predict water demand at end of 2046 years would be around 44946.68 m^3/day, whereas the total water production for this area is 19617.3m^3/d. in this area water supply situation is becomes difficult due to lack of additional sources. Based on the model simulation results, field survey and data analysis, urban water supply distribution network the best performance indicators for water distribution modeling results are: pressure head at network nodes (15 - 70 mH2O) and flow velocity in pipes (0.6 – 2 m/s) (MOWR, 2006). Hence the extended state simulation of pressure 44.61% limited standards, 17.55% above and only 37.84% is in normal standard out 547 counted junction pressure. This implies around 62.16% of water pressure in the distribution system is out of the ranges this implies water is not properly delivered. Similarly the simulated water velocity were, 63.25% below standards, 11.8% beyond and 24.94% is normal permissive level from total counted 449 of pipeline. The velocity and pressure in distributions network are affected by the elevation of reservoir, sizes of the pipes and limited volume of reservoir. Finally the estimated of total water losses were 23%.

5.2. Recommendation

The existing services reservoir elevation's is constructed on sloped area and the size of this reservoir isn't enough to feed the current and the predicted water demands. Since this it's the main cause for low performance of water distribution system it's better to add the water supply sources, resize the capacity of services reservoir from the existing 500 m^3 to the 832.56 m^3 which is from designed approximately 1000m^3 and construct at high elevated area from the area's topography. During the failure or leakage of pipe and pumps it should be regular follow-up, operation and maintenance for minimization of water loss. It is most recommended that the areas located at the low pressure (higher ground level), needs additional pressure tanks or new pressure zone by pumping the water from the nearest booster pumps to solve the problems of poor pressures at the area and under sized pipe needs to be replaced to standard size. In this study water quality was not analyzed due to time and financial constraints; hence the future research should give attention for better performance evaluation.

REFERENCE

A.G.Chaudhari, A. K. (2017). Review study: experimental investigation by water gems software for redesign of water distribution system. International Journal of Advaced Research in Science and Engineering, 6(2), ISSN 2319-8346.

A.G.Chaudhari, A. K. (2017). Review Study: Experimental Investigation By Watergems Software For Redesign Of Water Distribution System. International Journal of Advanced Research in Science and Engineering, 7(2), ISSN:2319-8346.

Adeyemo A.M and Afolabi, S. (2005). Inequality in the service provision between the Costal nd Hinterland areas in the Niger Delta region; being a paper presented at the 47th nnual Conference of association of Nigerian geographers held at the University.

African Ministers' Council on Water, A. a. (2010). etting Africa on Track to Meet the MDGs on Water Supply and Sanitation A Status Review of Sixteen African Countries.

Alemayehu, Z. (2010). Water Supply Urban Drainage, Addis Ababa Ethiopia. Addis Ababa.

Amdework, B. (2012). Hydraulic network modeling and upgrading of Legedadi subsystem water supply. Civill Engineering. Addis Ababa, Addis Ababa University.

ASSFAW, M. T. (2016). Hydraulic Modeling Of Water Supply Distribution Network . Addis Ababa: A Thesis Submitted To The School Of Graduate Studies Of Jimma University In Partial Fulfilment Of The Requieriments For The Degree Of Master Of Science In Hydraulic Engineering.

Authority, A. A. (2011). City Government of Addis Ababa, Addis Ababa Water and Sewerage Authority Business Plan 2011–2020, Final Report, Addis Ababa.

Aydin and Nazli Yonca. (2014). Sustainability Assessment of Urban Water Distribution system. . Water resources management, v. 28(no. 12), pp. 4373-4384.

Bank, W. (2003). The World Bank Issue paper for project Design, Draft Final Report.

BCP. (2015). Socio Economic Profile of Bishoftu City Administration.

Belay, A. (2012). Hydaulic Network Modeling and upgrading of Legadadi subsystem Water supply.

Berihun, D. (2017). Assessment on the Current Water Quality Status of Walgamo River. Addis Ababa, Ethiopia.

Berihun, D. (2017). Assessment on the Current Water Quality Status of Walgamo River,Addis Ababa, Ethiopia.

Bhatt, B. V. (2017). Modernization in Water Distribution System. India: Sarvajanik College of Engineering and Technology.

Central Statistics Agency of Ethiopia. (2014).

Cunlifffe. (2014). Assessment of water system infrastructure and water supply. Altona.

Delesho, A. (2004). Urban Water Supply, The Case Of Assosa Town. Addis Ababa: Addis Ababa university.

Desalegn, W. B. (2015). Water supply coverage and water loss in distribution system in case of Addis Ababa.

Doe, W. H. (2015). Assessing the Challenges of Water Supply in Urban Ghana: The case of North Teshie. Master thesis, stockholm. Sweden.

Eshetu, D. (2015). Urban water supply System performance Assessment, the case of Bahirdar Town, Ethiopia.

Ethiopia, A. R. (2017). Drinking Water Quality in Ethiopia. Addis Ababa: Ministry of Water, Irrigation and Electricity.

(2004). Evaluation of Intermittent Water Supply System and Design of 24x7 for a residential area in Mysore,. India: Karnataka.

Frank, C. (2010). Fresh Water Supply : Global issues. . New York: InfoBase Publishing.

G. Anisha, A. K. (2016). Analysis and Design of Water Distribution Network Using EPANET for Chirala Municipality. International Journal of Engineering and Applied Sciences, 3(4), ISSN: 2394-3661.

G.P, P. K. (2017). Assessment and Design of Water Distribution System.

Health, M. o. (2005). Federal Democratic Republic of Ethiopia National hygiene and sanitation strategy Ministry of Health. Addis Ababa.

Ilesenim. (2006). Pre-feasibility assessment of onsite and decentralized sanitation systems for new satellite settlements in Abuja, Nigeria. PhD Thesis. Hamburg University of Technology.

Institute, W. B. (2005). Training Module 6 ,Performance Indicators. Roland Liemberger.

Jessy. (2011). Partitioning of unaccounted for water for Zambia City.

JTWSSA. (2020). Jimma Town Water Supply and Sewerage Authority. Jimma, Ethiopia.

Kahalekar, S. S. (2017). Design of Optimal Water Supply Network and Its Water Quality Analysis by using Water GEMS. International Journal of Science and Research, 8(2).

Kebede, T. G. (2010). Water supply; produced in collaboration with the Ethiopia Public Health Initiative, the Carter Center The Ministry of Health and Ministry of Education. Addis Ababa: Haramaya University.

Kebeto, S. (2016). Water Supply Coverage and Water loss in distribution system modeling.

Liu, L. J. (2010). For the Child Health Global, regional, and national causes of child mortality: an updated systematic analysis. 179(2), 2151–61.

Maina, K. M. (2015). Ssessment Of The Challenges Of Water Supply And Sanitation In Uncontrolled Residential Developments. Nairobi County.

Management, N. W. (2000). Federal Democratic Republic of Ethiopia National Water Resources Management Policy,. Ethiopia.

Mays, L. (1999). Reliability Analysis of Water Distribution Systems. New York, NY, USA,: American Society of Civil Engineers .

Melaku, A. (2015). Assessment of Water loss in water supply net work.

Mersha, S. A. (2007). Evaluation Of Technical Sustainability Of Rural Water Supply Projects In The Amhara Regional State Ase Study In South Wollo. Addis Ababa, Ethiopia.

Mesfine, A. (2017). Hydraulic performance evaluation of Tulu bolo town water supply distribution networks. Jimma university.

Ministry of Water Resource. (2016). urban water supply design criteria by ministry of water resource. Customers Satisfacion with Clean Drinking Water provided by Lahore Cantonment, 5(2).

Ministry of water resources. (2006). Data compilation and analysis project(1997). Standard design and construction guideline for water supply structure and their main components.

Minster of Water Resource. (2006). Urban water supply design criteria, Urban water supply and sanitation department. Addis Ababa: Addis Ababa, Minstory of Water Resource.

Minwuye, Y. (2015). Assessing Potable Water Supply And Distribution Problems Of Rebu Gebeya Town Amhara Region. Addis Ababa: Addis Ababa University.

Minwuye, Y. (2015). ssessing potable water supply and distribution problems of Rebu Gebeya town, Amhara Region. Addis Ababa, Ethiopia: Addis Ababa University.

MoWR. (2006). Water supply design guideline.

Ms. P. S. Salunke, M. M. (2018). An Overview: Water Distribution Network by Using Water GEMS Software. Journal of Advances and Scholarly Researches in Allied Education, XV(2), ISSN 2230-7540.

Mutikanga. (2012). water loss management, tools and methods for developing country.

Mwanza, D. (2004). African Public Utilities Not Performing Efficiently, Paper presented at the 12th Union for African Water Suppliers Congress. Ghana: Accra.

Neufville, R. d. (2000). Systems Analysis of Water Distribution Networks.

ohammed Ali I. Al-Hashim, N. J.-M. (2014). Analysis And Evaluation Of The Potable Water Network And Water Quality . Diyala Journal Of Engineering Sciences, 5(1), 191-204.

Oljira, G. (2015). Investigation of Drinking Water quality from source to point of Distribution (the case of Gimbi Town,in Oromia Regional State of Ethiopia).

Organization, W. h. (2010). The global water supply and sanitation assessment. Geneva.

Pieter, T. G. (2013). Issues and Challenges in Local and Regional Development, Rural Urban Linkages, and Inequalities in Developing Countries.

Rahmato, D. (1999-2000). Water Resources Development in Ethiopia:Issue of Sustainability and Participation. ddis Ababa, Ethiopia: Forum for Social Studies.

Reforms, M. o. (2008).

Report, H. d., & Holeta urban planning office. (2009,2010). Holeta Town water supply and sanitation project Design Review Report.

Resource, M. o. (2009). Ministry of Water Resource Water sector development program; main report volume 1. Addis Ababa.

Resources, M. o. (2012-2016). Water Sector Development Prgoramme . Water Supply and Sanitation Programme.

Rossman, L. A. (2000). Water Supply and Water Resources Division National Risk Management Research Laboratory.US-EPA.

Sharma. (2008). Performance indicators of water losses in distribution system.

Shinstine, D. A. (2015). Availability Analysis of Municipal Water Distribution Networks. Water Resources Planning & Management, 128(1), 140-151.

Solomon, B. (2011). n assessment on the status of water supply and sanitation in Ethiopia.

Sonaje. (2015). A review of modeling and application of water distribution networks software's.

Sonaje. (2015). A review of modeling and application of water distribution networks software's.

Source: Design Guideline for WSP, O. (2008).

Stevens. (2004). Water Supply Coverage and Water loss in distribution system modeling.

Suraj Kumar Bhagat, T. ,. (2019). Evaluating Physical and Fiscal Water Leakage in Water Distribution System. MDPI.

Taha, A.-W., Sharma, S., & Kennedy, M. (2019). Methods of assessment of water losses in water supply systems. Water Resour. Manag, 30(3), 4985–5001.

TAHAL Consulting Engineering. (2003). Addis Ababa Water Supply Project IIIA (AAWSP-IIIA).

Temesgen Mekuriaw, Y. K. (2018). Water Supply Distribution System Design. Addis Ababa: In Holeta Town Wolmera Woreda West (Shewa Zone of Oromia region, Ethiopia).

Towns, T. W. (2006). Towns Water Supply Feasibility Study and Engineering Design Report Oromia Towns.

Tynan, N. a. (2002). A water scorecard: Setting Performance Targets for Water Utilities. Public Policy for the Private Sector, Note No. 242, World Bank.

UNICEF, W. a. (2008). A Snapshot of Drinking Water and Sanitation in Africa A regional perspective based on new data from the WHO/UNICEF Joint Monitoring Program for Water Supply and Sanitation.

Vidhi N. Mehta, G. S. (2019). Design and Analysis of Rural Water Supply System Using Loop 4.0 and Water Gems V8i. International Journal of Engineering and Advanced Technology (IJEAT), 9(1), ISSN: 2249 – 8958.

Walski. (2003). Water demand forecast methodology for california water planning areas-work plan and model review. Carbondale: Planning and Management Consultants.

WaterGEMS. (2016). WaterGEMS V8i user guide.

Welday. (2005). Water supply Coverage and water loss in Distribution System. Addis Ababa.

WHO. (2010). Public Stand post Water supply, a design manual, Technical paper series 14. Netherlands: WHO, international references centre for community water supply.

YitayhLeul. (2012). Assessment of problems to sustainability of rural water supply and management systems in MachakelWoreda, Amhara region, M.A. thesis. Addis Ababa: Addis Ababa University.

Zewdu, A. (2014). Assessing Water Supply Coverage and Water Losses from Distribution System for planning Water loss Reduction Strategies. Aksum.

Appendixes

Appendix -1: Negative junction pressure recorded in distribution systems

Message Id	Scenario	Element Type	Element Id	Label	Time (hours)	Message
40004	Base	Junction	31	J-2	0.000	Negative pressure at Junction J-2.
40004	Base	Junction	42	J-8	0.000	Negative pressure at Junction J-8.
40004	Base	Junction	227	J-73	0.000	Negative pressure at Junction J-73.
40004	Base	Junction	229	J-74	0.000	Negative pressure at Junction J-74.
40004	Base	Junction	231	J-75	0.000	Negative pressure at Junction J-75.
40004	Base	Junction	239	J-78	0.000	Negative pressure at Junction J-78.
40004	Base	Junction	241	J-79	0.000	Negative pressure at Junction J-79.
40004	Base	Junction	243	J-80	0.000	Negative pressure at Junction J-80.
40004	Base	Junction	247	J-82	0.000	Negative pressure at Junction J-82.
40004	Base	Junction	251	J-84	0.000	Negative pressure at Junction J-84.
40004	Base	Junction	259	J-86	0.000	Negative pressure at Junction J-86.
40004	Base	Junction	261	J-87	0.000	Negative pressure at Junction J-87.
40004	Base	Junction	276	J-94	0.000	Negative pressure at Junction J-94.
40004	Base	Junction	280	J-95	0.000	Negative pressure at Junction J-95.
40004	Base	Junction	288	J-98	0.000	Negative pressure at Junction J-98.
40004	Base	Junction	323	J-107	0.000	Negative pressure at Junction J-107.

Appendix 2; existing water supply distribution network junction result at low flow Flex Table Junction Table at extended state simulation results

Label	Elevation (m)	X	Y	Demand (l/s)	Pressure (m H2O)
J-887	2,222.00	499,964	974,086	0.59	66.5
J-884	2,220.50	490,000	979,287	0.40	85.5
J-882	2,220.00	490,278	974,395	0.94	-5
J-880	2,223.00	491,025	973,292	0	28.5
J-888	2,221.00	490,123	970,989	0.25	9.5
J-890	2,219.00	499,575	978,988	0.57	66.5
J-551	2,223.00	492,393	975,988	0.99	85.5
J-550	2,222.80	491,598	969,913	1.64	57
J-883	2,218.30	491,390	970,572	0.45	9.5
J-538	2,218.00	493,275	979,084	1.04	47.5
J-549	2,222.00	492,003	970,072	0	151.9
J-1382	2,221.00	495,174	970,213	1.87	87
J-1399	2,220.00	495,174	971,002	0.47	81
J-1278	2,220.00	494,283	970,037	0.79	80.9
J-1383	2,220.00	495,373	971,016	1.18	10.5
J-553	2,224.50	497,322	979,188	0.50	13.5
J-1400	2,218.00	492,244	975,795	1.21	0
J-1401	2,218.00	494,252	976,123	0.90	4.5
J-552	2,223.20	495,172	975,994	0.87	1.5
J-554	2,224.50	496,174	976,233	0.85	10.5
J-1277	2,217.00	497,228	975,882	0	13.5
J-602	2,216.00	494,815	973,759	0.81	45.5
J-603	2,215.00	494,825	976,122	0.57	58.5
J-581	2,213.00	494,985	974,455	0	-4.8
J-576	2,212.50	494,785	976,264	0.66	19.5
J-577	2,210.50	494,439	975,895	0	6.5
J-1311	2,210.00	494,678	965,909	0.93	45.5

J-562	2,209.90	494,847	974,825	0.84	58.5
J-1402	2,210.00	495,786	976,047	0.19	39
J-1384	2,209.00	498,790	974,598	0.56	6.5
J-582	2,209.00	493,738	972,226	0.70	32.5
J-1310	2,208.00	494,786	976,302	0.50	103.9
J-555	2,225.00	494,789	974,548	0.40	52
J-563	2,207.40	494,753	975,871	0.60	45.5
J-564	2,206.00	494,790	974,024	0.80	84.5
J-1403	2,206.00	494,791	975,890	0.91	19.5
J-565	2,204.00	492,726	975,364	0.94	45.5
J-1323	2,203.00	496,532	973,810	0.90	97.5
J-1230	2,201.50	491,627	97,134	1.01	45.5
J-1306	2,201.00	490,620	973,653	0	52
J-921	2,199.90	495,694	974,515	0.80	65
J-1237	2,199.90	496,940	976,316	0.67	136.4
J-1238	2,199.90	491,527	974,828	0.33	6.5
J-1236	2,199.89	494,734	976,079	0.50	45.5
J-566	2,199.50	494,594	973,342	1.10	58.5
J-1313	2,199.00	494,247	975,827	1.28	0
J-1233	2,198.98	496,763	973,455	0.83	19.5
J-1301	2,198.80	492,737	971,782	0.90	6.5
J-1232	2,198.60	497,873	975,634	0	45.5
J-1286	2,198.00	494,676	971,035	1.32	58.5
J-1231	2,197.90	493,871	978,424	1.00	39
J-1235	2,197.90	495,593	975,766	1.05	6.5
J-1305	2,197.80	491,662	976,106	0	32.5
J-1291	2,196.90	493,854	975,807	0.58	-5
J-1229	2,196.00	492,767	974,442	1.22	2
J-594	2,195.60	491,038	974,182	0.85	60
J-1239	2,195.90	497,693	974,964	0.94	-1
J-1292	2,195.60	497,575	975,865	1.18	10
J-595	2,194.30	498,622	934,915	0.90	7
J-1295	2,194.50	499,823	971,685	1.01	-1
J-1308	2,194.50	497,821	971,152	0	-1
J-1289	2,193.50	497,932	976,819	1.18	-2
J-1290	2,192.80	492,931	973,876	0.97	-7
J-596	2,192.10	496,829	978,534	0	15
J-1297	2,191.20	497,764	973,864	0.90	0
J-1298	2,191.20	491,700	960,642	0.83	-2

J-1307	2,191.20	497,136	979,411	0.80	-10
J-1316	2,191.20	493,824	979,308	0.75	-3
J-1299	2,191.10	496,975	970,980	0.74	0
J-1300	2,191.05	494,980	973,327	0.56	-4
J-1302	2,190.90	495,043	970,238	1.01	-6
J-597	2,190.10	496,047	978,098	0.72	-4
J-599	2,189.40	497,053	978,866	0.57	-2
J-1179	2,190.00	498,152	970,022	0.87	0
J-1320	2,190.00	494,052	972,252	1.15	-10
J-1294	2,189.98	495,218	974,034	1.30	-24
J-1234	2,189.96	497,077	970,076	0	-9
J-1385	2,189.90	494,184	970,877	0	2
J-1375	2,189.50	495,209	970,899	0	7
J-598	2,189.30	496,198	979,488	1.68	-3
J-952	2,189.30	493,475	973,458	0	-16
J-953	2,189.30	491,598	976,046	0.96	-28
J-556	2,225.00	492,488	972,088	0.47	-16
J-1227	2,189.00	493,769	978,757	0.71	-4
J-1287	2,189.00	495,417	977,251	0	-19
J-919	2,188.50	496,207	979,791	1.83	-7
J-1177	2,188.50	497,318	971,515	0	-14
J-1322	2,187.60	491,537	973,579	0.62	-16
J-1059	2,186.70	491,319	976,110	1.06	-22
J-1060	2,185.60	493,707	9,737,184	0	-5
J-1228	2,185.60	495,829	976,702	0	-2
J-1273	2,184.60	494,419	971,404	0	-3
J-1057	2,184.50	492,710	976,232	2.70	-3
J-557	2,225.00	494,829	973,746	2.02	10
J-1055	2,183.70	496,777	972,796	1.94	-1
J-604	2,182.90	495,706	971,438	1.90	7
J-1056	2,182.60	497,926	973,769	0	20
J-1058	2,181.50	494,629	979,517	0	11
J-1178	2,181.10	496,871	977,775	1.28	19
J-977	2,205.00	496,599	978,844	1.11	13
J-957	2,179.80	495,719	970,286	0	1
J-958	2,179.90	492,384	976,350	0.74	22
J-1180	2,180.10	492,757	973,694	0	1
J-717	2,178.90	491,830	975,557	0	7
J-607	2,178.90	494,830	976,663	0.43	10

J-899	2,178.90	495,721	972,312	0	-11
J-1390	2,178.70	493,659	970,045	1.58	-5
J-1061	2,178.90	494,502	975,778	0	-7
J-606	2,177.60	497,921	971,061	0.89	4
J-1225	2,176.00	493,256	973,339	0.59	-7
J-1367	2,175.80	497,571	956,040	0.03	9
J-558	2,227.00	497,344	976,360	0.49	-1
J-1296	2,175.00	497,681	974,439	0.39	-5
J-900	2,173.80	497,243	943,284	0.34	-10
J-1293	2,173.50	493,801	972,176	0.28	-4
J-608	2,170.90	494,293	978,383	0.26	-3
J-605	2,169.90	494,212	973,314	0.01	12
J-920	2,169.90	493,688	971,006	0.12	-5
J-980	2,169.50	494,797	971,896	0.07	-2
J-1151	2,169.80	491,885	975,123	1.11	4
J-609	2,168.98	493,969	971,943	0.61	4
J-610	2,168.90	493,775	975,026	0.30	12
J-1371	2,169.20	494,067	971,665	0.46	-6
J-1195	2,167.81	494,153	973,856	0.37	-7
J-1331	2,167.40	493,905	979,706	0.53	-1
J-1319	2,168.00	494,491	971,009	0.22	-7
J-611	2,166.70	495,294	947,764	0.64	-29
J-979	2,166.45	493,984	979,868	0.81	15
J-922	2,166.80	498,482	977,400	0.58	-9
J-584	2,201.00	497,261	973,040	0.46	-1
J-1226	2,166.50	496,158	974,998	0.69	-21
J-1332	2,165.80	494,264	976,216	0.92	-1
J-983	2,200.50	491,147	958,957	0.40	-21
J-1216	2,165.90	495,179	974,450	0.43	-1
J-976	2,200.10	496,161	975,573	0.39	-19
J-696	2,200.10	497,171	975,808	0.52	-17
J-950	2,200.00	495,255	974,410	0.06	-7
J-947	2,199.90	493,177	97,561	0.28	-5
J-923	2,165.55	495,127	976,132	0.13	-3
J-583	2,200.10	498,147	978,880	0.38	-5
J-1314	2,165.00	497,138	976,122	0.57	-5
J-971	2,198.80	491,275	974,758	0.63	7
J-585	2,198.89	493,366	970,698	0.18	3
J-1268	2,198.70	495,771	970,793	0.32	6

J-1315	2,164.00	494,759	972,718	0.39	11
J-944	2,197.89	492,880	978,813	0.30	13
J-942	2,197.80	496,473	979,719	0.23	11
J-984	2,197.70	495,762	973,917	0.51	-2
J-943	2,196.80	495,880	971,009	0.56	-3
J-586	2,196.70	493,828	975,927	0.17	5
J-699	2,196.80	492,758	970,584	0.02	5
J-587	2,196.40	493,976	950,600	0.12	3
J-1206	2,196.50	497,682	940,595	0.34	5
J-1076	2,195.80	495,922	970,921	0.44	5
J-1078	2,195.70	494,652	961,008	0.07	-4
J-700	2,195.80	495,771	959,721	0.39	3
J-1046	2,195.70	492,439	970,127	0.52	-6
J-1025	2,195.60	491,808	979,078	0.55	5
J-1096	2,194.90	492,881	978,393	0.07	7
J-1047	2,194.60	490,881	975,935	0.00	9
J-1026	2,194.40	492,773	978,890	0.21	12
J-1079	2,194.20	491,712	979,074	0.02	6
J-612	2,159.56	493,555	970,908	0.15	7
J-1329	2,159.70	497,971	975,106	0.42	-4
J-1062	2,160.00	498,311	974,925	0.55	9
J-1309	2,160.00	499,624	976,847	0.09	-6
J-1376	2,159.40	493,399	954,971	0.49	4
J-559	2,227.00	493,733	943,648	0.65	-5
J-1018	2,192.80	493,299	942,504	0.69	-3
J-1280	2,157.90	493,301	963,918	0.09	9
J-1077	2,192.40	493,794	951,578	0.59	14
J-941	2,191.70	493,722	961,140	0.03	5
J-1041	2,191.80	493,189	969,066	0.49	-2
J-1339	2,155.87	493,298	958,898	0.39	-5
J-946	2,190.40	493,385	949,609	0.34	-2
J-972	2,189.90	494,465	970,882	0.28	9
J-1204	2,189.90	494,564	926,780	0.26	-2
J-1042	2,189.98	494,775	974,939	0.01	-3
J-1205	2,189.98	494,465	978,060	0.12	-3
J-698	2,189.90	494,564	977,793	0.07	12
J-1336	2,154.89	494,775	975,500	0.23	6
J-1043	2,188.80	494,751	971,717	0.10	8
J-1200	2,188.60	494,621	972,693	0.24	12

J-693	2,187.90	494,080	975,642	0.00	-5
J-981	2,186.90	494,889	974,836	0.17	-5
J-1125	2,186.70	494,103	970,505	0.00	15
J-1073	2,186.70	494,886	976,456	0.21	10
J-969	2,186.50	494,772	970,594	0.16	29
J-1072	2,185.70	494,542	978,492	1.00	33
J-871	2,185.70	494,672	976,631	0.10	22
J-1201	2,185.60	494,672	973,633	0.13	29
J-975	2,184.70	494,780	977,582	0.07	4
J-695	2,183.77	494,869	975,746	0.18	26
J-692	2,183.80	494,818	975,729	0.16	41
J-703	2,183.60	494,741	979,153	0.04	16
J-705	2,183.00	494,749	978,555	1.00	18
J-1082	2,182.40	494,670	976,581	0.14	58
J-1014	2,182.00	494,672	978,959	0.10	40
J-1034	2,182.00	494,725	973,691	0.00	1
J-707	2,181.70	493,372	974,520	0.20	0
J-688	2,181.40	493,482	972,931	0.16	29
J-1033	2,181.00	494,540	970,139	0.18	-14
J-936	2,180.80	494,343	978,405	0.00	-37
J-1088	2,180.60	49,600	975,823	1.00	-51
J-689	2,179.90	494,237	967,925	0.20	57
J-1092	2,179.90	496,403	975,210	0.23	46
J-694	2,179.90	492,344	975,714	0.00	32
J-935	2,180.00	496,347	974,370	1.00	44
J-1015	2,180.00	496,296	973,365	0.07	23
J-1209	2,179.90	495,344	977,179	0.10	23
J-1016	2,179.90	499,346	974,481	0.00	-9
J-1253	2,179.90	493,310	975,891	0.25	11
J-704	2,179.80	492,347	973,702	0.16	-6
J-1017	2,178.90	491,348	976,982	0.00	3
J-1074	2,178.70	492,784	975,791	0.27	20
J-547	2,200.00	493,092	976,876	0.26	20
J-1118	2,177.89	495,186	972,162	0.20	20
J-1006	2,178.00	494,179	975,734	0.21	14
J-1244	2,178.00	493,449	974,816	0.25	0
J-593	2,178.00	494,545	972,888	0.00	2
J-708	2,178.00	493,538	973,695	0.24	5
J-1196	2,177.90	495,613	976,580	0.17	1

J-1029	2,177.80	497,860	971,509	0.00	2
J-1080	2,177.50	497,444	971,001	0.23	2
J-1089	2,176.98	497,653	960,614	0.18	1
J-1075	2,176.90	497,512	970,967	0.20	1
J-1030	2,177.00	497,163	972,756	0.20	5
J-1032	2,177.00	495,949	974,712	0.23	5
J-1144	2,176.80	497,656	976,686	0.00	27
J-690	2,176.70	497,793	971,760	0.22	46
J-1084	2,176.70	497,595	972,907	0.18	73
J-1126	2,176.40	497,791	976,800	0.00	24
J-1031	2,176.50	497,511	975,807	0.16	24
J-1119	2,175.70	497,581	974,610	1.00	1
J-1122	2,175.60	497,774	974,698	0.15	58
J-933	2,175.70	497,686	975,072	1.00	5
J-716	2,175.40	496,953	978,502	0.24	5
J-1259	2,174.88	493,223	972,638	0.13	3
J-683	2,174.50	493,245	973,553	0.00	4
J-706	2,174.60	495,432	977,765	0.13	4
J-1175	2,174.50	492,567	978,772	0.14	2
J-932	2,173.60	496,322	979,572	0.12	8
J-1005	2,173.50	494,656	979,000	1.00	10
J-1266	2,172.60	495,322	975,888	0.20	13
J-1008	2,172.50	496,532	973,590	0.05	18
J-1123	2,171.70	495,643	971,601	0.12	20
J-1011	2,171.70	492,678	976,768	0.18	19
J-1271	2,171.60	494,573	975,624	1.00	20
J-1245	2,171.50	493,456	971,236	0.07	23
J-990	2,171.10	492,907	978,580	0.12	22
J-1131	2,170.60	494,912	976,490	0.20	19
J-1108	2,170.60	495,975	979,849	0.30	5
J-546	2,199.10	492,979	979,030	0.13	55
J-588	2,169.80	497,382	970,974	0.31	61
J-691	2,169.78	495,482	974,016	0.65	66
J-1113	2,169.70	494,694	974,796	0.22	113
J-1009	2,169.70	492,670	971,041	0.00	125
J-1199	2,169.60	497,540	976,967	0.27	54
J-684	2,168.90	496,995	967,783	1.00	54
J-1037	2,169.00	497,808	975,870	0.00	13
J-1262	2,168.80	497,018	978,811	0.67	131

J-1252	2,168.90	497,805	970,998	0.17	105
J-1112	2,168.70	497,691	971,619	0.08	104
J-589	2,167.90	497,460	993,712	1.00	6
J-1257	2,167.80	497,590	975,492	0.21	10
J-1107	2,167.90	497,590	971,992	0.05	16
J-1007	2,167.90	497,699	979,372	0.14	5
J-991	2,167.80	493,788	979,690	0.18	5
J-1035	2,167.70	492,738	975,705	0.00	0
J-686	2,166.78	494,660	976,724	0.10	13
J-1036	2,166.80	495,668	978,854	0.16	1
J-1065	2,165.90	491,588	978,868	0.00	1
J-685	2,165.87	494,590	971,918	0.23	1
J-949	2,165.78	493,644	976,116	1.00	1
J-1176	2,165.50	496,595	971,812	0.00	1
J-1256	2,165.30	495,717	997,880	0.26	1
J-674	2,164.70	498,379	970,435	0.30	2
J-1100	2,164.60	497,755	970,276	0.21	2
J-590	2,163.70	497,829	976,477	0.17	3
J-1023	2,163.65	496,829	987,062	0.00	4
J-1044	2,163.70	497,719	976,897	0.13	3
J-1091	2,163.50	494,656	973,592	0.28	6
J-1099	2,163.30	496,497	979,589	0.33	9
J-1094	2,162.80	496,721	973,499	0.21	3
J-1093	2,162.60	496,249	975,136	1.00	3
J-1174	2,162.50	493,567	977,206	0.35	0
J-1121	2,162.10	491,338	977,156	0.34	7
J-1103	2,161.56	496,678	977,001	0.26	1
J-711	2,161.70	493,224	977,258	0.00	1
J-673	2,161.50	490,239	977,405	0.32	0
J-1070	2,161.60	491,740	977,925	0.15	0
J-1109	2,161.00	492,664	976,786	0.31	1
J-675	2,160.60	494,124	978,946	0.22	0
J-560	2,228.00	496,235	979,084	0.00	0
J-1143	2,160.10	495,324	976,975	0.30	0
J-682	2,159.90	497,914	977,204	0.23	0
J-1049	2,159.89	497,015	975,936	0.26	1
J-1069	2,159.98	491,229	976,193	0.27	12
J-1139	2,159.89	492,206	975,158	0.00	20
J-1136	2,159.90	493,073	974,627	0.25	3

J-1104	2,159.70	497,262	972,061	0.29	11
J-1134	2,159.70	497,653	975,117	0.23	35
J-1270	2,159.80	497,191	975,154	0.21	108
J-1071	2,159.60	496,491	974,163	0.20	52
J-1105	2,159.10	495,684	975,100	0.19	62
J-1203	2,159.00	494,672	974,065	0.19	13
J-1135	2,158.90	492,794	972,816	0.14	27
J-681	2,158.80	491,385	971,254	0.00	96
J-712	2,158.90	494,675	970,094	1.00	17
J-1137	2,158.70	498,794	978,966	0.25	123
J-1149	2,157.90	497,742	979,073	0.00	119
J-676	2,157.80	496,671	977,910	0.27	141
J-1148	2,156.90	494,891	977,342	0.00	138
J-1048	2,156.89	498,595	975,147	0.24	22
J-930	2,156.98	497,836	975,125	0.33	113
J-1145	2,156.80	496,564	975,970	0.39	51
J-1045	2,156.80	493,684	976,936	0.00	34
J-680	2,156.50	496,350	973,168	0.23	54
J-1098	2,156.50	497,793	976,935	0.36	115
J-1124	2,156.40	494,595	974,155	0.31	170
J-1146	2,155.80	492,791	973,892	0.14	190
J-1012	2,155.90	493,511	976,884	0.00	195
J-1138	2,155.80	498,964	972,138	0.40	200
J-939	2,155.76	489,020	977,328	0.60	194
J-1269	2,155.70	489,297	972,446	0.25	101
J-677	2,155.50	490,043	971,345	0.00	109
J-1001	2,155.50	489,143	969,047	0.46	145
J-1120	2,154.98	498,576	977,030	0.44	152
J-1116	2,154.50	491,408	974,036	0.43	10
J-613	2,197.30	490,615	967,973	0.53	28
J-543	2,206.00	490,407	968,631	0.41	19
J-1013	2,154.10	492,288	977,126	0.00	29
J-1003	2,153.70	491,019	968,132	0.25	63
J-1022	2,153.70	494,184	968,273	0.34	94
J-542	2,207.30	494,184	969,060	0.17	70
J-1102	2,152.60	493,294	968,097	0.48	5
J-545	2,198.80	494,382	969,074	0.00	11
J-679	2,151.80	496,327	977,230	0.10	38
J-998	2,151.60	491,260	973,843	0.29	7

J-993	2,150.90	493,263	974,171	0.36	48
J-544	2,200.50	494,182	974,042	0.26	86
J-669	2,150.40	495,182	974,281	0.20	55
J-999	2,150.50	496,234	973,930	0.31	94
J-1261	2,150.20	493,825	971,811	0.00	252
J-938	2,150.10	493,835	974,170	0.46	47
J-1087	2,149.90	493,995	972,506	0.48	56
J-614	2,195.90	493,795	974,311	0.46	12
J-1129	2,149.89	493,450	973,943	0.52	25
J-709	2,149.90	493,689	963,977	0.60	87
J-541	2,209.00	493,857	972,875	0.00	15
J-1117	2,149.79	494,794	974,095	0.34	112
J-1111	2,149.70	497,792	972,649	0.17	198
J-1127	2,149.30	492,751	970,282	0.00	128
J-1128	2,148.98	493,796	974,349	0.56	217
J-1027	2,148.90	493,799	972,599	0.65	191
J-592	2,148.90	493,763	973,919	0.43	20
J-1086	2,148.70	493,800	972,076	0.46	14
J-1004	2,148.60	493,801	973,938	0.70	38
J-1133	2,147.80	491,741	973,413	0.00	46
J-992	2,147.90	495,539	971,862	0.51	68
J-1251	2,147.66	490,644	96,940	0.54	76
J-994	2,147.10	489,639	971,706	0.64	83
J-901	2,193.65	494,703	972,566	0.29	79
J-1395	2,146.80	495,946	974,363	0.00	77
J-710	2,146.50	490,544	972,878	0.44	80
J-1020	2,145.76	493,745	974,127	0.48	86
J-1028	2,145.40	493,605	971,395	0.60	80
J-1002	2,144.60	493,259	973,875	0.46	100
J-1396	2,144.50	495,769	971,508	0.52	17
J-1397	2,143.80	491,752	969,838	0.00	28
J-997	2,143.60	496,877	973,683	0.60	16
J-1254	2,143.20	493,687	969,093	0.50	56
J-1021	2,142.94	492,883	976,467	0.58	83
J-591	2,142.50	494,602	973,814	0.46	47
J-713	2,142.30	490,679	974,154	0.00	79
J-1141	2,142.20	492,866	973,855	0.41	83
J-1051	2,141.90	491,781	972,493	0.38	74
J-714	2,141.00	490,056	972,234	0.38	86

J-1050	2,140.70	496,698	973,014	0.29	91
J-1140	2,140.20	496,580	973,913	0.62	68
J-1068	2,140.00	497,625	933,045	0.00	85
J-1142	2,140.00	498,823	969,742	0.51	11
J-1303	2,179.50	496,825	969,210	0.48	13
J-902	2,178.96	496,936	974,865	0.53	14
J-1304	2,177.80	491,945	971,928	0.00	10
J-1368	2,177.50	495,835	976,577	0.47	13
J-1318	2,176.40	496,768	971,916	0.65	13
J-903	2,176.80	490,717	958,721	0.78	4
J-925	2,176.54	496,142	977,452	0.20	36
J-571	2,175.78	492,836	977,349	0.46	41
J-904	2,175.60	495,981	969,038	0.00	44
J-569	2,174.55	493,990	971,380	0.62	68
J-573	2,174.45	494,053	968,298	0.28	110
J-916	2,174.30	495,055	976,142	0.48	36
J-540	2,200.00	496,059	976,908	0.81	36
J-1220	2,174.35	497,156	968,082	1.20	9
J-574	2,173.99	493,064	970,307	0.51	87
J-924	2,171.80	494,228	972,086	0.00	70
J-575	2,173.97	496,083	968,136	0.92	69
J-615	2,170.90	493,196	968,935	0.88	4
J-616	2,173.95	494,219	968,957	0.86	7
J-617	2,173.89	495,206	977,529	1.06	11
J-619	2,173.96	492,488	971,511	0.83	4
J-636	2,170.00	490,615	974,094	0.58	37
J-618	2,173.89	491,503	970,144	0.51	57
J-988	2,173.94	492,781	976,799	0.68	92
J-1373	2,174.45	494,426	975,296	1.00	30
J-1386	2,173.93	495,215	977,831	0.95	30
J-635	2,167.45	496,323	969,572	0.85	7
J-1224	2,173.90	490,554	971,632	0.20	73
J-1221	2,173.35	490,336	974,158	1.00	58
J-1222	2,173.94	492,720	9,717,710	0.72	58
J-637	2,166.50	494,837	974,749	0.51	3
J-1219	2,173.89	493,430	969,461	0.41	6
J-701	2,173.85	491,725	974,280	0.62	9
J-638	2,165.43	493,839	971,799	0.00	3
J-647	2,164.80	495,783	970,850	0.93	67

J-1285	2,165.80	494,715	969,495	0.96	34
J-651	2,173.26	496,930	971,821	0.92	52
J-1190	2,163.50	493,640	977,558	1.03	84
J-1282	2,173.00	495,877	975,819	0.00	28
J-623	2,173.80	495,606	976,886	0.82	28
J-621	2,173.78	494,728	968,345	0.68	7
J-648	2,162.60	491,399	974,397	0.34	67
J-1283	2,173.20	491,771	971,747	0.51	53
J-630	2,173.70	490,846	973,606	1.13	53
J-1312	2,160.50	493,840	974,710	1.30	3
J-620	2,173.80	494,730	970,367	0.85	5
J-649	2,161.54	492,672	968,105	0.92	8
J-1324	2,160.10	493,513	973,826	0.00	3
J-1356	2,173.59	496,925	969,119	1.34	4
J-639	2,159.55	492,269	971,392	1.02	7
J-1317	2,158.90	496,576	954,128	1.07	11
J-622	2,173.69	496,349	974,407	1.29	3
J-650	2,159.98	496,686	972,490	0.59	3
J-1187	2,159.96	496,249	941,397	0.00	1
J-1288	2,159.00	492,813	970,232	0.87	8
J-1354	2,173.57	493,304	976,426	0.97	7
J-891	2,173.75	493,224	971,367	1.20	2
J-928	2,156.43	492,701	969,064	0.92	0
J-654	2,158.60	493,807	969,952	0.00	4
J-1284	2,157.90	490,901	973,173	1.06	6
J-632	2,173.67	492,981	969,999	1.20	9
J-652	2,157.65	492,787	973,076	0.99	3
J-1189	2,157.65	493,079	969,722	0.00	64
J-968	2,173.58	493,165	971,908	0.92	5
J-878	2,156.45	492,917	977,747	0.85	10
J-641	2,154.78	493,502	969,067	0.81	34
J-655	2,156.40	494,303	945,868	0.77	6
J-1321	2,154.62	492,996	977,908	0.75	44
J-624	2,173.74	497,485	975,445	0.58	78
J-653	2,155.90	496,266	971,094	0.00	50
J-631	2,173.65	495,166	973,048	1.01	85
J-656	2,155.70	493,275	974,264	0.96	5
J-1193	2,155.45	490,165	957,039	1.07	8
J-1343	2,153.34	494,189	972,501	0.00	3

J-1352	2,154.76	495,169	973,622	0.94	15
J-1276	2,154.60	496,177	973,856	1.31	89
J-1342	2,152.74	494,264	972,461	1.56	90
J-643	2,152.70	492,191	97,366	0.39	16
J-633	2,173.65	494,137	974,180	0.93	129
J-658	2,154.40	497,151	976,922	1.43	24
J-644	2,152.00	496,144	974,170	1.23	29
J-893	2,173.73	490,292	972,808	0.56	6
J-1366	2,153.70	492,379	968,757	0.97	13
J-1358	2,153.20	494,779	968,851	1.61	44
J-1353	2,152.70	493,769	970,773	0.00	8
J-642	2,151.20	491,894	976,855	1.01	57
J-634	2,173.64	495,480	977,760	0.00	101
J-1365	2,151.10	494,770	971,969	1.83	65
J-875	2,152.34	494,888	969,067	1.76	110
J-1348	2,150.32	492,840	973,975	1.72	97
J-625	2,173.74	491,772	968,643	1.00	23
J-1370	2,173.63	492,988	948,699	0.00	180
J-964	2,173.59	496,687	938,714	1.16	34
J-645	2,149.50	494,930	968,979	1.01	40
J-626	2,173.60	493,663	959,086	1.35	8
J-1377	2,150.50	494,779	957,802	0.67	18
J-657	2,150.45	491,454	968,187	0.00	62
J-1361	2,148.70	490,824	977,120	1.70	11
J-646	2,148.60	491,895	976,436	0.39	80
J-627	2,173.70	489,899	973,983	0.00	141
J-659	2,149.56	491,787	976,932	1.43	91
J-1328	2,149.43	490,729	977,116	1.03	155
J-1378	2,148.93	492,568	968,966	0.81	136
J-660	2,148.76	496,975	973,156	1.23	20
J-1327	2,148.70	497,314	972,975	1.64	4
J-1192	2,148.67	498,625	974,893	1.85	9
J-702	2,173.59	492,412	953,061	0.00	32
J-1214	2,173.67	492,746	941,761	0.00	5
J-1344	2,146.40	492,312	940,619	2.06	41
J-1362	2,147.50	492,314	961,990	0.00	72
J-1052	2,147.90	492,806	949,675	1.63	47
J-661	2,147.88	492,735	959,218	1.36	79

J-1157	2,147.65	492,203	967,128	0.67	70
J-1380	2,146.87	492,311	956,980	1.01	12
J-1218	2,173.56	492,398	947,710	0.81	20
J-1182	2,144.60	493,476	968,940	0.58	21
J-1053	2,146.40	493,575	924,926	0.46	2
J-1274	2,146.50	493,785	972,989	0.69	5
J-1337	2,145.78	493,476	976,104	0.00	3
J-1349	2,145.67	493,575	975,837	0.24	10
J-1275	2,145.70	493,785	973,549	0.27	77
J-1379	2,144.89	493,761	969,774	0.23	14
J-1345	2,143.30	493,632	970,748	0.36	17
J-662	2,145.34	493,092	973,691	0.54	4
J-1223	2,144.60	493,899	972,886	0.12	7
J-1326	2,144.56	493,115	968,564	0.77	26
J-1381	2,143.67	493,896	974,503	0.38	5
J-1054	2,143.56	493,782	968,653	0.57	34
J-1351	2,143.56	493,553	976,535	0.47	60
J-1393	2,143.00	493,683	974,678	0.66	39
J-663	2,142.76	493,683	971,686	0.28	66
J-1335	2,173.49	493,790	975,627	0.80	58
J-629	2,173.50	493,879	973,795	1.01	4
J-628	2,173.59	493,828	973,778	0.72	9
J-664	2,141.56	493,752	977,195	0.57	31
J-1364	2,139.78	493,760	976,598	0.87	5
J-1064	2,173.40	493,681	974,628	1.15	40
J-1166	2,140.45	493,683	977,001	0.50	71
J-665	2,139.78	493,736	971,744	0.54	46
J-1154	2,139.54	492,385	972,571	0.49	77
J-1363	2,138.67	492,495	970,985	0.65	68
J-1159	2,138.56	493,551	968,199	0.08	17
J-1153	2,138.56	493,354	976,448	0.35	34
J-1162	2,137.90	49,501	973,871	0.16	25
J-1173	2,173.20	493,249	965,989	0.47	29
J-1158	2,136.45	495,410	973,260	0.71	6
J-1164	2,138.65	491,359	973,763	0.78	13
J-1325	2,134.67	495,354	972,421	0.23	45
J-1165	2,136.88	495,303	971,418	0.40	8
J-1156	2,133.78	494,353	975,225	0.49	58
J-1168	2,135.30	498,347	972,532	0.37	103

J-1155	2,133.70	492,323	973,939	0.29	67
J-1191	2,131.10	491,362	971,755	0.64	113
J-1160	2,133.70	490,365	975,028	0.70	99
J-1161	2,133.67	491,798	973,839	0.21	24
J-1163	2,133.32	492,106	974,922	0.02	13
J-1171	2,133.45	494,196	970,218	0.15	15
J-666	2,131.78	493,191	973,783	0.42	27
J-1374	2,115.00	492,462	972,866	0.55	1
J-667	2,130.90	493,556	970,942	0.09	-2
J-668	2,124.00	492,551	971,748	0.49	19
J-1334	2,130.00	494,622	974,627	0.65	67
J-1392	2,123.00	496,864	969,566	0.69	53
J-1372	2,173.78	496,449	969,059	0.09	65

Appendix 3: Flex table for pipe reports in extended state period simulation results of the study area (links at average day demand)

Label	Length (m)	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C	Flow (l/s)	Velocity (m/s)	Head loss Gradient m/m
P-1	8	J-655	J-654	40	Ductile Iron	130	16	5.130	0.076
P-2	15	J-875	J-655	30	Ductile Iron	130	13	1.840	0.011
P-3	87	J-650	J-649	40	Ductile Iron	130	20	1.140	0.005
P-4	197	J-654	J-650	40	Ductile Iron	130	8	0.980	0.004
P-11	8	J-890	J-883	250	Ductile Iron	130	12	0.840	0.003
P-12	11	J-884	J-888	250	Ductile Iron	130	-11	0.170	0.000
P-13	9	J-888	J-887	250	Ductile Iron	130	23	1.340	0.006

P-14	10	J-891	J-624	40	Ductile Iron	130	17	1.090	0.004
P-15	52	J-624	J-893	40	Ductile Iron	130	6	1.020	0.004
P-16	120	J-621	J-891	50	Ductile Iron	130	9	0.800	0.002
P-17	330	J-701	J-621	50	Ductile Iron	130	16	1.720	0.010
P-18	66	J-638	J-637	40	Ductile Iron	130	37	0.600	0.001
P-19	100	J-639	J-638	30	Ductile Iron	130	2	0.040	0.050
P-21	6	J-899	J-900	80	Ductile Iron	130	12	0.200	0.067
P-22	7	J-901	J-902	40	Ductile Iron	130	24	0.390	0.001
P-23	9	J-903	J-904	40	Ductile Iron	130	38	0.620	0.001
P-24	12	J-575	J-574	50	Ductile Iron	130	15	0.240	0.045
P-25	14	J-902	J-903	60	Ductile Iron	130	85	1.380	0.007
P-26	23	J-615	J-903	60	Ductile Iron	130	65	1.060	0.004
P-27	28	J-574	J-573	50	Ductile Iron	130	43	0.690	0.002
P-28	36	J-571	J-902	80	Ductile Iron	130	21	0.330	0.056
P-29	36	J-595	J-594	250	Ductile Iron	130	5	0.070	0.065
P-30	48	J-597	J-596	250	Ductile Iron	130	25	0.400	0.001
P-31	58	J-617	J-616	50	Ductile Iron	130	29	0.480	0.001
P-32	58	J-903	J-916	60	Ductile Iron	130	15	0.250	0.098
P-33	62	J-618	J-617	50	Ductile Iron	130	10	0.170	0.067
P-34	69	J-616	J-575	50	Ductile Iron	130	11	0.170	0.034
P-35	71	J-902	J-614	80	Ductile Iron	130	-4	0.060	0.035
P-36	89	J-919	J-899	80	Ductile Iron	130	6	0.100	0.320
P-38	103	J-900	J-920	80	Ductile Iron	130	26	0.420	0.001

P-39	144	J-596	J-595	250	Ductile Iron	130	-9	0.150	0.023
P-40	166	J-594	J-921	250	Ductile Iron	130	-4	0.070	0.025
P-41	195	J-922	J-923	40	Ductile Iron	130	-2	0.040	0.025
P-42	286	J-924	J-925	40	Ductile Iron	130	1	0.010	0.012
P-43	323	J-614	J-613	80	Ductile Iron	130	-10	0.160	0.021
P-44	310	J-622	J-928	40	Ductile Iron	130	-5	0.070	0.027
P-45	196	J-701	J-618	50	Ductile Iron	130	17	0.280	0.012
P-46	80	J-649	J-648	40	Ductile Iron	130	-37	0.600	0.001
P-47	381	J-648	J-636	50	Galvanized iron	130	9	0.140	0.000
P-48	8	J-930	J-712	20	Galvanized iron	130	39	0.630	0.002
P-49	6	J-932	J-933	30	Galvanized iron	130	6	0.090	0.000
P-50	9	J-708	J-935	20	Galvanized iron	130	1	0.010	0.000
P-51	11	J-936	J-688	25	Galvanized iron	130	-1	0.010	0.000
P-52	16	J-938	J-939	20	Galvanized iron	130	1	0.010	0.000
P-53	19	J-693	J-941	25	Galvanized iron	130	74	1.210	0.005
P-54	20	J-942	J-943	25	Galvanized iron	130	49	0.800	0.002
P-55	26	J-944	J-587	20	Galvanized iron	130	-50	0.810	0.002
P-56	28	J-587	J-946	20	Galvanized iron	130	-423	6.870	0.130
P-57	32	J-947	J-944	20	Galvanized iron	130	-7	0.110	0.870
P-58	30	J-939	J-930	20	Galvanized iron	130	-23	0.370	0.001
P-59	35	J-711	J-949	20	Galvanized iron	130	-31	0.510	0.001
P-60	39	J-950	J-933	25	Galvanized iron	130	18	0.300	0.098
P-61	47	J-712	J-711	20	Galvanized iron	130	12	0.190	0.047

P-62	60	J-949	J-708	20	Galvanized iron	130	1	0.010	0.038
P-63	61	J-684	J-936	25	Galvanized iron	130	3	0.050	0.067
P-64	7	J-952	J-953	80	HDPE	130	16	0.270	0.066
P-65	16	J-919	J-952	80	HDPE	130	7	0.110	0.087
P-67	338	J-717	J-599	250	HDPE	130	-2	0.010	0.006
P-68	481	J-953	J-596	80	HDPE	130	0	0.000	0.004
P-69	503	J-957	J-599	250	HDPE	130	0	0.000	0.004
P-70	9	J-958	J-604	80	HDPE	130	-1	0.000	0.002
P-71	46	J-633	J-634	20	HDPE	130	0	0.000	0.010
P-72	60	J-631	J-633	20	HDPE	130	0	0.000	0.001
P-73	61	J-632	J-631	20	HDPE	130	0	0.000	0.049
P-74	69	J-622	J-632	40	HDPE	130	2	0.010	0.066
P-75	84	J-634	J-964	20	HDPE	130	0	0.000	0.001
P-76	110	J-621	J-622	50	HDPE	130	2	0.010	0.001
P-77	150	J-623	J-701	40	HDPE	130	-2	0.010	0.044
P-78	175	J-620	J-623	40	HDPE	130	-2	0.010	0.007
P-79	177	J-605	J-958	80	HDPE	130	-1	0.000	0.004
P-80	435	J-620	J-968	30	HDPE	130	0	0.000	0.002
P-81	4	J-969	J-693	25	HDPE	130	-11	0.040	0.055
P-82	8	J-696	J-950	25	HDPE	130	21	0.070	0.064
P-83	5	J-971	J-942	25	HDPE	130	3	0.010	0.001
P-84	8	J-972	J-941	25	HDPE	130	-30	0.110	0.001
P-85	38	J-935	J-707	20	HDPE	130	-18	0.060	0.097
P-86	39	J-705	J-975	20	HDPE	130	-29	0.100	0.066
P-87	46	J-707	J-705	20	HDPE	130	-22	0.080	0.034
P-88	76	J-947	J-976	25	HDPE	130	-66	0.240	0.035
P-89	80	J-688	J-972	25	HDPE	130	-29	0.110	0.316
P-90	104	J-941	J-971	25	HDPE	130	-48	0.170	0.001
P-91	123	J-971	J-947	25	HDPE	130	-51	0.180	0.023
P-93	467	J-979	J-717	250	HDPE	130	0	0.000	0.025
P-95	6	J-871	J-981	20	HDPE	130	-1	0.000	0.025
P-96	5	J-975	J-981	20	HDPE	130	-35	0.120	0.012
P-97	11	J-696	J-976	25	HDPE	130	66	0.240	0.021
P-98	31	J-584	J-983	30	HDPE	130	89	0.320	0.027
P-99	63	J-983	J-696	25	HDPE	130	87	0.310	0.012
P-100	78	J-984	J-584	30	HDPE	130	-43	0.160	0.001
P-101	207	J-981	J-984	30	HDPE	130	-38	0.140	0.642
P-102	301	J-583	J-977	100	HDPE	130	634	2.260	0.002
P-103	293	J-584	J-583	50	HDPE	130	-132	0.470	0.049
P-105	127	J-988	J-619	40	HDPE	130	22.31	1.300	0.745
P-106	12	J-990	J-991	20	HDPE	130	16.49	1.057	0.967

P-107	11	J-992	J-993	20	HDPE	130	5.82	0.989	0.118
P-108	12	J-993	J-994	20	HDPE	130	8.73	0.776	0.005
P-109	12	J-710	J-709	20	HDPE	130	15.52	1.668	0.002
P-110	14	J-997	J-710	20	HDPE	130	35.89	0.582	0.002
P-111	14	J-998	J-999	20	HDPE	130	1.94	0.039	0.128
P-112	13	J-669	J-1001	20	HDPE	130	11.64	0.194	0.859
P-113	15	J-710	J-1002	20	HDPE	130	23.28	0.378	0.001
P-114	18	J-1003	J-998	20	HDPE	130	36.86	0.601	0.001
P-115	17	J-709	J-1004	20	HDPE	130	14.55	0.233	0.097
P-116	21	J-1005	J-990	20	HDPE	130	82.45	1.339	0.046
P-117	22	J-998	J-993	20	HDPE	130	63.05	1.028	0.038
P-118	27	J-1006	J-1007	20	HDPE	130	41.71	0.669	0.002
P-119	33	J-1008	J-1009	20	HDPE	130	20.37	0.320	0.054
P-120	31	J-706	J-1011	20	HDPE	130	4.85	0.068	0.063
P-121	24	J-1012	J-1013	20	HDPE	130	24.25	0.388	0.001
P-122	27	J-1014	J-1015	20	HDPE	130	0	0.000	0.026
P-123	38	J-1016	J-1017	20	HDPE	130	0	0.000	0.026
P-124	29	J-1018	J-700	20	HDPE	130	0	0.000	0.786
P-125	29	J-1020	J-1021	20	HDPE	130	2	0.010	0.786
P-126	31	J-1022	J-709	20	HDPE	130	0	0.000	0.786
P-127	31	J-1023	J-685	25	HDPE	130	0	0.000	0.003
P-128	31	J-1025	J-1026	20	HDPE	130	2	0.010	0.003
P-129	32	J-1027	J-1028	20	HDPE	130	0	0.000	0.116
P-130	15	J-1029	J-1030	20	HDPE	130	0	0.000	0.116
P-131	45	J-1031	J-1032	20	HDPE	130	-3	0.010	0.116
P-132	34	J-1033	J-1034	20	HDPE	130	-314	1.120	0.116
P-133	48	J-1035	J-1036	20	HDPE	130	314	1.120	0.116
P-134	35	J-1037	J-990	20	HDPE	130	-3	0.010	0.116
P-136	33	J-699	J-1041	20	HDPE	130	-3	0.010	0.116
P-137	73	J-1042	J-1043	20	HDPE	130	-10	0.030	0.116
P-138	53	J-1044	J-1045	20	HDPE	130	-8	0.030	0.116
P-139	60	J-1046	J-1047	20	HDPE	130	0	0.000	0.075
P-140	65	J-1048	J-1049	25	HDPE	130	-1	0.000	0.011
P-141	71	J-1050	J-1051	20	HDPE	130	0	0.000	0.005
P-142	34	J-1052	J-1053	20	HDPE	130	0	0.000	0.004
P-143	67	J-1054	J-1052	20	HDPE	130	0	0.000	0.003
P-144	55	J-1055	J-1056	25	HDPE	130	1	0.000	0.060
P-145	21	J-1057	J-1055	25	HDPE	130	2	0.010	0.906
P-146	27	J-1055	J-1058	25	HDPE	130	2	0.010	1.176
P-147	40	J-1059	J-1060	25	HDPE	130	1	0.000	0.144
P-148	61	J-1061	J-1062	30	HDPE	130	1	0.000	0.006
P-149	151	J-629	J-1064	20	HDPE	130	0	0.000	0.002
P-150	11	J-1065	J-590	25	HDPE	130	4	0.010	0.002

P-151	8	J-714	J-1068	20	HDPE	130	15.472	4.961	0.156
P-152	8	J-1069	J-1070	25	HDPE	130	12.571	1.779	1.044
P-153	13	J-1070	J-1071	25	HDPE	130	19.34	1.102	0.001
P-154	14	J-1072	J-1073	25	HDPE	130	7.736	0.948	0.001
P-155	14	J-1074	J-1075	25	HDPE	130	11.604	0.812	0.118
P-156	15	J-1076	J-1077	15	HDPE	130	-10.637	0.164	0.056
P-157	16	J-1078	J-1079	25	HDPE	130	22.241	1.296	0.046
P-158	16	J-1074	J-1080	25	HDPE	130	16.439	1.054	0.080
P-159	17	J-695	J-1082	25	HDPE	130	5.802	0.986	0.079
P-160	28	J-950	J-698	25	HDPE	130	8.703	0.774	0.104
P-161	20	J-698	J-1084	25	HDPE	130	15.472	1.663	0.010
P-162	28	J-586	J-1076	15	HDPE	130	35.779	0.580	0.001
P-163	16	J-1086	J-1087	25	HDPE	130	1.934	0.039	0.048
P-164	23	J-1073	J-698	25	HDPE	130	11.604	0.193	0.065
P-165	23	J-1088	J-1016	20	HDPE	130	23.208	0.377	0.001
P-166	24	J-1089	J-694	25	HDPE	130	36.746	0.600	0.001
P-167	26	J-1091	J-1070	25	HDPE	130	14.505	0.232	0.044
P-168	26	J-1092	J-1074	25	HDPE	130	82.195	1.334	0.007
P-169	30	J-590	J-1093	25	HDPE	130	62.855	1.025	0.004
P-170	28	J-1094	J-674	25	HDPE	130	41.581	0.667	0.002
P-171	29	J-1076	J-1096	15	HDPE	130	20.307	0.319	0.054
P-172	30	J-681	J-1098	25	HDPE	130	4.835	0.068	0.063
P-173	30	J-1099	J-1100	29	HDPE	130	24.175	0.387	0.001
P-174	12	J-676	J-1102	25	HDPE	130	28.043	0.464	0.001
P-175	30	J-1103	J-1104	25	HDPE	130	14.505	0.242	0.095
P-176	30	J-1105	J-675	25	HDPE	130	9.67	0.164	0.065
P-177	31	J-1107	J-1108	20	HDPE	130	10.637	0.164	0.033
P-178	31	J-1109	J-673	25	HDPE	130	-3.868	0.058	0.034
P-179	31	J-669	J-1111	25	HDPE	130	5.802	0.097	0.309
P-180	31	J-1112	J-1113	20	HDPE	130	25.142	0.406	0.001
P-182	32	J-1116	J-1117	20	HDPE	130	-8.703	0.145	0.022
P-183	32	J-1118	J-1119	25	HDPE	130	-3.868	0.068	0.024
P-184	33	J-1120	J-1001	25	HDPE	130	-1.934	0.039	0.024
P-185	47	J-590	J-1121	25	HDPE	130	0.967	0.010	0.012
P-186	35	J-1122	J-1123	25	HDPE	130	-9.67	0.155	0.020
P-187	37	J-676	J-1124	25	HDPE	130	-4.835	0.068	0.026
P-188	50	J-1073	J-1125	25	HDPE	130	16.439	0.271	0.012
P-189	37	J-1118	J-1126	25	HDPE	130	-35.779	0.580	0.001
P-190	41	J-1127	J-669	25	HDPE	130	8.703	0.135	0.629
P-191	63	J-1128	J-1129	20	HDPE	130	37.713	0.609	0.002
P-192	62	J-683	J-1131	25	HDPE	130	5.802	0.087	0.048
P-193	19	J-677	J-1133	250	HDPE	130	0.967	0.010	0.730
P-194	43	J-1134	J-1135	25	HDPE	130	-0.967	0.010	0.948

P-195	64	J-1136	J-1137	20	HDPE	130	0.967	0.010	0.116
P-196	48	J-1138	J-1139	20	HDPE	130	71.558	1.170	0.005
P-197	53	J-1140	J-1141	20	HDPE	130	47.383	0.774	0.002
P-198	54	J-1142	J-714	20	HDPE	130	-48.35	0.783	0.002
P-199	56	J-590	J-1143	25	HDPE	130	-409.041	6.643	0.126
P-200	59	J-1144	J-1145	20	HDPE	130	-6.769	0.106	0.841
P-201	65	J-1146	J-680	25	HDPE	130	-22.241	0.358	0.001
P-202	67	J-1148	J-1149	25	HDPE	130	-29.977	0.493	0.001
P-203	101	J-606	J-1151	80	HDPE	130	17.406	0.290	0.095
P-204	227	J-598	J-606	80	HDPE	130	11.604	0.184	0.045
P-206	7	J-1155	J-1156	30	HDPE	130	0.967	0.010	0.037
P-207	36	J-1154	J-1157	30	HDPE	130	2.901	0.048	0.065
P-208	36	J-1158	J-1159	20	HDPE	130	15.472	0.261	0.064
P-209	42	J-1160	J-1161	20	HDPE	130	6.769	0.106	0.084
P-210	43	J-1159	J-1052	20	HDPE	130	80	0.290	0.001
P-211	48	J-1159	J-1162	20	HDPE	130	0	0.000	0.000
P-212	49	J-1156	J-1160	30	HDPE	130	2	0.010	0.000
P-213	52	J-1163	J-1155	30	HDPE	130	-3	0.010	0.000
P-214	56	J-1164	J-1165	20	HDPE	130	-314	1.120	0.009
P-215	69	J-1166	J-664	20	HDPE	130	218	0.780	0.005
P-216	148	J-1156	J-1168	40	HDPE	130	-330	1.180	0.010
P-217	391	J-663	J-1166	30	HDPE	130	-96	0.340	0.001
P-219	281	J-1166	J-1164	20	HDPE	130	-314	1.120	0.009
P-220	342	J-1171	J-1163	20	HDPE	130	-2	0.010	0.060
P-221	253	J-628	J-1173	20	HDPE	130	0	0.000	0.906
P-222	13	J-1091	J-1174	25	HDPE	130	1	0.000	1.176
P-223	14	J-1175	J-1091	25	HDPE	130	4	0.020	0.144
P-224	57	J-1100	J-1176	20	HDPE	130	-2	0.010	0.006
P-225	4	J-1177	J-1059	25	HDPE	130	7	0.020	0.002
P-226	25	J-1059	J-1057	25	HDPE	130	5	0.020	0.002
P-227	93	J-1057	J-1178	25	HDPE	130	2	0.010	0.156
P-228	69	J-1179	J-1180	25	HDPE	130	1	0.000	1.044
P-229	81	J-646	J-1182	20	HDPE	130	0	0.000	0.001
P-231	9	J-662	J-663	30	HDPE	130	-40	0.140	0.001
P-233	229	J-659	J-661	40	HDPE	130	-103	0.370	0.118
P-234	244	J-1187	J-657	20	HDPE	130	-83	0.300	0.056
P-235	812	J-1189	J-1190	40	HDPE	130	131	0.470	0.046
P-236	65	J-664	J-1158	20	HDPE	130	155	0.550	0.080
P-237	97	J-1155	J-1191	30	HDPE	130	325	1.160	0.079
P-238	124	J-1191	J-1165	20	HDPE	130	314	1.120	0.104
P-239	195	J-1192	J-1193	30	HDPE	130	131	0.470	0.002
P-240	165	J-662	J-664	30	HDPE	130	-63	0.230	0.000

P-241	318	J-666	J-1191	20	HDPE	130	-11	0.040	0.000
P-242	10	J-598	J-597	80	HDPE	130	-5	0.020	0.000
P-243	92	J-604	J-598	250	HDPE	130	-2	0.010	0.000
P-244	264	J-1195	J-604	250	HDPE	130	10.72	3.437	0.051
P-245	4	J-1196	J-706	20	HDPE	130	8.71	1.233	0.007
P-247	5	J-593	J-708	20	HDPE	130	13.4	0.764	0.003
P-248	8	J-1199	J-1035	20	HDPE	130	5.36	0.657	0.003
P-249	8	J-1087	J-677	25	HDPE	130	8.04	0.563	0.002
P-250	9	J-695	J-1092	25	HDPE	130	-7.37	0.114	0.000
P-251	13	J-1122	J-683	25	HDPE	130	15.41	0.898	0.004
P-252	15	J-1200	J-1201	20	HDPE	130	11.39	0.730	0.003
P-253	16	J-693	J-695	25	HDPE	130	4.02	0.683	0.003
P-254	18	J-690	J-1122	25	HDPE	130	6.03	0.536	0.001
P-255	19	J-680	J-1149	25	HDPE	130	10.72	1.152	0.007
P-256	27	J-1176	J-1035	20	HDPE	130	24.79	0.402	0.001
P-257	23	J-677	J-1203	25	HDPE	130	1.34	0.027	0.034
P-258	24	J-1204	J-1200	20	HDPE	130	8.04	0.134	0.045
P-259	25	J-706	J-1008	20	HDPE	130	16.08	0.261	0.001
P-260	38	J-1205	J-1042	20	HDPE	130	25.46	0.415	0.001
P-261	41	J-1206	J-1025	20	HDPE	130	10.05	0.161	0.030
P-262	66	J-1134	J-589	25	HDPE	130	56.95	0.925	0.005
P-263	54	J-713	J-1141	20	HDPE	130	43.55	0.710	0.003
P-264	54	J-1209	J-1200	20	HDPE	130	28.81	0.462	0.001
P-265	7	J-660	J-659	40	HDPE	130	14.07	0.221	0.038
P-266	10	J-625	J-626	40	HDPE	130	3.35	0.047	0.044
P-267	11	J-629	J-628	20	HDPE	130	16.75	0.268	0.001
P-268	24	J-615	J-635	40	HDPE	130	19.43	0.322	0.001
P-269	33	J-1214	J-627	20	HDPE	130	10.05	0.168	0.066
P-270	49	J-1216	J-605	80	Galvanized iron	130	6.7	0.114	0.045
P-271	63	J-657	J-659	40	Galvanized iron	130	7.37	0.114	0.023
P-272	63	J-702	J-1218	20	Galvanized iron	130	-2.68	0.040	0.023
P-273	95	J-624	J-625	40	Galvanized iron	130	4.02	0.067	0.214
P-274	123	J-574	J-619	40	Galvanized iron	130	17.42	0.281	0.001
P-275	154	J-617	J-1219	40	Galvanized iron	130	-6.03	0.101	0.015
P-276	157	J-628	J-626	30	Galvanized iron	130	-2.68	0.047	0.017
P-277	160	J-1220	J-1221	40	Galvanized iron	130	-1.34	0.027	0.017

P-278	165	J-619	J-1222	40	Galvanized iron	130	0.67	0.007	0.008
P-279	164	J-626	J-702	30	Galvanized iron	130	-6.7	0.107	0.014
P-280	238	J-702	J-631	20	Galvanized iron	130	-3.35	0.047	0.018
P-281	224	J-627	J-625	30	HDPE	130	11.39	0.188	0.008
P-282	234	J-660	J-1223	40	HDPE	130	-24.79	0.402	0.001
P-283	291	J-1218	J-633	20	HDPE	130	6.03	0.094	0.436
P-284	287	J-575	J-1224	40	HDPE	130	26.13	0.422	0.001
P-285	354	J-1225	J-1226	80	HDPE	130	4.02	0.060	0.034
P-286	17	J-1227	J-1177	30	HDPE	130	0.67	0.007	0.506
P-287	38	J-1177	J-1228	20	HDPE	130	-0.67	0.007	0.657
P-288	8	J-1229	J-1230	50	HDPE	130	0.67	0.007	0.080
P-289	33	J-1231	J-1232	25	HDPE	130	49.58	0.811	0.003
P-290	45	J-1233	J-1234	25	HDPE	130	32.83	0.536	0.001
P-291	45	J-1235	J-1236	30	HDPE	130	-33.5	0.543	0.001
P-292	48	J-1232	J-1233	25	HDPE	130	83	4.603	0.087
P-293	49	J-1231	J-1237	60	HDPE	130	-4.69	0.074	0.583
P-294	53	J-1238	J-1235	40	HDPE	130	-15.41	0.248	0.001
P-295	59	J-1232	J-1239	25	HDPE	130	-20.77	0.342	0.001
P-296	94	J-1236	J-1229	30	HDPE	130	12.06	0.201	0.066
P-297	108	J-1235	J-1234	25	HDPE	130	8.04	0.127	0.031
P-298	109	J-1233	J-1236	25	HDPE	130	0.67	0.007	0.025
P-299	209	J-1234	J-1231	25	HDPE	130	2.01	0.034	0.045
P-302	16	J-887	J-880	250	HDPE	130	11	0.181	0.044
P-303	5	J-1244	J-593	20	HDPE	130	4.69	0.074	0.058
P-304	5	J-1108	J-1245	20	HDPE	130	0	0.000	0.005
P-305	6	J-1118	J-690	25	HDPE	130	0	0.000	0.084
P-306	6	J-704	J-1196	20	HDPE	130	1	0.000	0.012
P-307	7	J-689	J-1118	25	HDPE	130	1	0.000	0.005
P-309	8	J-1139	J-691	20	HDPE	130	-2	0.010	0.004
P-310	9	J-1113	J-1245	20	HDPE	130	0	0.000	0.003
P-311	9	J-1005	J-716	20	HDPE	130	0	0.000	0.005
P-312	11	J-1020	J-1251	20	HDPE	130	0	0.000	0.007
P-313	12	J-1252	J-716	20	HDPE	130	0	0.000	0.004
P-314	12	J-673	J-674	50	Ductile Iron	130	-8	0.030	0.004
P-315	13	J-1253	J-704	20	Ductile Iron	130	2	0.010	0.002
P-316	35	J-1254	J-591	20	Ductile Iron	130	0	0.000	0.011
P-317	14	J-943	J-1078	25	Ductile Iron	130	0	0.000	0.001

P-318	14	J-1203	J-676	25	Ductile Iron	130	-2	0.010	0.055
P-319	9	J-708	J-1006	20	Ductile Iron	130	2	0.010	0.074
P-320	14	J-713	J-1254	20	Ductile Iron	130	0	0.000	0.001
P-321	15	J-681	J-1103	25	Ductile Iron	130	-3	0.010	0.001
P-322	15	J-705	J-1034	20	Ductile Iron	130	5	0.020	0.049
P-323	16	J-1049	J-1256	25	Ductile Iron	130	-5	0.020	0.008
P-324	17	J-685	J-1257	25	Ductile Iron	130	-8	0.030	0.004
P-325	18	J-1103	J-685	25	Ductile Iron	130	-4	0.020	0.002
P-326	18	J-675	J-673	25	Ductile Iron	130	-7	0.020	0.062
P-327	23	J-984	J-699	30	Ductile Iron	130	4	0.010	0.071
P-328	23	J-933	J-1175	25	Ductile Iron	130	4	0.020	0.001
P-329	16	J-1006	J-1029	20	Ductile Iron	130	1	0.000	0.001
P-330	21	J-682	J-1049	25	Ductile Iron	130	-3	0.010	0.108
P-331	22	J-691	J-1259	20	Ductile Iron	130	-4	0.010	0.074
P-332	22	J-1012	J-1003	20	Ductile Iron	130	3	0.010	0.037
P-333	22	J-679	J-1261	25	Ductile Iron	130	1	0.000	0.038
P-334	22	J-676	J-675	25	Ductile Iron	130	-5	0.020	0.352
P-335	23	J-699	J-700	30	Ductile Iron	130	2	0.010	0.001
P-336	24	J-707	J-1088	20	Ductile Iron	130	2	0.010	0.025
P-337	26	J-700	J-1205	20	Ductile Iron	130	2	0.010	0.027
P-338	27	J-1001	J-681	25	Ductile Iron	130	-2	0.010	0.027
P-339	14	J-1065	J-1262	25	Ductile Iron	130	-6	0.020	0.013
P-340	29	J-1034	J-1014	20	Ductile Iron	130	2	0.010	0.023

P-341	30	J-1027	J-1254	20	Ductile Iron	130	0	0.000	0.030
P-342	23	J-589	J-588	25	Ductile Iron	130	-1	0.000	0.013
P-344	34	J-930	J-1012	20	Ductile Iron	130	4	0.010	0.001
P-345	37	J-1256	J-686	25	Ductile Iron	130	-16	0.060	0.714
P-346	43	J-1266	J-1199	20	Ductile Iron	130	7	0.030	0.002
P-347	64	J-585	J-1046	20	Ductile Iron	130	11.2	3.591	0.055
P-348	45	J-1268	J-1206	20	Ductile Iron	130	9.1	1.288	0.830
P-349	46	J-1149	J-682	25	Ductile Iron	130	14	0.798	1.077
P-350	48	J-1269	J-712	20	Ductile Iron	130	5.6	0.686	0.132
P-351	53	J-939	J-1050	20	Ductile Iron	130	8.4	0.588	0.005
P-352	75	J-587	J-1204	20	Ductile Iron	130	-7.7	0.119	0.002
P-353	75	J-711	J-1270	20	Ductile Iron	130	16.1	0.938	0.002
P-354	76	J-1128	J-1116	20	Ductile Iron	130	11.9	0.763	0.143
P-355	62	J-949	J-1044	20	Ductile Iron	130	4.2	0.714	0.956
P-356	76	J-714	J-1020	20	Ductile Iron	130	6.3	0.560	0.001
P-357	69	J-1245	J-1271	20	Ductile Iron	130	11.2	1.204	0.001
P-358	68	J-944	J-586	15	Ductile Iron	130	25.9	0.420	0.108
P-359	79	J-692	J-1144	20	Ductile Iron	130	1.4	0.028	0.052
P-360	120	J-1116	J-691	20	Ductile Iron	130	8.4	0.140	0.042
P-361	92	J-674	J-1256	25	Ductile Iron	130	16.8	0.273	0.074
P-362	119	J-704	J-1136	20	Ductile Iron	130	26.6	0.434	0.073
P-363	114	J-1032	J-1244	20	Ductile Iron	130	10.5	0.168	0.096
P-364	162	J-716	J-1244	20	Ductile Iron	130	59.5	0.966	0.005

P-365	237	J-953	J-1273	80	Ductile Iron	130	45.5	0.742	0.003
P-366	65	J-1274	J-1275	30	Ductile Iron	130	30.1	0.483	0.001
P-367	147	J-1189	J-1276	30	Ductile Iron	130	14.7	0.231	0.039
P-368	171	J-1277	J-1278	300	Ductile Iron	130	3.5	0.049	0.046
P-369	189	J-612	J-1280	40	Ductile Iron	130	17.5	0.280	0.001
P-370	189	J-1221	J-651	40	Ductile Iron	130	20.3	0.336	0.001
P-371	237	J-651	J-1282	30	Ductile Iron	130	10.5	0.175	0.069
P-372	329	J-651	J-1283	30	Ductile Iron	130	7	0.119	0.047
P-373	5	J-1284	J-1285	40	Ductile Iron	130	7.7	0.119	0.024
P-374	46	J-1286	J-1287	40	Ductile Iron	130	-2.8	0.042	0.025
P-375	131	J-1285	J-1288	20	Ductile Iron	130	4.2	0.070	0.224
P-376	137	J-649	J-1284	40	Ductile Iron	130	18.2	0.294	0.001
P-377	6	J-1289	J-1290	50	Ductile Iron	130	-6.3	0.105	0.016
P-378	7	J-1291	J-1292	30	Ductile Iron	130	-2.8	0.049	0.018
P-379	12	J-1293	J-1061	80	Ductile Iron	130	-1.4	0.028	0.018
P-380	11	J-1294	J-1295	70	Ductile Iron	130	0.7	0.007	0.008
P-381	10	J-1296	J-1293	40	Ductile Iron	130	-7	0.112	0.015
P-382	14	J-1297	J-1298	30	Ductile Iron	130	-3.5	0.049	0.019
P-383	22	J-1295	J-1286	50	Ductile Iron	130	11.9	0.196	0.008
P-384	23	J-1290	J-1299	50	Ductile Iron	130	-25.9	0.420	0.001
P-385	24	J-1300	J-1297	25	Ductile Iron	130	6.3	0.098	0.455
P-386	24	J-1301	J-1291	30	Ductile Iron	130	27.3	0.441	0.001
P-387	25	J-1299	J-1297	30	Ductile Iron	130	4.2	0.063	0.035

P-388	28	J-1302	J-1294	60	Ductile Iron	130	0.7	0.007	0.529
P-389	29	J-1303	J-1304	30	Ductile Iron	130	-0.7	0.007	0.686
P-390	32	J-1302	J-1305	45	HDPE	130	0.7	0.007	0.084
P-391	33	J-1306	J-1301	50	HDPE	130	51.8	0.847	0.004
P-392	38	J-1290	J-1307	30	HDPE	130	34.3	0.560	0.001
P-393	42	J-1291	J-1308	30	HDPE	130	-35	0.567	0.001
P-394	44	J-1061	J-1294	80	HDPE	130	26	4.809	0.091
P-395	63	J-1296	J-1309	30	HDPE	130	-4.9	0.077	0.609
P-396	47	J-1179	J-1227	30	HDPE	130	-16.1	0.259	0.001
P-397	48	J-1286	J-1306	50	HDPE	130	-21.7	0.357	0.001
P-398	48	J-1301	J-1289	50	HDPE	130	12.6	0.210	0.069
P-399	50	J-1229	J-1310	50	HDPE	130	8.4	0.133	0.033
P-400	49	J-1311	J-1230	80	HDPE	130	0.7	0.007	0.027
P-401	77	J-1299	J-1179	50	HDPE	130	2.1	0.035	0.047
P-402	55	J-638	J-1312	30	HDPE	130	11.2	0.189	0.046
P-403	61	J-1237	J-1313	60	HDPE	130	4.9	0.077	0.061
P-404	64	J-1306	J-1310	60	HDPE	130	-17	0.060	0.091
P-405	64	J-1314	J-1315	40	HDPE	130	0	0.000	0.013
P-406	62	J-1316	J-1289	30	HDPE	130	0	0.000	0.006
P-407	75	J-1312	J-1317	30	HDPE	130	-1	0.240	0.005
P-408	77	J-1295	J-1314	56	HDPE	130	-1	0.210	0.004
P-409	87	J-1303	J-1318	30	HDPE	130	0	0.140	0.000
P-410	93	J-1319	J-1296	40	HDPE	130	1	0.120	0.000
P-411	106	J-1320	J-1229	40	HDPE	130	1	0.370	0.001
P-412	135	J-1312	J-1321	30	HDPE	130	2	0.670	0.003
P-413	120	J-1230	J-1237	60	HDPE	130	2	1.500	0.019
P-414	143	J-1322	J-1302	60	HDPE	130	1	0.210	0.007
P-415	137	J-1323	J-1311	80	HDPE	130	0	0.140	0.005
P-416	164	J-637	J-1324	40	HDPE	130	0	0.000	0.005
P-417	237	J-893	J-627	40	HDPE	130	0	0.000	0.002
P-418	343	J-614	J-1303	40	HDPE	130	0	0.000	0.012
P-419	87	J-1153	J-1325	20	HDPE	130	-56	0.200	0.001
P-420	165	J-1326	J-1153	30	HDPE	130	-37	0.130	0.060
P-421	224	J-1327	J-1328	40	HDPE	130	0	0.000	0.080
P-422	280	J-899	J-1329	80	HDPE	130	1	0.000	0.001
P-424	57	J-1332	J-611	40	HDPE	130	0	0.000	0.001
P-425	115	J-667	J-1334	20	HDPE	130	3	0.010	0.054
P-426	146	J-1335	J-629	20	HDPE	130	0	0.000	0.008
P-427	121	J-611	J-1336	60	HDPE	130	2	0.010	0.005
P-428	177	J-660	J-1337	40	HDPE	130	0	0.000	0.002
P-429	38	J-609	J-612	60	HDPE	130	1	0.000	0.067

P-430	77	J-612	J-1339	40	HDPE	130	1	0.000	0.078
P-431	139	J-1052	J-658	40	HDPE	130	80	0.290	0.001
P-432	286	J-648	J-1187	20	HDPE	130	-83	0.300	0.001
P-433	10	J-645	J-646	20	HDPE	130	0	0.000	0.117
P-434	12	J-1342	J-1343	250	HDPE	130	(N/A)	(N/A)	0.080
P-435	25	J-645	J-1344	20	HDPE	130	0	0.000	0.041
P-436	68	J-646	J-1345	20	HDPE	130	0	0.000	0.042
P-437	114	J-643	J-645	20	HDPE	130	0	0.000	0.384
P-438	142	J-641	J-643	30	HDPE	130	0	0.000	0.001
P-439	152	J-639	J-1342	30	HDPE	130	0	0.000	0.028
P-440	116	J-1342	J-1348	20	HDPE	130	0	0.000	0.030
P-441	76	J-1349	J-1157	30	HDPE	130	-57	0.200	0.030
P-442	87	J-1158	J-1154	20	HDPE	130	58	0.210	0.014
P-443	87	J-1157	J-1159	20	HDPE	130	-17	0.060	0.025
P-444	115	J-656	J-654	40	HDPE	130	20	0.070	0.032
P-445	163	J-1154	J-1351	30	HDPE	130	37	0.130	0.014
P-446	212	J-656	J-657	40	HDPE	130	-20	0.070	0.001
P-447	31	J-1352	J-1353	30	HDPE	130	2.672	0.857	0.779
P-448	60	J-1354	J-630	30	HDPE	130	2.171	0.307	0.002
P-449	54	J-630	J-1356	30	HDPE	130	3.34	0.190	0.060
P-451	62	J-650	J-652	40	HDPE	130	1.336	0.164	0.905
P-452	91	J-623	J-630	40	HDPE	130	2.004	0.140	1.175
P-453	75	J-644	J-1361	20	HDPE	130	-1.837	0.028	0.144
P-454	84	J-643	J-644	30	HDPE	130	3.841	0.224	0.006
P-455	101	J-1362	J-652	30	HDPE	130	2.839	0.182	0.002
P-456	89	J-1363	J-1362	30	HDPE	130	1.002	0.170	0.002
P-457	97	J-1364	J-1362	30	HDPE	130	1.503	0.134	0.156
P-458	95	J-1365	J-644	20	HDPE	130	2.672	0.287	1.043
P-459	12	J-656	J-1366	30	HDPE	130	6.179	0.100	0.001
P-460	4	J-1225	J-1367	40	HDPE	130	0.334	0.007	0.001
P-461	17	J-606	J-1225	80	HDPE	130	2.004	0.033	0.117
P-462	15	J-919	J-922	80	HDPE	130	4.008	0.065	0.056
P-463	27	J-1368	J-636	60	HDPE	130	6.346	0.104	0.046
P-464	47	J-605	J-1367	80	HDPE	130	2.505	0.040	0.080
P-465	73	J-597	J-607	80	HDPE	130	14.195	0.230	0.079
P-466	112	J-1370	J-634	20	HDPE	130	10.855	0.177	0.104
P-467	121	J-607	J-1371	80	HDPE	130	7.181	0.115	0.000
P-468	137	J-1372	J-620	30	HDPE	130	3.507	0.055	0.009
P-469	153	J-607	J-606	80	HDPE	130	0.835	0.012	0.011
P-470	186	J-573	J-1373	40	HDPE	130	4.175	0.067	0.000
P-471	200	J-1374	J-632	20	HDPE	130	4.843	0.080	0.000
P-472	251	J-1375	J-595	80	HDPE	130	2.505	0.042	0.016
P-473	270	J-900	J-1376	80	HDPE	130	1.67	0.028	0.011

P-474	274	J-952	J-594	80	HDPE	130	1.837	0.028	0.006
P-475	578	J-1367	J-922	80	HDPE	130	-0.668	0.010	0.006
P-476	76	J-1189	J-1377	30	HDPE	130	1.002	0.017	0.053
P-477	91	J-1378	J-1379	30	HDPE	130	4.342	0.070	0.000
P-478	132	J-1380	J-1381	30	HDPE	130	-1.503	0.025	0.004
P-480	9	J-1310	J-1311	60	HDPE	130	-0.668	0.012	0.004
P-481	130	J-1238	J-1310	45	HDPE	130	-0.334	0.007	0.004
P-482	247	J-1311	J-1384	150	HDPE	130	0.167	0.002	0.002
P-483	219	J-1385	J-1238	45	HDPE	130	-1.67	0.027	0.004
P-484	230	J-616	J-1386	40	HDPE	130	-0.835	0.012	0.005
P-487	50	J-1351	J-1192	30	HDPE	130	2.839	0.047	0.002
P-488	60	J-1192	J-1349	30	HDPE	130	-6.179	0.100	0.000
P-489	161	J-658	J-655	40	HDPE	130	1.503	0.023	0.109
P-490	91	J-958	J-1390	80	HDPE	130	6.513	0.105	0.000
P-491	130	J-668	J-1392	20	HDPE	130	1.002	0.015	0.008
P-492	167	J-661	J-1274	30	HDPE	130	0.167	0.002	0.126
P-493	251	J-1274	J-1393	30	HDPE	130	-0.167	0.002	0.164
P-494	55	J-1328	J-658	40	HDPE	130	0.167	0.002	0.020
P-495	5	J-694	J-969	25	HDPE	130	12.358	0.202	0.001
P-496	8	J-1257	J-684	25	HDPE	130	8.183	0.134	0.000
P-497	9	J-585	J-1268	20	HDPE	130	-8.35	0.135	0.000
P-498	10	J-686	J-1257	25	HDPE	130	-70.641	1.147	0.022
P-499	18	J-592	J-1395	20	HDPE	130	-1.169	0.018	0.145
P-500	13	J-936	J-689	25	HDPE	130	-3.841	0.062	0.000
P-502	14	J-1271	J-1266	20	HDPE	130	-5.177	0.085	0.000
P-503	18	J-1395	J-1396	20	HDPE	130	3.006	0.050	0.016
P-504	25	J-588	J-694	25	HDPE	130	2.004	0.032	0.008
P-505	18	J-983	J-585	25	HDPE	130	0.167	0.002	0.006
P-506	23	J-592	J-938	20	HDPE	130	0.501	0.008	0.011
P-507	24	J-1395	J-1397	20	HDPE	130	2.672	0.045	0.011
P-508	28	J-1269	J-1022	20	HDPE	130	1.169	0.018	0.015
P-509	28	J-1251	J-592	20	HDPE	130	0	0.000	0.000
P-510	42	J-703	J-1253	20	HDPE	130	3	0.010	0.000
P-511	49	J-1259	J-692	20	HDPE	130	-4	0.010	0.000
P-512	37	J-946	J-692	20	HDPE	130	6	0.020	0.000
P-513	39	J-1266	J-932	30	HDPE	130	-8	0.030	0.000
P-514	17	J-1399	J-1278	450	HDPE	130	-1	0.260	0.007
P-515	56	J-1400	J-1401	450	HDPE	130	0	0.070	0.001
P-516	96	J-1401	J-1399	450	HDPE	130	-1	0.180	0.003
P-517	243	J-1278	J-1382	450	HDPE	130	-2	0.010	0.000
P-518	1,025	J-1402	J-1403	180	HDPE	130	0	0.000	0.000
P-16	1,015	J-882	J-538	250	HDPE	130	-1	0.010	0.000
P-17	9	J-538	J-883	250	HDPE	130	0	0.000	0.000

P-26	265	J-540	J-541	350	HDPE	130	89	2.810	0.051
P-27	255	J-541	J-542	250	HDPE	130	67	1.630	0.019
P-28	137	J-542	J-543	250	HDPE	130	43	1.630	0.019
P-29	109	J-543	J-544	250	HDPE	130	44	1.630	0.019
P-30	171	J-544	J-545	100	HDPE	130	2	1.630	0.019
P-31	188	J-545	J-613	100	HDPE	130	6	1.630	0.019
P-32	286	J-613	J-546	50	HDPE	130	10	2.740	0.049
P-33	153	J-546	J-547	50	HDPE	130	90	2.740	0.049
P-34	424	J-547	J-583	50	HDPE	130	46	2.740	0.049
P-36	38	J-549	J-550	250	HDPE	130	66	0.230	0.000
P-37	11	J-550	J-551	250	HDPE	130	5	0.230	0.000
P-38	30	J-551	J-552	250	HDPE	130	9	5.070	0.153
P-39	107	J-552	J-553	250	HDPE	130	8	0.710	0.001
P-40	11	J-553	J-554	250	HDPE	130	34	5.070	0.154
P-41	71	J-554	J-555	250	HDPE	130	62	5.070	0.154
P-42	118	J-555	J-556	250	HDPE	130	56	5.070	0.154
P-43	35	J-556	J-557	250	HDPE	130	23	5.070	0.154
P-44	67	J-557	J-558	250	HDPE	130	32	5.070	0.154
P-45	110	J-558	J-559	250	HDPE	130	11	5.070	0.154
P-46	215	J-559	J-560	250	HDPE	130	22	5.070	0.154
P-51	35	J-562	J-563	200	HDPE	130	82	0.290	0.001
P-52	227	J-563	J-564	250	HDPE	130	82	0.290	0.001
P-53	162	J-564	J-565	250	HDPE	130	82	0.290	0.001
P-54	85	J-565	J-566	250	HDPE	130	17	0.060	0.000
P-55	159	J-566	J-921	250	HDPE	130	17	0.060	0.000
P-57	6	J-1368	J-925	60	HDPE	130	0	0.000	0.000
P-60	22	J-1102	J-679	25	HDPE	130	1	0.010	0.000
P-72	48	J-653	J-1358	30	HDPE	130	0	0.000	0.000
P-73	10	J-1352	J-653	30	HDPE	130	0	0.000	0.000
P-74	11	J-573	J-569	50	HDPE	130	-3	0.010	0.000
P-75	83	J-569	J-571	50	HDPE	130	-3	0.010	0.000
P-82	49	J-1383	J-565	152.4	HDPE	130	-65	0.230	0.001
P-85	691	J-977	J-576	250	HDPE	130	633	2.260	0.034
P-86	836	J-576	J-581	350	HDPE	130	532	0.270	0.000
P-88	373	J-577	J-562	200	HDPE	130	100	0.360	0.001
P-89	10	J-577	J-576	300	HDPE	130	-101	0.360	0.001
P-90	23	J-1402	J-577	280	HDPE	130	0	0.000	0.000
P-91	13	Source	J-560	152.4	HDPE	130	1,422	5.080	0.154
P-92	12	J-549	S/R 500m3	152.4	HDPE	130	449	0.230	0.000
P-99	9	J-581	S/R 500m3	152.4	HDPE	130	532	0.270	0.000
P-101	59	J-562	J-582	150	HDPE	130	18	0.060	0.000

P-102	11	J-582	J-1384	152.4	HDPE	130	9	0.030	0.000
P-103	11	J-1384	J-582	152.4	HDPE	130	-9	0.030	0.000
P-104	7	J-588	J-1262	152.4	HDPE	130	6	0.020	0.000
P-105	6	J-975	J-703	152.4	HDPE	130	5	0.020	0.000
P-106	30	J-938	J-1027	152.4	HDPE	130	0	1.608	0.007
P-108	148	J-880	J-602	250	HDPE	130	-58	1.308	0.005
P-109	669	J-602	J-599	250	HDPE	130	3	1.224	0.005
P-111	207	J-1382	J-603	450	HDPE	130	-2	0.960	0.002
P-112	646	J-603	J-1383	250	HDPE	130	-65	2.064	0.012
P-113	11	J-602	J-603	250	HDPE	130	-62	0.720	0.001
P-114	30	J-1371	J-1151	152.4	HDPE	130	0	0.048	0.060
P-115	758	J-717	J-608	250	HDPE	130	2	0.240	0.080
P-116	68	J-608	J-980	250	HDPE	130	0	0.468	0.001
P-118	13	J-611	J-610	40	HDPE	130	-2	0.744	0.001
P-119	29	J-610	J-1331	40	HDPE	130	0	0.288	0.054
P-120	5	J-608	J-610	152.4	HDPE	130	2	1.656	0.008
P-121	6	J-610	J-609	152.4	HDPE	130	1	1.272	0.005
P-122	31	BH	PMP-2	400	HDPE	130	787	0.828	0.002
P-123	209	PMP-2	J-540	400	HDPE	130	787	0.396	0.067
P-124	9	J-615	J-1368	60	HDPE	130	-314	0.084	0.078
P-125	12	J-639	J-641	152.4	HDPE	130	0	0.480	0.001
P-126	21	J-1321	J-1343	152.4	HDPE	130	0	0.576	0.001
P-127	12	J-1324	J-1317	152.4	HDPE	130	0	0.300	0.118
P-129	12	J-1342	J-642	20	HDPE	130	0	0.204	0.080
P-130	12	J-642	J-1361	20	HDPE	130	0	0.204	0.041
P-131	12	J-1361	J-642	152.4	HDPE	130	0	0.072	0.042
P-132	341	J-637	J-647	40	HDPE	130	0	0.120	0.384
P-133	5	J-647	J-636	40	HDPE	130	23	0.504	0.001
P-134	8	J-1190	J-647	40	HDPE	130	12	0.180	0.028
P-135	15	J-1220	J-569	40	HDPE	130	0	0.084	0.030
P-136	30	J-652	J-653	152.4	HDPE	130	0	0.048	0.030
P-137	6	J-1378	J-1380	152.4	HDPE	130	0	0.012	0.014
P-138	18	J-661	J-662	152.4	HDPE	130	4	0.192	0.025
P-139	5	J-1154	J-1153	152.4	HDPE	130	-20	0.084	0.032
P-140	7	J-1189	J-878	30	HDPE	130	-131	0.336	0.014
P-141	6	J-878	J-1193	30	HDPE	130	43	0.720	0.001
P-142	6	J-1351	J-1326	30	HDPE	130	-37	0.168	0.780
P-145	195	J-665	J-663	30	HDPE	130	-56	0.756	0.002
P-147	34	J-1325	J-665	60	HDPE	130	-56	0.200	0.000
P-148	237	J-541	J-1168	50	HDPE	130	30	1.180	0.010
P-149	9	J-667	J-666	30	HDPE	130	-9	0.030	0.000
P-150	6	J-668	J-667	30	HDPE	130	-5	0.020	0.000
P-151	13	J-551	J-880	250	HDPE	130	9	3.460	0.076

P-153	7	J-887	S/R 10m3	80	HDPE	130	0	4.630	0.041
P-155	6	J-888	S/R 10m3	150	HDPE	130	34	4.670	0.042
P-157	7	J-884	S/R 10m3	250	HDPE	130	40	3.360	0.071
P-158	10	S/R 10m3	J-890	250	HDPE	130	1	0.000	0.000
P-165	10	J-1362	J-1378	30	HDPE	130	0	0.000	0.000

Appendix 4: Sample Questionnaire on Drinking Water Services

Name of Investigator: _______Starting Time: ___ Date: ___________ Ending Time: _________

Investigator Introduction:

Hello, my name is ______________, MSc student from ____________, I am collecting information on drinking water services in ____________. May I speak to an adult member of your household?

Demographic Questions

1. What is your name____________________________?
2. Gender of respondent 1- Male 2- Female
3. What is your age ________________ years?
4. a. Number of adult males in the household _____________________

   b. Number of adult females in the household__________________

   c. Number of male children ________________________

   d. Number of female children_________________________
5. How many members in the household are employed______________________?
6. What is the monthly household income?

   1- <1000 EBR 2- 1001-2500 EBR 3- 2501-5000 EBR

   4- 5001-10000 EBR 5- > 10000 EBR

Drinking water question

7. Which of the following sources of drinking water are available in your neighborhood? (Multiple responses are possible)

   1- Bore well/ hand pump 2- Public tap 3- Community well

   4- Household water supply (piped) 5- Other
8. Which of the following sources of drinking water does your household use? (Multiple responses are possible)

   1- Bore well/ hand pump 2- Public tap 3- Open well

   4- Household water supply (piped) 5- Other
9. Has the bore well / hand pump broken down in the past one year?

   1- Yes 2- No
10. How frequently has the bore well/ hand pump broken down during the past one year?

1, once a week 2. Once a fortnight 3. Once a quarter

4. Once in six months 5. Once a year

11. Is the bore well/ hand pump fixed promptly when it breaks down?

 1- Yes 2- No

12. How far (in meters) is the public tap that you use_____________________? How long (in minutes) does it take to fetch water and return home______________?

13. Who fetches water most often?

 1- Adult male 2- Adult female 3- Male child 4- Female child

14. What is the frequency of water supply?

 1- More than once a day 2- Once a day 3- Once in two days

 4- Once in three days 5- Once a week 6- Other

15. Is this frequency sufficient for your needs?

 1- Yes 2- No

16. On the days that you get water, how many hours do you usually get water for_____________?

17. Has the public tap broken down in the past one year?

 1- Yes 2- No

18. How frequently has it broken down?

 1- Once a week 2- Once a fortnight 3- Once a quarter

 4- Once in six months 5- Once a year

19. Is the public tap fixed properly when it breaks down?

 1- Yes 2 - No

20. Is the quantity of water that you receive (from your main source of water) adequate?

 1- Yes 2- No

21. Is water available (from your main source) throughout the year?

 1- Yes, 2- No

22. Which months do you face scarcity?

 1- Jan, 2- Feb., 3- Mar, 4- Apr, 5- May, 6- Jun, 7- Jul, 8- Aug, 9- Sept, 10- Oct, 11- Nov, 12- Dec

Appendix 5 Measuring pressure using pressure gauge