Hydraulic Performance of Addis Ababa Water Distribution Systems

(The Case of Jan Meda, Teferi Mekonnen, Belay Zeleke, Entoto, and Ras Kassa Sub-Systems)

Seifemicheal Molla Geta

October, 2018

ADDIS ABABA UNIVERSITY

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SCHOOL OF CIVIL & ENVIRONMENTAL ENGINEERING

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A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfilment of the Degree of Masters of Science in Civil Engineering.

(Major in Water Supply and Environmental Engineering)

By: Seifemicheal Molla
Advisor: Geremew Sahilu (Dr.Ing)

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Approved by Board of Examiners

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Chairman (department of graduate committee)

______________________ ______________________
Signature

October, 2018
Addis Ababa, Ethiopia

Declaration

This thesis is my original work and has not been presented for a degree in any other university and that all sources of materials used for this thesis have been dully acknowledged.

Declared by

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Date:________________________________

Confirmed by

Name: ______________________________

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Place and data of submission: Addis Ababa, October, 2018

Abstract

The design of water distribution systems in Addis Ababa is implemented by using universal design factors without taking into consideration the effects of local conditions such as intermittent pumping, which is the way of operating water distribution systems in most cities of the developing world. By this way the water systems are divided into several pressure zones through which water is pumped alternatively and provide a large number of homes with a high quantity of water in a shorter period. This way makes the using of roof storage tanks more efficient during the non – pumping intervals, so that the hydraulic performance of the water network expected to be degraded by affecting the pressure and velocities values.

To investigate the behavior of Addis Ababa water distribution system under the action of intermittent supply conditions; the Janmeda, Teferi Mekonnen, Belay Zeleke, Entoto and Ras Kassa sub water distribution network is taken as a case study and a procedure of modeling the system as in reality depending on operational factors, ways of operating and managing the system, representing each cluster of houses by one consumption node, making control by check valves, and then modeling the system by using (WaterCad Program). The outputs show that the network is highly exposed to fluctuating pressure and velocity values, which have negative effects on the performance of the network. As the result of intermittency and insufficient water supply, there is unreliable service and uneven distribution of water; a reduced network pressure due to the increased hydraulic losses associated with increased flows and undersized pipe diameters; and increased water leakage. The comparison of pressure results and field measurements at specific locations shows a reasonable and small difference.

The modeling of the system as continuous supply system depending on assumptions considering with future water consumption, availability of water, enhancement of operation & management of the water supply system, overcoming the problems of high and low pressures by hydraulic modifications of distribution system, and assuming steady state analysis, the model output shows the ability of the existing system to serve the Janmeda, Teferi Mekonnen, Belay Zeleke, Entoto and Ras Kassa sub system and to cope the future extension. The output values of velocities are parallel reasonably to the assumed limits of velocities (0.1 m/s – 0.3 m/s) to avoid stagnation and water quality problems, also the pressure values are within the limits of the design pressures in the residential areas.

Further evaluation has been carried out to investigate the daily water consumption, daily peak factors and to study the variations of water levels in roof tanks under the conditions of continuous supply by implementing an experiment of monitoring daily water consumption for different consumers at different locations for a period of 15 days. The average daily peak factor is calculated to be 2.0, and a value of 79 l/c/d was recorded as average daily water consumption. The result has similarity with a little difference in comparison with the daily water consumption projected for year 2018 by Tahal Consulting Engineers LTD.

Hydraulic performance of the study area water supply system is improved by employing design and operational modifications through a planned augmentations of the water supply and improving the distribution to meet the total demand and extending the supply hours, adjusting the oversized & undersized pipes and the pressure zone boundaries, and installing a new tanks & pumps to overcome pressure related problems of the system, and replacing the aged pipes to reduce leakage rates.

Key Words: Hydraulic Performance, Intermittent water supply, Pressure-driven demands, Calibration, Water distribution system

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Abbreviations and Acronyms

AAWSA	Addis Ababa Water and Sewerage Authority
CSA	Central statistics agency
DN	Nominal diameter
EPS	Extended Period Simulation
l/c/d	Liter capita per a day
m.a.s.l	Meter above sea level
m^3/ d	Meter cubic per a day
PDO	Pressure dependent outflow
P.F	Peak factor
P.R.V	Pressure Reducing Valve
UFW	Unaccounted For Water.
NRW	Non-Revenue Water
WDS	Water Distribution System

Chapter One

1. Introduction

1.1 Background

Access to safe, reliable, affordable, and sustainable supply and distribution of drinking water is a crucial aspect of developing and maintaining a good quality of life in any part of the world. Meeting these commitments embraces multiple challenges in urban areas.

The continuous and repeated deficiency in the performance of the Addis Ababa water supply networks in supplying sufficient quantity of water continually & equitably to the consumers became one of the most critical issues in the water supply sector that requires immediate action.

Experience suggests that implementing a systematic, more focused and integrated water demand management approach/instruments are necessary, but not sufficient to solve the continuous and repeated deficiency in the performance of Addis Ababa water supply networks in supplying sufficient quantity of water continually & equitably to the consumers which are usually linked to the accelerated demand for water, operational factors, ways of operating and managing the system need to be appropriately dealt with as well. Addis Ababa is characterized by having old water distribution networks upon which new extensions are linked in order to serve new areas, adding complexity to an aging network where full rehabilitation may not be practical due to economic constraints.

Many sectors of the water distribution system of Addis Ababa suffers by the deficiency of water supply quantities and the extremely fluctuating pressure in the distribution system; which have caused performance shortcomings, meaning: failing to achieve the consumer demand at satisfactory level. For instance, the city is receiving only 49% of its demand with an average supply time of 14.8 hours per day, High levels of Non-Revenue Water (37-40% of System Input Volume) & leakage losses (28-30% of System Input Volume) in 2018, have a serious impact on AAWSA's finances as well as on available water resources in the context of the overall city water scarcity (Water Audit & Benchmarking Report, P. Antonaropoulos & Associates S.A).

Even though various type of actions have been taken by Addis Ababa Water & Sewage Authority (AAWSA) to upgrade its reliability and efficiency of service based on well considered development plans; the hindrances encountered on different occasions(such as: the increased on water demand & the water shortage crises following the accelerated growth of city population & urbanization, large volume of unaccounted for water due to breakage of the aging pipe lines) have caused the defect in the performance of the water network led to the negative influence in most of the socioeconomic sectors and on the capital city to achieve credibility on a global scale (AAWSA "Weha lehiwot" Magazine, 2001).

Water distribution systems are designed to adequately satisfy the water requirements for a combination of domestic, commercial, industrial, and firefighting purposes. The system should be capable of meeting the demands placed on it at all times and at satisfactory hydraulic performance (Warren V. et al, 1994). It should enable reliable operation during irregular situations and perform adequately under varying demand loads (James E. Funk, 1994).

The availability of water makes it possible for pumping water to the consumers at 24 hours per day with a constant flow rate, if water is not available in sufficient quantities then it should be pumped for shorter time periods at higher flow rate to meet the demand of the consumers (i.e. intermittent pumping), and a storage tank in this case for the entire supply area is usually provided in order to provide storage where the pumping rate is higher than the demand at night times, and this storage can be used in the case that the pumping rate is below the needed demand, and to equalize the pressure in the network in the cases of pressure increasing. Unlike in continuous supply, this creates smaller range of hourly peak factors allowing fairly stable supply through the distribution pipes. Balancing of the actual demand is therefore done individually for each household, whereby replenishing of the volume will happen somewhere later for the consumers located far away from the supplying points. Despite the risks of water contamination this way of water supply is still seen as the only possibility for even share of limited quantity of water (Jarrar H, 1998).

Experience suggests that the water shortage and the topographic conditions of Addis Ababa, forces to divide the water distribution networks in the serving area into several pressure zones through which water is pumped alternatively. This means that every zone in the network will be under the action of intermittent pumping. The gradual linking of new extensions on the existing water supply system in order to serve new areas without rehabilitating/upgrading its service components due to economic constraints & without considering intermittent pumping service as design assumptions, before the procedure of operating water distribution system forcing people to collect water individually, by means of ground or /and roof tanks. These roof tanks satisfy the water demand during its high periods & the non-pumping intervals by providing storage space. By tapping water from their own tanks, the consumers there do not rely on the pressure in the distribution system, as long it is sufficient to provide refilling of the tank at certain period of the day. This pressure zones are not designed to operate within a suitably limited range and requiring adjustment (AAWSP-Stage IIIA, TAHAL Consulting Engineers Ltd, 2005).

The above-mentioned way of operating the municipal water supply networks will affect the expected performance of the network by affecting the pressure values and the velocities. It also increases pipes breakage rates. The breakage in mains results from oscillating pressures due to providing a large number of homes with a high quantity of water in a short period (Masri M., 1997).

This study will investigate the state of the existing water distribution systems of Addis Ababa (Janmeda, Teferi Mekonnen, Belay Zeleke, Entoto and Ras Kassa sub systems as a case study) and to evaluate the hydraulic performance of the supply network under varying conditions of supply.

Addis Ababa is the largest political and commercial capital of Ethiopia, and the seat of many international organizations & embassies including African Union. Currently the city covers over 540km^2 area; with 1000m high altitude difference (AAWSA published magazine, June 2015). There are 10 sub-cities (Kifle ketema) and about 99 Kebeles. According to the Addis Ababa Water Supply Situation drawing dated March 2011 and prepared by the AAWSA NWR & SCD team, 23% of the total city area has no supply. The city water supply Authority (AAWSA) has, thus, a big task of supplying the city with adequate and quality water to fulfill the different demands so that the status of the city is kept.

1.2 Problem Statement

The performance of any water distribution system is strongly related to appropriate design assumptions and exercised management model. The design of water distribution systems in general is based on the assumption of keeping the hydraulic parameters within an acceptable range, taking into account the effects of local operating conditions & cost effective: in order to guarantee satisfactory performance & efficient water distribution systems.

This study intends to determine the extent to which the hydraulic performance of the Addis Ababa's water supply networks (the case of Janmeda, Teferi Mekonnen, Belay Zeleke, Entoto and Ras Kassa sub systems) is affected by the intermittent supply, operational ways and management system.

According to AAWSA Special issue magazine published on December 2014, Addis Ababa has suffered from serious problem of water shortage, only 67% of its urban area is covered with regular water supply, approximately 1 million people can't enjoy safe & healthy drinking water. Intermittent water supply, rotational batch water supply or central water supplies are adopted in many areas to alleviate water supply difficulties. Meanwhile, urban infrastructure and sustainable development have been severely constrained by water shortage.

The current average supply of 460,000 m^3/ day is not sufficient to cover the city's needs and supply interruptions are necessary. The city is receiving only 49% of its demand with an average supply time of 14.8 hours per day & 28% Non-Revenue Water. In 2018 Budget year out of 116 woredas; 91 woredas or 78% are receive water intermittently (Conference for conscious of short and long-term solutions to the difficulties of water supply services of Addis Ababa, Addis Ababa Water and Sewerage Authority, October, 2018).

Even though several actions are taken by Addis Ababa Water & Sewage Authority (AAWSA) to upgrade its reliability and efficiency of service based on well considered development plans; the hindrances encountered on different occasions (such as: the increased on water demand & the water shortage crises following the accelerated growth of city population & urbanization, large volume of unaccounted for water mainly due to old and deteriorated piping, high pressure in parts of the system, and complex extension of pipe lines) have caused the defect in the performance of the water network led to the negative influence in most of the socioeconomic sectors and on the capital to achieve credibility on a global scale (AAWSA "Weha lehiwot" Magazine, 2001 and TAHAL Consulting Engineers Ltd, 2005).

Experts suggests that, the necessity of AAWSA to implement a systematic & integrated approach to manipulate available supplies to meet perceived water needs & to improve the level of service rather than only concentrating on expansion based on new systems aggravates the deficiency in the performance of city's water supply networks by affecting the system adequacy & dependability (Mosissa M, 2008).

The understanding of the performance of water supply networks and their behavior in Addis Ababa city taking into account the effects of local conditions, such as (intermittent pumping) in which the water distribution networks in the serving area are divided into several pressure zones through which water is pumped with interruptions to serve different users at different times. And the division of these pressure zone boundaries and their operational condition is not implemented within a suitable limited range. This has resulted in severe supply, extreme pressure fluctuations & impermissible velocity values in the network, which is mark out by the frequent bursting of pipes, joints and malfunctioning of valves. Contamination of water by intrusion of pollutants through weak joints, by stagnation of water in service reservoirs and great inequities in the distribution of water has resulted in due short duration of supply and nominal settings of flow regulating valves. Also intermittent supplies have resulted on consumers need to store water between supplies and tend to throwaway remnant store, which causes much more water wastage: and emphasized by the fact that taps are often left opened during the whole supply time. These all will lead to the importance of appropriate design assumptions, and on consideration of the effects of the intermittent supply on the value of the design factors in cost effective design of municipality water supply networks.

To lead appropriate design, we must study the hydraulic parameters, the variations, and the relations between them and other factors, which control the performance of the water supply networks; also it must investigate the effects of local conditions and improve them for increasing the efficiencies of the water distribution systems.

In Addis Ababa there is a need to evaluate the performance of the water distribution system and to define the appropriate design and operational requirements.

1.3 Research Questions

What are the problems of the existing water supply networks that affect their efficiency?

How the Janmeda, Teferi Mekonnen, Belay Zeleke, Entoto and Ras Kassa sub distribution network behaves under the action of intermittent supply and continuous supply system?

How the hydraulic performance of Janmeda, Teferi Mekonnen, Belay Zeleke, Entoto and Ras Kassa sub distribution systems does affect by local operating conditions?

What are the appropriate design parameters & assumptions, which lead to a better network operation under the action of intermittent pumping?

1.4 Objectives of Research

1.4.1 General objective

The main objective of this study is to evaluate the hydraulic performance of Addis Ababa water supply network (the case of Janmeda, Teferi Mekonnen, Belay Zeleke, Entoto and Ras Kassa sub distribution system) taking into account the effects of local operating conditions.

1.4.2 Specific Objectives

Under the main objective, the paper addresses the following specific objectives:

1- Investigate the efficiencies of the existing water supply networks and identify the existing water supply problems.

2- Investigate the effects of local operating conditions (pumping, pressure zoning, and management) on the hydraulic performance of the water supply networks.

3- Model the existing water supply system as an intermittent supply system and as a continuous system in order to study the effects of the two models on the performance of the system.

4- Study the interrelation between hydraulic parameters (pressure, velocity) & with other factors (such as the time).

1.5 Significance of the Study

This research will provide valuable information on how the implementing design assumptions and exercised management model for water distribution systems are strongly related with the performance of any water distribution system.

Also, this study will offer insight that more local studies and investigations will be needed to understand how the water systems in our city perform under the local conditions of operation and management and to evaluate the performance of the water distribution systems in Addis Ababa city. Hopefully, the insights that can be drawn from this study will initiate further similar researches on other sub-systems and will provide a way forward for Addis Ababa water planners and policy makers to improve the water supply sector.

1.6 Thesis Structure

In addition to the introductory part, the following is a brief description of discussions held in the study under each section:

Chapter two contains literature reviews related to study the behavior of water distribution systems, and optimal solutions and assumptions in order to improve the hydraulic performance, cost effective, and to increase the efficiencies of the water supply systems. Detailed concepts of intermittent water supply systems, comparison between the continuous and intermittent supply systems, and the proposed methods of modeling the intermittent water supply systems are discussed.

Chapter Three discusses the methodology used in data collection and preparation, a Procedure of modeling to evaluate the hydraulic performance and the methods used to reach at findings and conclusion.

Chapter Four is devoted to modeling the selected sub distribution system as an intermittent and continuous supply system, in order to study the effects of the two models on the performance of the system, and how the system behaves. Studying a pilot zone in the network to develop the water consumption and unaccounted for water (UFW), studying the variations in levels of roof tanks to estimate the peak factors, and analyze the outputs of these works.

Chapter Five discusses and interprets results with emphasis on the findings of the model out-puts, Assesses out-put of the models on hydraulic performance of the system at critical points, and how the system behaves under intermittent and continuous supply conditions.

Chapter Six deals with conclusion and proposed solutions that will lead to a better network performance based on results and findings of the studied sub distribution systems.

Under Appendix, collection of major tabular data on data input parameters, data output parameters and other relevant parameters attributed to the study are included.

Chapter Two

2. Literature Review

2.1. Introduction

Providing quality service at minimum possible cost is the ultimate goal of drinking water utilities. Water distribution systems that help to achieve this goal seek integrated utilization of efficient design constraints, and principal local operational & management activities. The design, operation, and maintenance of water systems, are concerned with the adequacy and its reliability aspects of the total water supply system.

This is fairly typical of what one needs to understand in evaluating water supply systems to assure on the capability of the water delivery system components to meet the service objectives by measuring the efficiency and effectiveness of the delivery of service in terms of performance evaluating criteria and use the results of these assessments to monitor the performance of the water delivery system to improve the quality of service by determining the water system component which limits the system from meeting its service objectives (Harry E. Hickey 2008).

Multi objective optimization is a process of identifying the best alternative solutions that provide, ideally, a range of cost and benefits are generated while meeting water distribution system objectives.

The following section will address the major issues on reaching optimal solutions and assumptions in order to meet water distribution systems objectives especially(improving the hydraulic performance, cost effective, and increasing the efficiencies) from perspectives of different sources are summarized as follows:

2.2. Water Supply Systems

The objective of water distribution systems is to deliver water of suitable quality to individual users in an adequate amount and at a satisfactory pressure. It should be capable of delivering the maximum instantaneous design flow at a satisfactory pressure.

2.2.1 Types of Water Distribution System

For efficient distribution it is required that the water should reach to every consumer with required rate of flow. Therefore, some pressure in pipeline is necessary, which should force the water to reach at every place. The most common types of distribution system are either of the following: Gravity Distribution, Distribution by Pumping without Storage, Distribution by means of pumps with storage, and Combined Pumping & Gravity Distribution.

2.2.2 Methods of Water Supply Systems

The available water sources through the world are becoming depleted and this has brought into focus the urgent need for planned action to manage water resources effectively for sustainable development.

The problem of water scarcity in urban areas of developing countries is of particular concern and as the water quantity available for supply generally is not sufficient to meet the demands of the population, water conservation measures are employed (Vairavamoorthy, K. et al., 2000).

One of the most common methods of controlling water demand is the use of intermittent water supplies, usually by necessity rather than design. As reported in the literature that the majority of water supply systems in developing countries are intermittent. Also, such systems are prevalent in many developing countries, encouraged by low tariffs and investments, often in a will to optimize water and economic resources. Paradoxically, more water is needed for such systems due to high wastage.

Water can be supplied to the consumers by the following two systems/operational ways/:

2.2.2.1 Continuous Supply

This is the best system and water is supplied for all 24 hours. This system is possible when there is adequate quantity of water for supply. In this system sample of water is always available for firefighting and due to continuous circulation water always remains fresh. In this system less diameter of pipes are required and rusting of pipes will be less. Losses will be more if there are leakages in the system.

2.2.2.2 Intermittent Supply

Drinking water systems should invariably be operated on continuous pattern for twenty four hours a day. But due to financial constraints it is not practically possible to operate drinking water systems for twenty-four hours a day in developing countries. Generally a period of eight hours or less is considered adequate to supply the drinking water. Due to present faulty design practice, which is derived from continuous water supply the consumers are deprived of adequate water quantity and pressure. Intermittent water supplies' is unique by it-self and need different approach for design and modeling other than the continuous water supplies. Demand of water at particular node is important characteristic in the continuous water supply, but it is ***Supply*** of water at a node what drives the intermittent systems. Many factors like charging of water mains at the start of supply each day, ingress of contaminant due to negative pressure, application of peak factors, changing resistance coefficients, equitable water distribution using zoning valves, leakages etc… are peculiar features of intermittent water supply (World Water & Environmental Resources Congress, 2003).

It is of interest to note that many cities, more typically in Asia and Africa, either do not have a 24 hour supply, or the supply pressure is so low that many consumers receive an intermittent supply. The ADB survey of 1996 (ADB, 1997) showed that 40% of 50 Asian cities surveyed did not have a 24-hour supply and that about two-thirds had street standpipe supplies. 91% of systems in South East Asia are intermittent as reported by WHO survey (Pickford, J.A, 1987). Practically all-Indian cities are reported to operate intermittent systems (Kumar, A., and Abhyankar, G.V, 1988).

The design of water distribution systems in general has been based on the assumption of continuous supply. In most developing countries water supply is not continuous but intermittent, and this could have been foreseen at the design stage. This has resulted in severe supply, pressure problems in the network and great inequities in the distribution of water. Technically, these problems can be mitigated or eliminated if the intermittent supply conditions are considered while designing the water distribution systems (Izquierdo, Montalvo, Perez-Garcia, and Matias, 2012).

Most design engineers in the developing world are aware that their approach to design is incorrect, but argue there is no alternative since there are no proper design tools developed specifically for intermittent systems (Vairavamoorthy,K. et al., 2000).

It is evident from literature surveyed that the design of distribution networks operating intermittent supplies has in general been based on the assumption of continuous supply, the concepts and methods used are identical with those used in the developed countries (Vairavamoorthy,K. et al., 2001).

An important component of a water supply system is the distribution network, which conveys water to the consumer from the sources. These systems constitute a substantial proportion of the cost of a water supply system, in some cases as much as half the overall cost of the system (Vairavamoorthy, K. et al., 2001).

Maher Abu-Madi & Nemanja Trifunovic (2013) analyzes the impacts of reduced supply duration on the design and performance (i.e. the hydraulics and costs of water distribution) of intermittent water distribution system in the West Bank. It shows that designing systems based on intermittent supply criteria implies increasing the diameters of pipes & capacity of storage tanks significantly, which is expensive and infeasible. They recommend that studying the local conditions should precede the design of new systems to avoid reduced supply duration and related negative impacts.

L. Fan et al., (2014) studied the influence of intermittent and continuous water supply on domestic water consumption and patterns in villages in the central region of the Wei River basin, China. This work describes adopting an intermittent water supply (i.e. moderate supply restriction (>1.5 and<6 h/d)) can reduce domestic water consumption (33.6‑34.7 L. c. d). The study conclude that the determination of the daily water delivery duration for intermittent water supply in rural communities of developing countries should give greater consideration to differences in water use activities and patterns under the water supply time restrictions.

The design of supply systems in most of the developing regions based on the assumption of direct supply, although most of these systems are intermittent systems, which result in severe supply, pressure losses and great inequities in the distribution of water.

The problems of the intermittent supply systems:

- Overall shortage of water.
- Insufficient pressure in the distribution system (several areas in the network had zero pressure).
- Inequitable distribution of the available water.
- Very short duration of supply.

A serious problem arising from intermittent supplies, which is generally ignored, is the associated high levels of contamination. This occurs in networks where there are prolonged periods of interruption of supply due to negligible or zero pressures in the system. The factor that is most related to contamination is duration of supply (Vairavamoorthy, K. et al., 2001).

Both continuous and intermittent water distribution systems might suffer from the contaminant intrusion problem, and the intermittent systems were found more vulnerable of contaminant intrusion (Yan, J.M, 2001).

The design of water transport and distribution systems under intermittent conditions should not be based on the minimum and maximum peaks of the demand pattern but on the peaks of supply and delivery patterns that are governed by availability of sufficient water at the source, the capacity of the supply system, and the number of supply and delivery hours (Maher Abu-Madi & Nemanja Trifunovic, 2013).

As a major factor & important characteristic of the intermittent systems, the impact of reduced water supply duration on water demand/ consumption of the nodes to enlarges by necessitating the demand multipliers(pf) to be increase, and pipe diameter increases with proximity to the water source (main transmission pipes) & decreases with proximity to the consumer(distribution network). These results lead to insufficient water availability for consumers and causes unreliability of the existing distribution systems. These challenges will be exacerbated if the current design practices overlook this fact and assume water availability and appropriateness to provide continuous water supplies. Studying the local conditions of water availability is a necessary step before embarking on the design of new water supply systems to avoid reduced supply duration and the resulting negative impacts. As a result, increased demand multipliers will require increasing the diameters of pipes and capacity of public storage tanks, and thus, construction costs will increase substantially, under the existing conditions of limited financial resources (Maher Abu-Madi & Nemanja Trifunovic, 2013).

Also another negative impact of reduced water supply duration under intermittent-supply conditions will necessitate substantial increases of the flow, increases hydraulic gradient/friction & energy losses (due the existing pipelines will have to carry different water quantities depending on the number of supply hours), and reducing network pressure (which leads to unreliable service: water will fail to reach & fulfill the water demand of many consumers, especially those located at higher elevations of the network). Good design practices recommend that the hydraulic gradient not exceed 10 m/km. Lower values indicate minimized energy losses and reduced operational costs (Maher Abu-Madi & Nemanja Trifunovic, 2013).

As reported by several studies, the main consequences/ disadvantages of operating a water distribution system under intermittent supply conditions that was originally designed for 24-hour continuous supply can be summarized as follows:

- Systems do not operate as designed.
- Pumps and pipes failing to carry the required water demand during short periods, thus leading to unreliable service and uneven distribution of water.
- Low pressure due to increased hydraulic losses associated with increased flows and undersized pipe diameters.
- Increased water leakage.
- High doses of chlorine are needed.
- Over sizing the network is needed to supply the necessary quantities in a shorter time.
- Consumers have to pay for storage and pumping.
- Water meters malfunction, which can lead to a loss of revenue and customer disputes.

- In case of fire, immediate supply is unavailable.

But, intermittent supply systems also have their own merits:

- For older distribution systems having weaker joints and more leakage, restrained supply hours can limit leakage.
- Reduced pressure also helps lowering leakage.
- Overall scarcity may sometimes be managed by interrupting the water supply and equally balancing the resources (controversial).
- Time is available for repair and maintenance out of supply hours.

There is a tradeoff between the capital costs associated with proper sizing of pipeline diameter and the operational costs due to energy losses in the water supply systems. The Addis Ababa water policy makers and aid agencies are advised to recognize the trade-offs between reduced capital costs and increased operational costs of the water supply systems under implementation.

2.3 Principles of Pipe Network Hydraulics

Flow in a pipe network satisfies two basic principles, conservation of mass, and conservation of energy.

Conservation of Mass- Flows Demands: Conservation of mass states that, for a steady state system, the flow into and out of the system must be the same (Lansey, K, 1991).

$$\sum Q_{in} - \sum Q_{out} = Q_{demand} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

$$\Sigma Q_{in} \Delta t = \Sigma Q_{out} \Delta t + \Delta V_S \ldots\ldots\ldots\ldots\ldots\ldots (2.2)$$

Where:
ΣQ_{in}: flows in pipes entering the node or the total flow into the node.
ΣQ_{out}: flows in pipes exiting the node or the total demand at the node.
Q_{demand}: the user demand at that location.
ΔV_S: is the change in the storage.
Δt: is the change in time.

Conservation of Energy: It is the second governing equation states that, the head losses through the system must balance at each point. For pressure networks, this means that the total head loss between any two nodes in the system must be the same regardless of what path is taken between two points.

$$E_1 = E_2 \pm \Delta E \ldots\ldots\ldots\ldots\ldots\ldots (2.3)$$

where ΔE is the amount of transformed energy between cross-sections of a pipe.

2.3.1 The Energy Equation

The Energy equation is known as Bernoulli's equation (Daugherty,R.L., J.B.Franzinin, and E.J.Finnemore, 1989). It consists of the pressure head, elevation head, and velocity head. There may be also energy added to the system (such as by a pump), and energy removed from the system (due to friction). The changes in energy are referred to as head gains and head losses.

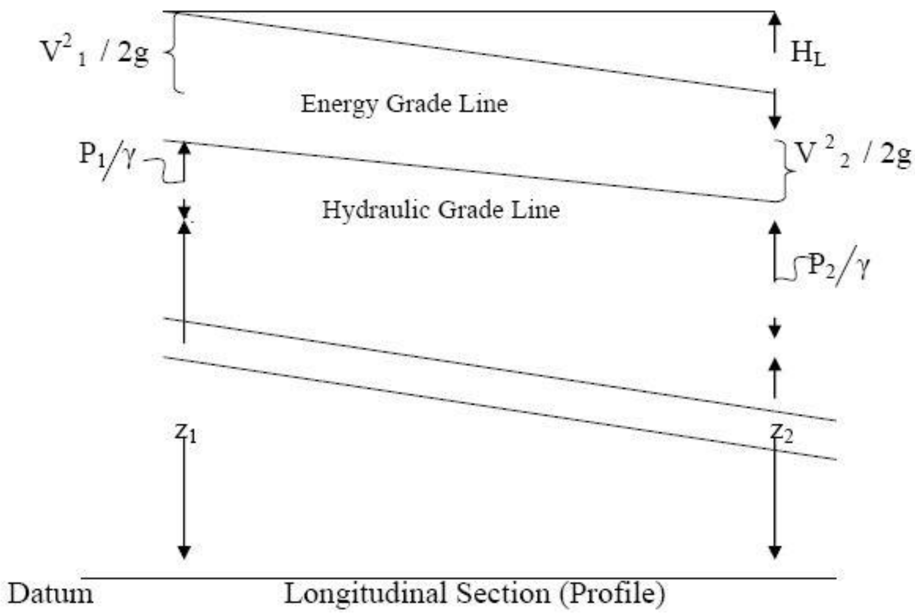


Figure (2.1): The Energy Principle

$$P_1 / \gamma + z_1 + V^2{}_1 / 2g + H_G = P_2 / \gamma + z_2 + V^2{}_2 / 2g + H_L \text{.................} \quad (2.4)$$

Where: P: is the pressure (Ib/ft^2 or N/m^2)
γ: is the specific weight of the fluid (Ib/ft$_3$ or N/m^3)
z: is the elevation at the centroid (ft or m)
V: is the fluid velocity (ft/s or m/ s)
g: is gravitational acceleration (ft/s^2 or m/ s^2)
H_G: is the head gain, such as from a pump (ft or m)
H_L: is the combined head loss (ft or m)

2.3.2 Energy Losses

There is a combination of several factors that cause the energy losses. The main reason of the energy loss is due to internal friction between fluid particles traveling at different velocities (Friction Losses). The other reason is due to localized areas of increased turbulence and disruption of the stream lines (Minor Losses) (Haestad Methods, 1999).

Hazen-Williams equation and the Darcy-Weisbach equation are the most commonly methods used for determining head losses or friction losses in pressure piping systems.

Hazen–Williams equation:

$V = KCR^{0.63}S^{0.54}$……………… (2.5)

Where: V: mean velocity (ft/s or m/s)

K: 1.32 for U.S. standard units, or 0.85 for S.I. units

C: Hazen –Williams roughness coefficient.

R: Hydraulic radius of the pipe in meters

S: the dimensionless slope of the energy grade line

Darcy – Weisbach (Colebrook-White) equation:

$V = ((8g\ R\ S)/\ f)^{0.5}$ …………… (2.6)

Where: V: flow velocity (ft/s or m/s)

g : gravitational acceleration (ft/s^2 or m/ s^2)

R : hydraulic radius (ft or m)

f : Darcy-Weisbach friction factor

S : Friction slope

2.4 Design and Operation of Water Distribution Systems

The water distribution networks should meet demands for potable water. If designed correctly, the network of interconnected pipes, storage tanks, pumps, and regulating valves provides adequate 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 (Haestad Methods, 1999).

The water distribution network, which is typically the most expensive component of a water supply system, is 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 (Kleiner,Y.;Adams, B.J., Roger,J.S, 2001).

2.4.1 Design Constraints

Efficient design of a WDS must satisfy several constraints. These constraints include water quantity requirements, limits on pressures and velocities, limits on water quality parameters, and fire protection requirements, besides the usual constraints on overall system costs.

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 (Masri M, 1997).

Constraints on Water Quantity: A well-designed WDS should supply adequate quantities of water to all consumers including fire demands within a certain time through a certain section. Therefore, estimating the desired quantities of water by various consumers becomes an important task. Normal water consumption originates from three distinct groups of consumers: residential, commercial, and industrial. State and local guidelines on per-capita consumptions would be helpful in estimating the commercial and residential demands (VAC, 2002). Industrial demands should be estimated in consultation with the industries being served. Demands may also be estimated based on land-use and associated consumption data from neighboring systems of similar characteristics (population and commercial activities). Demand calculations for the existing WDS should come from monthly meter records. Peaking factors must be applied to the average daily demands to account for maximum-day demand as well as maximum-hour (peak–hour) demand (AWWA.M32, 1989). Most water utilities ensure that the supplies (treatment plant and pumping capacities) are adequate to meet maximum-day demand and rely on the floating storage tank capacities to meet the maximum hour demand.

Constraints on Pressures and Velocities: It is not only important to deliver adequate quantities of water to the consumers but also to ensure that the water is delivered at adequate pressures. The pressure at nodes depends on the adopted minimum and maximum pressures within the network, topographic circumstances, and the size of the network (Masri M, 1997). 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. Pressures less than 30 psi under maximum-hour demand conditions are not acceptable for most water systems. Although the upper bound on pressure would depend on the pressure rating of the pipe material or the pipe joints, many water utilities are mandated to maintain pressures well below the rated capacities of pipes (e.g., 70–80 psi) to safeguard the appliances that derive water directly from the distribution network. Limiting the upper bound on pressures would also reduce the leakage losses as well as the pump operating costs (Lingireddy, S. and Wood, D.J, 1998).

Constraints on Water Quality: With the new safe drinking water regulations, the utilities are required to ensure delivery of water that meets or exceeds all drinking water standards (limits on physical, chemical, and microbial parameters) right at the consumer connection. In addition, the water supplied should also carry specified minimum levels of residual disinfectant (e.g., chlorine or chloramines).

As most disinfectants are non-conservative chemicals (i.e., concentrations drop with time), concentration levels higher than the required minimum values are necessary near the supply sources (Lingireddy, S., Ormsbee, L.E., and Wood, D.J., 1995).

Water Hammer: When the velocity of flow in a pipe changes suddenly, surge pressures are generated as some, or all, of the kinetic energy of the fluid is converted to potential energy & stored temporarily via elastic deformation of the system, and a surge pressure wave moves through the system. This phenomenon, generally known as "water hammer", occur most commonly when valves are opened or closed suddenly, or routine pump startup & shutdown, and pump trip resulting from power failure situations. High transient pressures might result in pipe breakages or loosening of pipe joints and other components of the distribution system. Pressures below the vapor pressure of water lead to formation of vapor cavities. Subsequent high pressures can collapse the vapor cavities producing high-pressure spikes. Recent studies have shown that pressures below atmospheric levels can lead to pathogen intrusion problems at certain vulnerable points such as leaky pipe joints (LeChevallier, M.W.,Gullick, R.W., and Karim, M., 2002). Therefore, it would be prudent to perform a transient analysis of potential rapid flow variation scenarios and provide adequate protection to the WDS. The protection methods include use of pressure vessels (surge tanks), relief valves, rupture disks, and air release/vacuum valves, air chambers, and special pump control systems (Wood, D.J. and Lingireddy, S., 2004).

2.4.2 Principal Operations

The operational tasks for distributing clean water in a city involve monitoring flows, pressures, storage levels, and water quality at different network locations; controlling and moving valves; attending to reports and enquiries from the public; billing and charging for consumption; keeping updated infrastructure maps and consumer records and census; repairing leaks; and replacing or improving pipes, hydrants, pumps, and other water distribution networks components (World Bank).

The most important operational activities of any water distributing system that helps to meet its operational goals are generally categorized under: Water delivery & Monitoring, Prevention & Safety, Maintenance & Repair, and Public relations & Management (Jay Lehr et al., 2005).

Distribution system monitoring and modeling are critical to maintaining hydraulic integrity. Water utilities can achieve a high degree of hydraulic integrity through a combination of proper system design, operation, and maintenance, along with monitoring and modeling (National Research Council, 2006). Hydraulic parameters to be monitored should include inflows/outflows and water levels for all storage tanks, discharge flows and pressures for all pumps, flows and/or pressure for all regulating valves, and pressures at critical points. An analysis of these patterns can directly determine if the system hydraulic integrity is compromised. Calibrated distribution system models can calculate the spatial and temporal variations of flow, pressure, velocity, reservoir level, water age, and other hydraulic and water quality parameters throughout the distribution system. Such results can, for example, help identify areas of low or negative pressure and high water age, estimate filling and draining cycles of storage facilities, and determine the adequacy of the system to supply fire flows under a variety of conditions.

Maintaining the hydraulic integrity of distribution systems is vital to ensuring that water of acceptable quality is delivered in acceptable amounts. The most critical element of hydraulic integrity is adequate water pressure inside the pipes. The loss of water pressure resulting from pipe breaks, significant leakage, excessive head loss at the pipe walls, pump or valve failures, or pressure surges can impair water delivery and will increase the risk of contamination of the water supply via intrusion. Another critical hydraulic factor is the length of time water is in the distribution system. Low flows in pipes create long travel times, with a resulting loss of disinfectant residual as well as sections where sediments can collect and accumulate and microbes can grow and be protected from disinfectants. Furthermore, sediment deposition will result in rougher pipes with reduced hydraulic capacity and increased pumping costs. Long detention times can also greatly reduce corrosion control effectiveness by impacting phosphate inhibitors and pH management. A final component of hydraulic integrity is maintaining sufficient mixing and turnover rates in storage facilities, which if insufficient can lead to short circuiting and generate pockets of stagnant water with depleted disinfectant residual.

Some of these operational goals may be: Continuity of supply (24 hours, 365 days per year), Keep low water tariffs (*in balance with expenditures and investments*) and in an increasing block fashion *(the more you consume, the more you pay per water unit to keep the water demand as small as possible and preserve the resource*), Promote and advise customers to keep their water consumption low (*demand management*), Keep pressure neither not too weak nor too strong at each house connection (*around 10 m to 30 m of water column, that is, between 1 to 3 bars*), Curb water leaks (*pipes burst*) and when they occur; repair them within a few hours, Satisfy daily & seasonal variations in water demand without spillage or damage to infrastructure or inconvenience to consumers, use the least possible energy for pumping & other processes (*low operating costs*), Water quality in all points of the network must meet established standards, courteous, fair & un-discriminatory treatment to all consumers, and Optimize the use of the system's installed capacity for; water storage, pumping and conduction (*profit from and use the existing infrastructure, keep it in good shape, and avoid the need for building more of it*) (Jay Lehr et al., 2005).

James, Liggest and Chen (1994) made a study about distribution systems. Data about pressure and flow rate were obtained by continuous monitoring of their system. Transient analysis, time lagged calculations and inverse calculations were applied as a tool for calibration and leak detection.

2.5 Performance Evaluation of Water Distribution System

The evaluation of municipal water systems starts with a thorough evaluation of the water system source or sources extends through the treatment of raw water to provide finished water or purified water for consumer consumption, moving this water through distribution piping to provide consumer consumption on demand. Of no less importance is determining just how well the municipal water system measures up in accomplishing this task 24 hours a day, 365 days a year, year in and year out. Each component or element of the water system can be analyzed individually to carry out such an evaluation, or the water system can be evaluated as a whole, integrated system to understand **the adequacy and reliability** of the complete water supply delivery system for all service areas of a specific community. This is fairly typical of what one needs to understand in evaluating water supply systems to assure on the capability of the water delivery system, plus the function of selected components of the water system to meet the service objectives (i.e. ensuring sufficient supply of safe and agreeable drinking water continually by minimizing adverse effects on the constituents) of the system in terms of performance evaluation criteria(i.e. adequacy, dependability, and efficiency) via water supply service performance assessment approaches/ measures(i.e. hydraulic, structural, water quality, customer perception & satisfaction, and overall system O & M costs) (Harry E. Hickey 2008).

2.5.1 Adequacy and Reliability Analysis of Water Distribution Networks

Adequacy, in the case of a water system supplying water for normal consumer consumption and for fire protection, means having the capability of simultaneously supplying water for maximum consumption demands plus water that may be needed to combat and extinguish a major fire within the area served by the water system. Adequacy concerns itself with sufficient flow and pressure on all installed fire hydrants on the water system (Cote, Arthur E., Ed., 2005).

"*Hydraulic availability*, as it relates to water distribution system design, can be defined as the ability of the system to provide service with an acceptable level of interruption in spite of abnormal conditions" (Cullinane et al., 1992). The evaluation of hydraulic availability relates directly to the basic function of the water distribution system, i.e., delivery of the specified quantity of water to a specific location at the required time under the desired pressure (Shinstine et al., 2002).

Reliability of a community water system is having the capability of supplying the maximum daily consumption plus a required fire-flow demand, even in the event of a malfunction or the outage of important system components, such as a pipeline break, valve failure, power outage, or stationary pump outage. Reliability is a more subjective evaluation and requires both a what-if look at the water system and a determination of what to do about the **what-if** happening (Cote, Arthur E., Ed., 2005).

Reliability of a water distribution system is "the ability of the system to provide service with an acceptable level of interruption in spite of abnormal conditions." Cullinane et al. (1992).

The performance of Water distribution system (Coelho, 1997) is measured based on its ability of the system to deliver good quality water at all the times under suitable set of operating conditions.

Besides measuring the efficiency and effectiveness of the delivery of service, an important part of evaluating water supply systems is to use the results of these assessments to monitor the performance of the water delivery system in relation to the existing/ new water supply services and the constant changes in demand on the water system, and improving the quality of service by determining the water system component which limits the system from meeting its service objectives (Harry E. Hickey 2008).

The design, operation, and maintenance of water systems, are concerned with the adequacy and its reliability aspects of the total water supply system. 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 are some of the important parameters required to be selected before designing any water system (Prabhata K. Swamee & Ashok K. Sharma, 2008).

To ensure delivery of finished water to the user, the water distribution system must be designed to accommodate a range of expected emergency loading conditions. These emergency conditions may generally be classified into three groups: broken pipes, fire demands, and pump and power outages. Each of these conditions must be examined with an emphasis on describing its impact on the system, developing relevant measures of system performance, and designing into the system the capacity required to handle emergency conditions with an acceptable measure of reliability. *Reliability* is usually defined as the probability that a system performs its mission within specified limits for a given period of time in a specified environment (Larry W. Mays, 2004).

Service levels are the standards of supply which a water utility affords its customers. The standards can be targets for achievement set by a utility for itself, or set by some outside authority. Levels of service are often set by, or agreed with, international funding agencies such as the World Bank, to define what a programme of rehabilitation or improvement of a utility should achieve. Records of how far such levels of service have been achieved can be used as performance indicators by regulators and customers to gauge the utility's annual service delivery performance. The three principal levels of service relating to distribution systems are hydraulic performance, continuity of supply and water quality.

Hydraulic performance defines the minimum pressure and flow that domestic consumers should experience.

Jarrar H (1998) studied the hydraulic performance of water distribution systems under the action of cyclic pumping; the results show that the network under consideration is exposed to relatively high-pressure values throughout. The velocity of the water through the network attained also high values. These high values of pressure and velocity have negative effects on the performance of the network.

Continuity of supply is measured by the number, duration and circumstances relating to interruptions or deficiencies of supply. This indicator also uses for assessing a water company's performance. Interruptions to supply can be either of:

- Unplanned interruptions due to bursts, etc…,
- Planned and warned interruptions due to planned maintenance, new connections, etc…,
- Unplanned interruptions caused by a third party, for example another utility damaging a water pipe while excavating for their own service; and
- Unplanned interruption due to overrun of a planned and warned interruption.

In poorer countries of the world, particularly where utilities are publicly owned, similar target service levels may be the aim but achieving them is often not possible due to lack of source capacity and limited financial resources. For some a more realistic target is to achieve 4-hour supply morning and evening to connected consumers and with standpipe coverage for all other householders. Under these circumstances other operational difficulties arise and maintaining **water quality** may be problematic. The principles for designing DMAs are applicable also for designing areas for controlling rationing. For systems subjected to severe supply constraints and water quality problems associated with infiltration and poor asset condition, it may be prudent to consider alternative methods of supply including tankering water to local storage connected directly to standpipes or to provide mobile storage at strategic locations in the supply area.

Measuring the **adequacy and reliability** of water distribution network involves studying water supply records & conducting of water Flow tests at some intervals by considering all known operational characteristics of a water system, which is essential to determine pressure and flow-producing capabilities, and to determine hydraulic availability of water at any representative locations within the distribution system. But the tests also serve as a means of determining the general condition of the distribution system piping network, and can help to detect the Setting of valves in the system. The results of flow tests are used extensively by insurance underwriters as a factor in setting property insurance rate premiums; they also are used by designers & managers for monitoring the municipal water system at specific locations over time (American Water Works Association, 3rd Ed.).

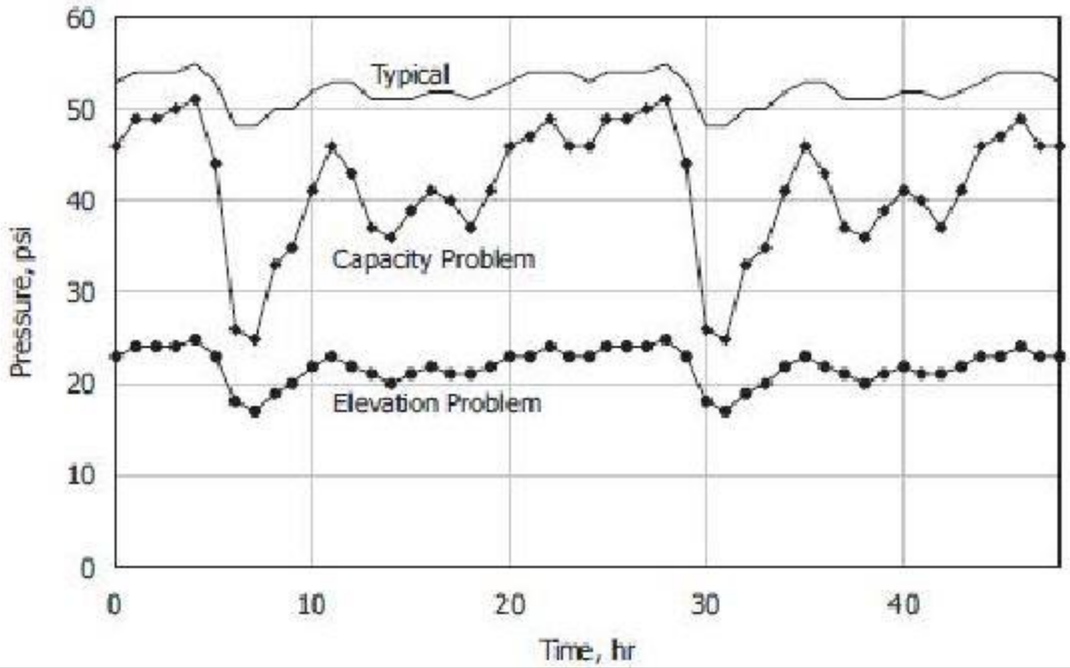
Urban water systems are large and have multi-input sources to cater for large population. To design, maintain, and operate such systems as a single entity with a single water supply system is difficult & there must also be an optimal geometry to meet a particular water supply demand. These systems are decomposed or split into a number of small subsystems (called water supply zones) with single input source, individual pumping and network system, and nominal linkage between the adjoining zones for inter-zonal water transfer in case of a system breakdown or to meet occasional spatial variation in water demands, which are all governed by economic and reliability criteria. The economic criterion pertains to minimizing the water supply cost per unit discharge. The optimum zone size depends upon the network geometry, population density, topographical features, and the establishment cost for a zonal unit (Prabhata K. Swamee & Ashok K. Sharma, 2008).

2.6 Identifying and Solving Common Distribution System Problems

Most water distribution systems share a number of common concerns. High and low pressures and velocities are among common problems found in most of water distribution systems. Models are helpful in pinpointing the cause of the problem (Walski et al., 2003).

2.6.1 Low Pressures

The most frequently occurring operational problem associated with water distribution systems is low or fluctuating pressures. Although confirming that the problem exists is usually easy, discovering the cause and finding a good solution can be much more difficult. In general, poor pressures tend to be caused by inadequate capacity in a pipe or pump, high elevations, or some combination of the two. Figure 2.2 shows how an EPS model can help determine whether the low pressure is due to capacity or elevation problems. Customers at high elevations may experience constant problems with low pressure, while a capacity problem may show up only during periods of high demand. The "Typical" line in Figure 2.2 represents pressure fluctuations in a typical system; the "Capacity Problem" line shows pressures for a system with pump or main capacity problems; and the "Elevation Problem" line shows pressure fluctuations in a portion of a system where the utility is attempting to serve a customer at too high of an elevation.



Source: (Advanced Water Distribution Modeling and Management, Haestad press. U.S., 2003)

Figure (2.2): EPS run showing low pressure due to elevation or system capacity

After the cause of the pressure problem has been identified and confirmed, the possible solutions are usually fairly straightforward, and include the following:

- Making operational changes such as opening valves
- Changing PRV or pump control settings
- Locating and repairing any leaks
- Adjusting pressure zone boundaries
- Implementing capital improvement projects such as constructing new mains
- Cleaning and lining pipes
- Installing pumps to set up a new pressure zone
- Installing a new tank

Undersized Piping: An undersized distribution main will not be easy to identify during average-day conditions, or even peak-day conditions, because demand and velocity are typically not high enough during those times to reveal the problem. If a pipe is too small, it may become a problem only during high-flow conditions such as fire flow. Fire flows are much greater than normal demands, especially in residential areas. Therefore, fire flow simulations are the best way to identify an undersized distribution main. If looking for sizing problems in larger pipes, such as those leaving treatment plants, the best time for diagnosing problems would likely be the peak hour or, in some cases, during periods when tanks are refilling.

If undersized pipes are suspected, they can usually be found by looking for pipes with high velocities. It is important to note that when evaluating models for undersized pipes, it is better to evaluate based on hydraulic gradient rather than head loss. Although one pipe may have a much larger head loss than another, the hydraulic gradient may actually be lower, depending on the length of the pipes being compared.

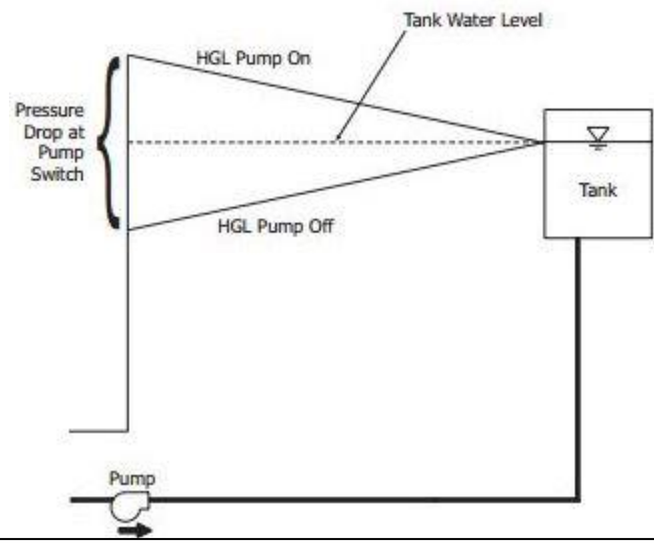
No fixed rule exists regarding the maximum velocity in a main (although some utilities do have guidelines), but pressures usually start to drop off (and water hammer problems become more pronounced) when velocities reach 10 ft/s (3 m/s). In larger pressure zones, several miles across, a velocity as low as 3 ft/s (1 m/s) may cause excessive head loss. Increasing the diameter of the pipe in the model should result in a corresponding decrease in velocity and increase in pressure. If not, then another pipe or pump may be the reason for poor pressures.

Inadequate Pumping: In a pressure zone that is served by a pump, pressures that drop off significantly may indicate a pump capacity problem. This drop will be most dramatic in situations in which most of the pumping energy is used for lift rather than for overcoming friction or in which there is no storage in the pressure zone (or the storage is located far from the problem area). When the flow rate increases above a certain level, the head produced by the pump drops off, and pressures decrease by a corresponding amount.

At first, undersized pipes might be suspected as the cause of the problem, but increasing pipe sizes has little impact in this case. A comparison of the pump's production with its rated capacity will indicate the problem. Installing a larger pump (in terms of flow, not head) or another pump in parallel corrects the problem if the pump flow capacity is the real cause.

Another factor to consider is that when velocity is high, changes in velocity are also high, and these accelerations can lead to harmful hydraulic transients (that is, water hammer). One approach to reducing transients is to reduce velocity.

The velocities are useful only for spot-checking network model output when locating bottlenecks in the system (that is, pipes with very high velocities, and therefore high head losses). The real test of a design's efficiency is not velocity, but residual pressures in the system during peak demand times. When checking designs for permissible velocities, some engineers use 5 ft/s (1.5 m/s) as a maximum, others use 8 ft/s (2.4 m/s), and yet still others use 10 ft/s (3.1 m/s).



Source: (Advanced Water Distribution Modeling and Management, Haestad press. U.S., 2003)

Figure (2.3): Effect of pump operation on customers near the pump

2.6.2 Consistent Low Pressure

If pressures are consistently low in an area, then the problem is usually due to trying to serve customers at too high an elevation for that pressure zone. This problem is apparent even during low-demand periods. Changing pipe sizes or pump flow capacity will not improve this situation. If this pressure zone has no storage tanks, it may be possible to increase the head for a fixed-speed pump or increase the control point for a variable-speed pump (provided this increase does not overly pressurize other portions of the system).

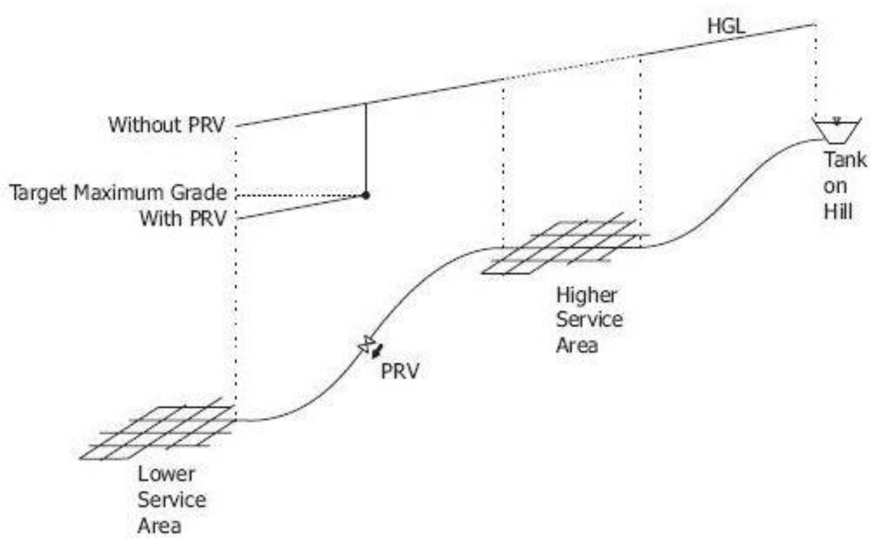
In many cases, the best solution is to move the pressure zone boundary so that those customers experiencing low pressures will be served from the next higher pressure zone. When a zone of higher pressure does not exist, one must be created. If a new zone is established, the hydraulic grade line in that zone should serve a significant area, not just a few customers around the current pressure zone boundary.

Each succeeding pressure zone should be approximately 100 ft (30.5 m) higher than the next lower zone. If they are less than 50 ft (15.2 m) apart in elevation, too many pressure zones may complicate operation. If they are more than 150 ft (45.7 m) apart in elevation, it is difficult to serve the highest customers without overly pressurizing the lowest customers in that zone.

2.6.3 High Pressures during Low Demand Conditions

High pressures are usually caused by serving customers at too low an elevation for the pressure zone. Some utilities consider 80 psi (55m) to be a high pressure, although most systems can tolerate 100 psi (69m) before experiencing problems (for example, increased leakage, increased breaks, water loss through pressure relief valves, and increased load on water heaters and other fixtures). Portions of some distribution systems can bear significantly greater pressures because pipe with a high-pressure rating has been installed. When dealing with high pressures, PRVs can be used to reduce pressures for individual customers, although they may result in additional maintenance issues.

Usually, high pressures are easiest to evaluate with model runs at low demands (say 40 to 60 percent of average flow). This range corresponds to minimum night-time demands for a typical system. If the engineer feels that pressures are too high, the usual solution is to establish a new pressure zone for the lower elevation using system PRVs (as opposed to individual home PRVs).



Source: (Advanced Water Distribution Modeling and Management, Haestad press. U.S., 2003)

Figure (2.4): Schematic network illustrating the use of a Pressure reducing valve

When a constant-speed pump is moving a substantially lower flow than its design flow, high pressures within the pumped zone can result. Possible solutions include a variable-speed pump, a storage tank, or a pressure relief valve that blows off water pressure to the suction side of the pump when the discharge pressure becomes too high.

Oversized Piping: oversized piping can be difficult to identify because the system often appears to work well. The adverse effects are excessive infrastructure costs and potentially poor water quality due to long travel times. If a pipe is suspected of being too large during a design study, its diameter should be decreased and the model rerun for the critical condition for that pipe (peak hour or fire flow). If the pressures do not drop to an unacceptable range, the pipe is a candidate for downsizing.

2.7 Modeling of direct (continuous) supply systems and intermittent supply systems

2.7.1 Modeling of Direct (continuous) supply systems

In the continuous supply systems, water is conveyed through the distribution network continuously without interruptions. The consumers use water at any time without any need for individual roof and or ground storage tanks (Abu Madi M, 1996*)*.

The main factors required to achieve direct water supply are summarized as follows:

- Enough water at source: to meet consumer's requirements for water (the demand increases due to availability of water)
- A good and reliable distribution network: to guarantee enough water with acceptable pressure to all consumers.
- Effective system parameters: capable pump stations, and suitable pipe diameters.
- Successful monitoring policy: to discover any interruptions, and to detect damaged pipes early as possible, to reduce leakage.

Operating of system components, pumps and reservoirs, in the continuous supply systems is a result of consumer's needs: with reduced demand in the night periods, pumps may operate at lower level and balancing reservoirs may be refilled, whereas during the maximum demand periods, the pumps will operate at their maximum capacity and the reservoirs will supply parts of the distribution network.

Water distribution network in the continuous supply systems should be designed to with stand the range of pressures corresponding to the minimum and maximum supply conditions.

In the continuous supply systems, the hydraulic relation between the demand and supply water is clear. The demand in the nodes or nodal water demand is the water consumption multiplied by the number of residents living around. The average demand will be subjected to hourly variations, which mean the demand pattern based on the differences in living standards, industrial water use, etc.

2.7.2 Modeling of Intermittent supply systems

The regime of intermittent water supply, is applied as mentioned in the developing areas, due to the scarcity of drinking water, and deteriorated distribution networks.

In the intermittent supply systems, the consumers depend on the individual roof and /or ground storage tanks to provide their daily needs of water for domestic, industrial, and other uses. This means that in the periods of use, the consumption of water is not necessarily provided from the network directly, but may be from the roof tanks and /or ground storage tanks in which water was stored when the pressure head in the system was higher than the reservoir. In this case the consumers of water are not restricted only by the pressure that is available in the distribution network, but also they are restricted by the capacity of the roof tanks and ground storage tanks.

From the hydraulic point view, when the consumers are using the water from their roof tanks, they are disconnected from the distribution system, and two independent patterns can be distinguished in this case: the first pattern at the consumer's tap which is actually a consumption pattern and may be equal for all domestic consumers, and the second pattern is at the tank which is actually a filling pattern, and it is a consequence of the hydraulic operation of the network, representing a pressure related discharge, and its different for each node in the network.

The consumers far away from the source of water supply in the intermittent systems will need to be more patient, especially that the refilling of their roof tanks will start later and go slower than for those consumers closer to the water source.

Intermittent supply yields a fundamentally different demand pattern than continuous supply, in fact there is no demand pattern: the storage tanks of the customers will fill up whenever the systems provides water, until they are full and the float valve closes (Battermann, A. and Macke, S, 2001).

2.7.3 Proposed methods for modeling intermittent water supply systems

The overall shortage in water availability in the most developing countries necessitates intermittent supply at a low per capita supply rate. These conditions force consumers to collect water in storage tanks.

Storage is an important feature of such systems since it is the storage facilities that provide water during non-supply hours. Because of the low supply rate of water and the intermittent nature of supply, the demand for water at the nodes in the network are not based on notions of diurnal variations of demand related to the consumers behavior (as with networks in developed countries), but on the maximum quantity of water that can be collected during supply hours (Vairavamoorthy,K. et al., 2001).

The design of water transport and distribution systems under intermittent conditions should not be based on the minimum and maximum peaks of the demand pattern but on the peaks of supply and delivery patterns that are governed by availability of sufficient water at the source, the capacity of the supply system, and the number of supply and delivery hours (Maher Abu-Madi & Nemanja Trifunovic, 2013).

2.7.3.1 Modified analysis tools

A modified network analysis program has been developed by the water development research unit at south bank university (London) that incorporates pressure dependent outflow functions (PDO) to model the demand. This model consists of four main components. This approach is far more sophisticated and may provide superior results, and it requires more specialized software:

1. Demand model

This model forecasts the end-users demand profile (intensity and distribution of usage over a given period of supply). Data needed for this model includes: type of connection, time of supply, duration of supply, and pressure regime (Vairavamoorthy,K. et al., 2001).

2. Secondary network model

In this model, the primary node assumed to be a constant head, and this node providing water to the secondary network. Such methods have been developed and take into account the hydraulic behavior of the secondary network (Vairavammorthy, K, 1994).

3. Network charging model

This model predicts the time at which different users receive water and simulates the charging up of the network after supply resumes (Vairavamoorthy,K. et al., 2001).

4. Modified network analysis method (pressurized flow)

This model has been developed to model the demand or outflow. The network governing equations are solved using the gradient algorithm of Todini and Pilati (1987).

2.7.3.2 Modeling of nodal demand as pressure related demand

The relation between pressure and demand can be illustrated obviously by the relation between leakage losses in the water distribution networks and the pressure. At low peaks through night hours the pressure in the system will be high and the leakage losses are expected to increase. At high peaks, the pressure will be small and the leakage losses are expected to decrease.

When the pressure in the system is higher than the elevation of the tank, the filling will start. It is clear that, the higher the pressure is, more water will enter into the tank, following the Bernoulli equation.

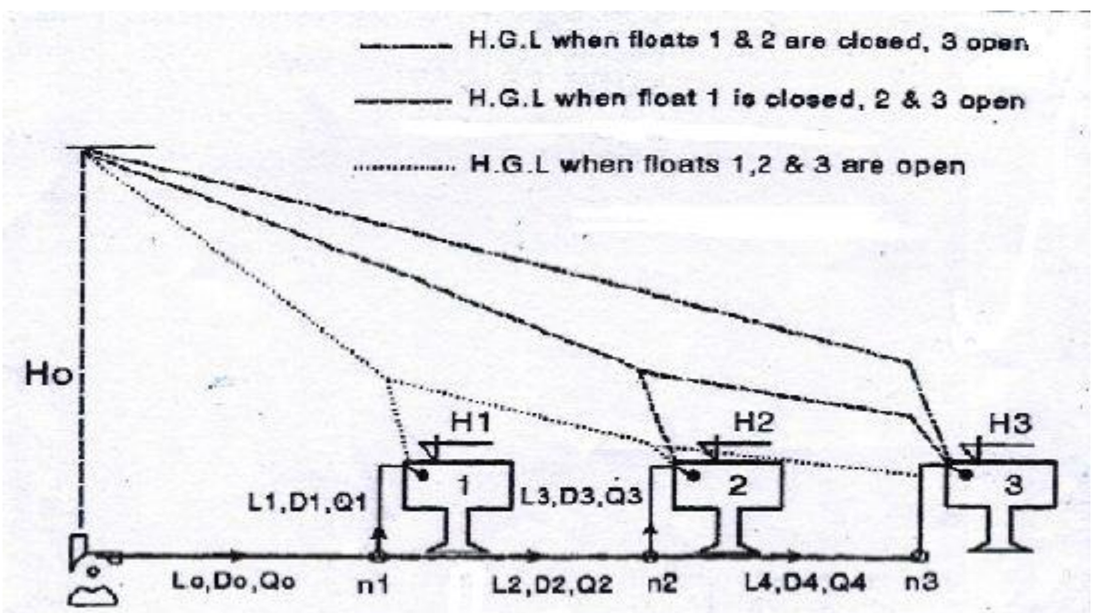


Figure (2.5) Illustration of Reservoir Operation

The filling of the roof tanks is output of pressure related demand, so it could be justified to model them as pressure related demand, but the results will not take into account the level variation in the tank, this lead to the conclusion that the tank not necessarily be empty, when the pressure in the nodes is not sufficient.

2.7.3.3 Modeling as equivalent reservoir

The principle of this approach is representing each cluster of roof tanks in the distribution system by one large but shallow reservoir. The assumed reservoir should have a large surface area with volume equal to the total volume of roof tanks and a depth of 1 m (as in reality), and this reservoir should be given an elevation equals to the house height (Abu Madi M, 1996*)*.

This way of modeling represents the water level variations in the roof tanks in the case of using special software which taking into account the demand in the tanks. It can be also used in the process of modeling nodal demand as pressure related demand.

In this model, the demand in the actual nodes modeled as zero, and the water consumption is specified at the reservoirs. The water utilization is based on the availability of water in the individual storage tanks or proposed reservoirs.

2.8 Model Calibration and Validation

For the majority of water distribution models, calibration is an iterative procedure of parameter evaluation and refinement, as a result of comparing simulated and observed values of interest. Model validation is in reality an extension of the calibration process. Its purpose is to assure that the calibrated model properly assesses all the variables and conditions which can affect model results, and demonstrate the ability to predict field observations for periods separate from the calibration effort.

2.8.1 Hydraulic Model Calibration

Hydraulic behavior refers to flow conditions in pipes, valves and pumps and pressure /head levels at junctions and tanks. according to (EPA, 2005) for hydraulic model calibration parameters that are typically set and adjusted include pipe roughness factors, minor losses, demands at nodes, the position of isolation valves (closed or open), control valve settings, pump curves, and demand patterns. When initially establishing and adjusting these parameters, care should be taken to keep the values for the parameters within reasonable bounds. Use of unreasonable values may lead to a better match for one set of data will typically not provide a robust set of parameters that would apply in other situations.

2.8.2 Calibration and Validation Using Time Series Data

According to (Walski et al., 2003) a vital step in calibrating and validating an extended period simulation is to compare time series data to model results. If the field data and model results are acceptably close, the model is calibrated. If significant variations exist, adjustments can be made to various model parameters in order to improve the match. Ideally, one set of data should be available for calibration, and another set of data should be available to validate that the model is properly calibrated. Hydraulic measurements, water quality data, and tracer data are frequently used in combination in the extended period simulation (EPS) calibration and validation process.

2.9 Optimized Design and Rehabilitation Planning

The capital costs of a water distribution system combined with the cost of maintaining and repairing the system are often immense. Researchers and practitioners are constantly searching for new ways to create more economical and efficient designs. However, the design and management of water distribution systems, if they are to be completed in the most effective and economic manner, are complex tasks requiring a systematic and scrupulous approach backed by skillful engineering judgment and significant capital resources. *Optimization*, as it applies to water distribution system design and rehabilitation planning, is the process of finding the best, or optimal, solution to the problem under consideration.

Optimization has not found its way into standard engineering practice, partly because existing algorithms have not typically been packaged as user-friendly tools. More significantly, with any model, differences always exist between reality and the model. This is certainly true for optimization models — the algorithms do not fully capture the design process (Walski, 2001). However, optimization should not be viewed as an automated process by which only one solution is identified. Rather, it is a process by which alternative solutions that provide, ideally, a range of cost and benefits are generated. The full involvement of design engineers is required.

Most optimization algorithms set up the problem as one of minimizing costs subject to:

(1) hydraulic feasibility, (2) satisfaction of demands, and (3) meeting of pressure constraints.

As Walski, Youshock, and Rhee (2000) pointed out using illustrative example problems, optimization models have not yet been able to fully address many of these considerations.

For this reason, most design engineers prefer to use a combination of steady-state and EPS model runs and engineering judgment as they develop their designs.

Part of the difficulty in applying optimization to water distribution design lies in describing design objectives. Different parties in the decision-making process have different perspectives (Walski et al., 2003), as summarized in the following list:

Customers: "We want great service at low price."
Upper Management: "Provide adequate capacity but remain within the capital budget."
Planning: "Meet demands even though there is a great deal of uncertainty in forecasts."
Engineering: "When in doubt, build it stout."
Construction: "If you're going to tear up a street and dig a hole, it doesn't cost much more to put in a big pipe."
Operations: "Give us flexibility and redundancy so we aren't hanging on a single pipe or pump."
Fire Protection: "Give us plenty of water to fight the fire." These different perspectives make it difficult to mirror the decision-making process with a computerized optimization.

2.9.1 Multi-objective Decision Making

The design of water distribution systems is often viewed as a least-cost optimization problem with pipe diameters acting as the primary decision variables. However, although the cost of operating a water distribution system can be substantial (arising from maintenance, repair, water treatment, energy costs, and so on), the costs of some items often do not greatly depend on pipe size. In most situations, pipe layout, connectivity, and imposed minimum head constraints at pipe junctions (nodes) are taken as fixed design targets.

Clearly, other elements (such as service reservoirs and pumps) and other possible objectives (reliability, redundancy, flexibility in the face of uncertain future demands, and satisfactory water quality) can be included in the optimization process. But the difficulties of including reservoirs and pumps and quantifying additional objectives for use within the optimization process have focused researchers on determining pipe diameters while maintaining the single objective of least cost. Typically, pumping and storage alternatives are taken as entirely separate approaches that are considered outside of the optimization process. Even this somewhat limited formulation of optimal network design offers a difficult problem to solve (Savic and Walters, 1997). The objective function of the pipe-sizing problem is assumed to be a cost function of pipe diameters and lengths (Thomas M. Walski, Donald V. Chase, Dragan A. Savic, Walter Grayman, Stephen Beck with,Edmundo Koelle 2003).

Methods for finding the best design solution include both trial-and-error approaches and formal optimization methods. Trial-and-error procedures are successful in meeting design criteria with respect to constraints (pressure, velocity, and so on) but are less successful at delivering these benefits at least cost. The term *optimization methods* often refers to mathematical techniques used to automatically adjust the details of the system in such a way as to achieve the best possible system performance or, alternatively, the least-cost design that achieves a specified performance level(Walski et al., 2003).

Masri M (1997) studied the optimum design of water distribution networks. A computerized technique was developed for the analysis and optimal design of water distribution networks. The results show that the selection of the hydraulic restrictions should be reasonable and reflects the real capacity of the water distribution system.

Naeeni S (1996) developed a computer program, which enables to obtain the optimum design of various kinds of water distribution networks so that all constraints such as pipe diameters, flow, velocities, and nodal pressures are satisfied.

AL-Abbase R (2000) showed that the optimum design of water distribution systems is a theoretical purpose, and cannot be achieved completely. His study dealt with evaluation the performance of five big sectors in Mosul city. A computerized technique was developed to obtain the optimum design, which achieves the demands of the consumers at lowest cost using the commercial pipes.

Genedese, Gallerano and Misiti (1987) were involved in the optimal design of closed hydraulic networks with pumping stations and different flow rate conditions. Their study had two aims in the design of water distribution systems. The first is minimum values of peizometric heads at the nodes. The second is maximum values of velocities in the branches.

Perez,Martinez and Vela(1993) suggested a method for optimal design by considering factors other than pipe size. Pressure reducing valves were suggested to reduce the pressure in the downstream pipes.

Estimating optimal zone size is difficult without applying optimization technique. Swamee and Kumar (2005) developed a method for optimal water supply zone sizing of circular and rectangular geometry using geometric programming optimization technique. The optimal size of a subsystem depends upon the geometry of the network, spatial variation of population density, topography of the area, and location of input points.

Vairavamoorthy, Akinpelu,Lin and Ali (2000) suggested a new method of design sustainable water distribution systems in developing countries. They developed a modified mathematical modeling tool specifically developed for intermittent water distribution systems. This modified tool combined with optimal design algorithms with the objective of providing an equitable distribution of water at the least cost forms the basis of this new approach. They also develop guidelines for the effective monitoring and management of water quality in intermittent water distribution systems. A modified network analysis program has been developed that incorporates pressure dependent outflow functions to model the demand.

2.10 Review of Scholarly Researches in Addis Ababa Water Supply System Context

Previous studies, which have been done in the context of Addis Ababa water supply system have been studied and investigated to get a better idea about the distribution system of the city. Some of them are summarized as follows:

Mosissa Meressa Gamtessa (2008) assess the leakage status in the city both at city level and at selected sub system levels based on outputs of the pressure model developed for the selected sub system. His study concentrates mainly on "Pressure Modeling for Leakage Reduction in Addis Ababa Water Supply Mains (The case study, Saint Paul and Rufael subsystem)". In his findings from pressure modeling part; high pressures in excess of 80m, negative pressures, and high pressure fluctuations are prevailing in the study area sub distribution system, rationing of water is a common phenomenon in the city due to acute shortage of water supply, and inadequate pipe sizes and disproportional mains spatial distribution are among the identified problems of the existing water supply system. Moreover, the hydraulic performance of the system in general is affected due to the excessive pressures by increasing the leakage rate, and the significant impact on water quality and the resulting social and Environmental effects due to negative pressures.

Shimeles Kabeto (2011) conducted a research titled "water Supply Coverage and Water Loss in Distribution systems with Modeling (The Case Study of Addis Ababa)". His intention was to assess the supply coverage and explore the water loss in city water supply distribution system. The researcher attempted to quantify the average water supply per person at city level and determine water loss as leakage at the city level and at the sub system level. In his findings, he found the average water supply coverage of the city as 86.59 liter/person/day and water loss at city level and sub-city level as 39% and 37.56% respectively. The researcher used model to evaluate alternative scenario to improve system performance.

The other research reviewed was conducted by Saleamlak Muluken Fitaye (2015) titled "Hydraulic Modeling and Improvement of Addis Ababa Water Supply System (The case of Bole Bulbula)". The main objective of his study was to improve the Bole Bulbula water supply distribution system and control its operation by using Water CAD. The modeling effort includes both hydraulic and water quality modeling. In his findings, based on simulation results of the hydraulic model, the Bole Bulbula sub-water distribution system has poor hydraulic performance due to violation of the maximum & minimum pressure and velocity requirements set to evaluate the system, and also water quality simulation result shows that deterioration in the quality of water distributed due to the availability of minimum residual chlorine concentration below WHO guideline recommendations. Moreover, the study identifies problems of the water supply system such as aged pipes, oversized & undersized pipes, low & high pressures and poor water quality status. The researcher modifies the operation and design of the system to improve situations of the case study water distribution system.

Chapter Three

3. Materials and Methods

The starting point of the study is collection of literature data that are relevant to the present work, selection of the study area and modeling software. Based on the research objectives and questions stated in the introduction chapter the method how the research was carried out is discussed in this chapter.

3.1 Selection of the Study Area

This study is conducted on Addis Ababa Water Supply Mains mainly Janmeda, Teferi Mekonnen, Belay Zeleke, Entoto and Ras Kassa sub systems, and representative sectors in the network as a case study representing the current operational situations. These sub systems are chosen due to its relative isolation from other sub systems, their proximity to one another and at the same time that they are interconnected to one another. Additionally, their data is relatively available. Its high pipes network breakage rate record & the overall scarcity of water which could depict the effects of intermittent supply on hydraulic performance easily.

3.2 Selection of Modeling Software

Nowadays, manual procedures are impractical for hydraulic analysis of large water networks due to highly time consuming, and liable to introduction of errors. Computer models for analyzing and designing water distribution systems have been available since the mid-1960s (Ormsbee and Chase, 1988).

Thus, a computer hydraulic simulation software package (WaterCAD® v6.5) is chosen for modeling the existing sub systems water supply network due to its relative capability to replicate the behavior of an actual or proposed system under various demand loading and operating conditions; which is necessary for decision- making purposes regarding real-world applications including planning, design, and operation of water distribution systems, its Versatility to identify the existing water supply problems, and produce accurate & user friendly hydraulic analysis outputs.

Also WaterCAD® v6.5 contains new features of hydraulic and operational analysis engine that includes the following capabilities in:

- Interoperability and Model building: Use Load-Builder directly from WaterCAD's stand-alone interface to allocate demands using geospatial water consumption data sets, and Extract elevation information from DEM's, CAD contour files, shapefiles, and spot elevations directly from the stand-alone interface.

- Data Management: A powerful Network navigator utility to find and fix network topology and connectivity issues resulting from inconsistent source data.
- Operations Modeling with:

  - ✓ Criticality analysis: Evaluate the consequence of failure across the entire system, and discover the assets with the highest hydraulic and operational impact.
  - ✓ Pressure-dependent demands: Calculate demands as a function of pressure to effectively model intermittent supply scenarios, sprinkler heads, and water loss.
  - ✓ New isolation valve element: Use this new element to model system segments, perform trace analyses, and find vulnerable infrastructure assets.
  - ✓ New hydrant element: Model hydrants as independent nodes leveraging the new pressure-dependent demands and fire flow navigator features.
  - ✓ New variable-speed pump battery element: Model complex batteries of variable speed pumps using a single simplified element that correctly models series and parallel installations as a whole.
- Fire flow and Demand management: Run system-wide fire flow analyses and navigate the entire network to evaluate flows, velocities, and pressures for every element. Also develop and maintain your own area, count, discharge, or population-based unit demands for quick demand estimation.
- Mapping and presentation: Use property-based element-sizing, color-coding, and annotation, to easily visualize and map the input data and modeling results.

3.3 Collection of Data for Demand Analysis & Modeling

Collection of secondary data that are required for implementation the modeling of the system includes: the digitalized water network data of the city, the cadastral information of the city, the characteristics & control information of water distribution system components, sources of water and available quantities of potable water, water use (demand), Population figures, and other information that are necessary to carry out the study has been collected. Beside secondary data, investigation of the previously studies, discussion with local AAWSA operators, field visits to visualize the physical condition & corrosion level of pipe layout on the ground, and field measurements of pressure & flow, and the roof tanks water levels variation was carried out in order to support it qualitatively and to assure data quality.

Field measurements on the variations of the water levels in number of ground/roof tanks for different consumers at different locations for a certain period has been carried out to investigate the daily water consumption, daily peak factors and drive the average peak factor.

Also, the results of Field measurements, which have been done in previous studies in other representative zones of the network, has been studied and investigated to get a better idea about the distribution system of the selected study area & to determine the unaccounted for water (UFW) for the whole network and the consumption figures.

Here below the brief description of city's & the study area, including their water supply system will be discussed.

Addis Ababa is located between 972000N to 1000500N and 462000E to 488000E UTM coordinates. It is situated in central highland of Ethiopia surrounded by the Blue Nile catchments in the north and the Wachacha Mountain which forms separation belt of the city from the Awash River catchments in the west (Adane Bekele, 1999). Fig. 3-1 shows the location of Addis Ababa with respect to the map of Ethiopia. The city descends from Entoto ridge which is at an altitude of 2,975m a.s.l. at Entoto to Akaki area to an elevation of about 2,050m a.s.l around Kality.

Addis Ababa has subtropical highland climate. According to National Meteorological Agency of Ethiopia, Mean minimum temperature varies from 7°C to 11°C and mean maximum varies from 21°C to 25°C. From June to mid-September is main rainy season for city of Addis Ababa. Mid-November to January is a season for occasional rain.
Based on the last population and housing census report of 2007, which was prepared by Ethiopian Central Statistical Agency (CSA) in December 2008, the population of Addis Ababa was estimated to be 2,739,551 in May 2007. The population of Addis Ababa is also estimated to be growing at 3.26% rate.

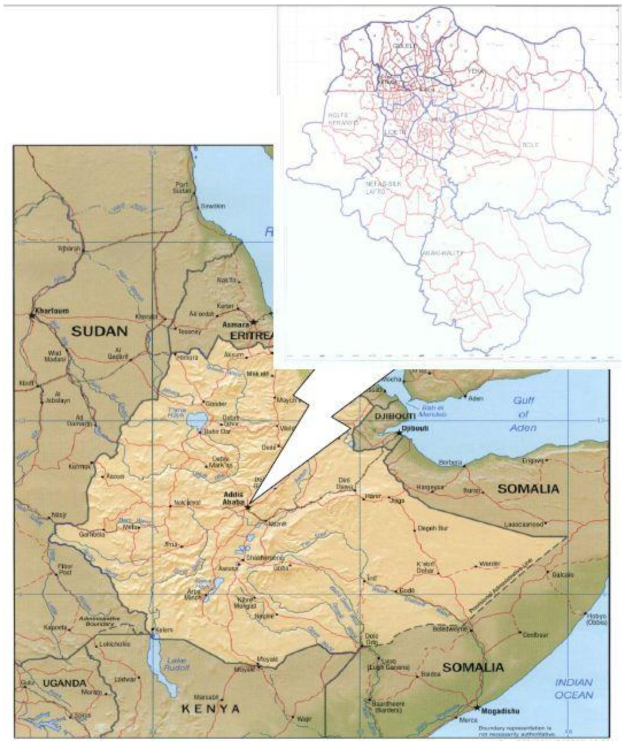


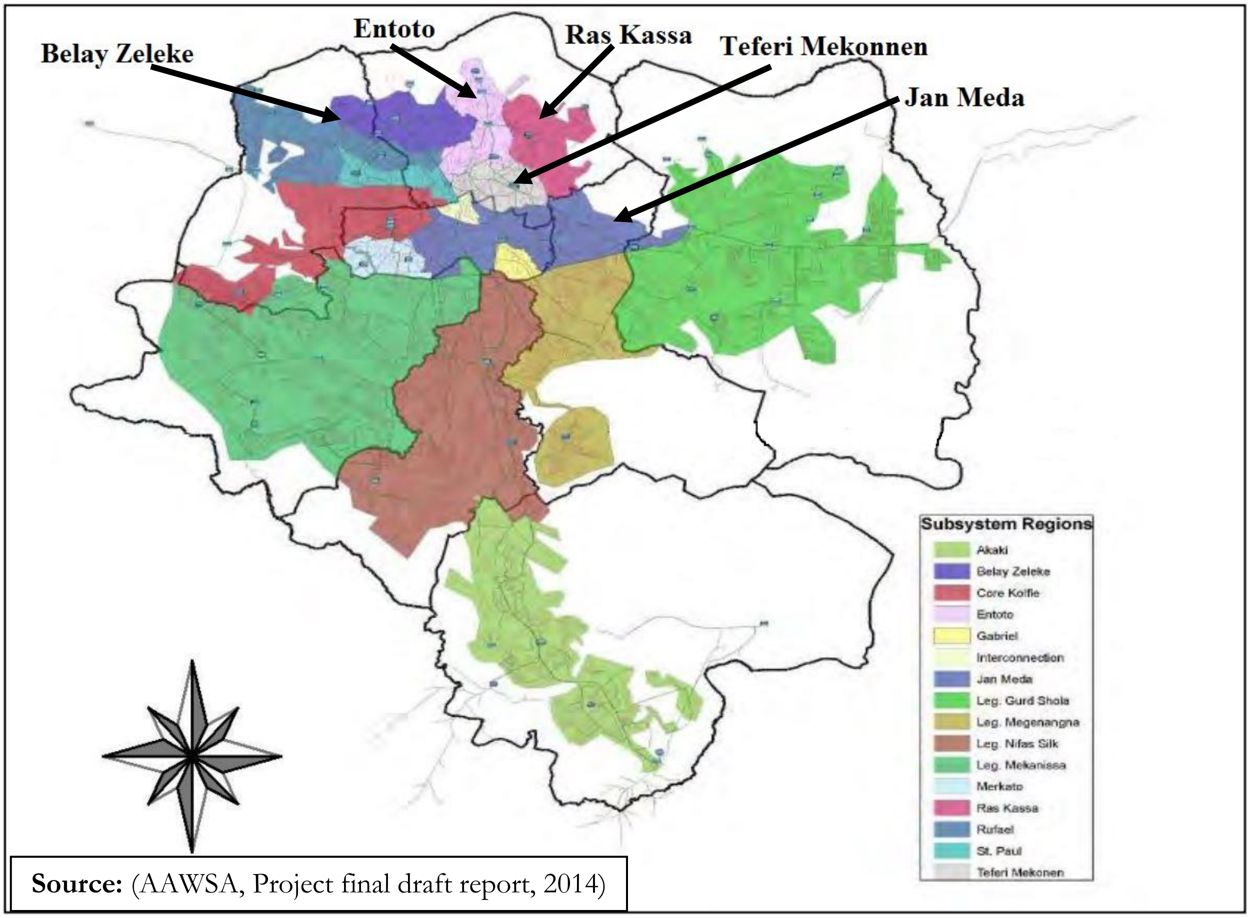
Figure (3.1) Location Map of Addis Ababa in Ethiopia

There are 16 Sub-distribution systems in Addis Ababa water supply system. Among these, the selected study area includes Janmeda, Teferi Mekonnen, Belay Zeleke, Entoto and Ras Kassa sub-systems which are located at Northern and North eastern part of the city are taken together by this study. By now the city distribution network is divided in to 20 pressure zones.

Figure 3.2 shows the location of the selected study area in Addis Ababa city administration while Figure 3.3 depicts the sub-system regions of the city water distribution network.

(source AAWSA)

Figure (3.2): Location of the selected study area in Addis Ababa City Administration



Source: (AAWSA, Project final draft report, 2014)

Figure (3.3): Sub-system Regions of the Addis Ababa Water Distribution Network

3.3.1 The City Water Network Data

A digital water network for the entire city including their attribute like the size, length, age and material of the pipes has been collected in AutoCAD format. The collected pipe network mainly comprises of main pipes that cover the major part of the city; it was collected from Heavy water line section of AAWSA.

According to AAWSA classification, pipes above and equal to 125mm are termed main lines and those below 125mm are termed secondary pipes. Based on GIS data collected from the AAWSA NRW Task Force, the city supply mains are about 1,200 km long while the secondary ones are 7,000 km long, respectively to a total network length of mains as 8,200 km. The city supply system has about 400,000 active service connections in fiscal year 2018.

The cadastral information of the city was collected from the municipality. The data includes boundary of each Sub-city, Woredas and Kebeles, information on buildings, parcels and blocks for each Kebeles.

3.3.2 The Sub-System Water Network Data

Basically the entire city is sub-divided in to sixteen sub-systems, but in practice the pipe networks at the local level were interconnected to each other.
All sub systems have water consumption data; whereas most of them lack water supply data due to malfunctioning of bulk flow meters. As explained earlier, the selected sub systems, Janmeda, Teferi Mekonnen, Belay Zeleke, Entoto and Ras Kassa, have relatively reliable supply data but they are interconnected while relatively isolated from other sub systems. That's why the selected sub systems altogether are considered for the study.

3.3.3 Reservoirs and Pump Stations of the Study Area Distribution System

The information on location of most of the water reservoirs is collected in conjunction with the main water network of the city. The reservoir/tank data including their number, capacity, dimension, serving zone, years of construction and material of construction were also collected. The locations of some of the reservoirs were not exactly indicated in the network, and the document found from the planning department indicates only the surrounding where they are located. Some of the reservoirs serve as transfer point to other reservoirs located elsewhere in addition to serving as a distribution to the surrounding areas. The reservoirs with their principal features and the water source for each reservoir along with their method of Supply are listed in Tables 3.1 & 3.2.
At the commencement of the study an inspection was conducted to pumping stations to get the head versus flow characteristic and daily operation hours of the pumps serving the study area sub-systems. List of the existing pumping stations with their duty characteristics and position is presented in Tables 3.3 below.

Figure (3.4) Areal view of Janmeda Reservoir **Figure (3.5)** Areal view of Teferi Mekonnen Reservoir *(Modified from Google Earth)*

Figure (3.6) Areal view of Upper Entoto Reservoirs (R1, R2 & R3) respectively *(Modified from Google Earth)*

Figure (3.7) Areal view of Entoto Reservoir & Pumping Station *(Modified from Google Earth)*

Regarding to the installed valves in the existing network; information related to their status (closed or regulated), and setting conditions is gathered by making discussions with AAWSA personnel & operators.

Table 3.1: Reservoirs in the Study Area Distribution System

Name	Code	No.	Sub-system served	No. of Tanks	Year Built	Construction Material	Capacity (m^3)
Belay Zeleke	BZ	1 2	Belay Zeleke	1	1959	Masonry	1000
AAWSA Main Office	MO	1 2	Interconnection	2	1956	Masonry	5000 5000
Ras Kassa	RK	1 2	Ras Kassa	2	1963	RC	500 500
Entoto R3 Entoto R2 Entoto R1	R3 R2 R1		Upper Entoto Upper Entoto Upper Entoto	1 1 1	1973 1973 1973	RC RC RC	100 100 100
Entoto	EN	1 2	Entoto	2	1940 1983	Masonry RC	1000 2500
Teferi-Mekonen	TM	1 2 3	Teferi-mekonen	3	1973 1973 1983	RC	1250 1250 2500
Jan-Meda	JM	1 2 3 4	Jan Meda	4	1973 1973 1983 1983	RC	1250 1250 5000 5000
Terminal	TR	1 2	Lagadadi	2	- 1969	RC	10,000 10,000
Gabriel	GR	1	Gabriel	1	1960	RC	1000
Ras Kassa upper		1	Ras Kassa	1	-	-	30
Palace		1 2	Gabriel	2	-	-	300 50

Table 3.2: Methods of Supply from Reservoirs

Supplied from Reservoir	Supplied to Reservoir/System	Method of Supply
Legadadi Plant	Terminal	Gravity
Terminal	Jan Meda	Pumped
Jan Meda	Teferi Mekonen	Pumped
Tefferi Mekonnen	Entoto	Pumped
Entoto	Entoto R1	Pumped
Entoto R1	Entoto R2	Pumped
Entoto R2	Entoto R3	Pumped
Jan Meda	Gabriel	Gravity
Jan Meda	AAWSA Main Office	Pumped
AWSSA Main Office	Belay Zeleke	Pumped
Teferi Mekonnen	Ras Kassa	Pumped
Belay Zeleke	Upper Belay Zeleke	Pumped
Ras Kassa	Upper Ras Kassa	Pumped
Gabriel	Gabriel S.S.	Both
Entoto R3	Upper Entoto S.S.	Gravity

Table 3.3: The Study Area Existing Pumps and Pumping Stations in Regular Service

Pumping Station	Code	Pump No.	Design (l/s)	Head (m)	Delivery to	Pump position
Terminal	TR	1	313	75	Jan Meda Reservoir	Working
		2	313	75	"	"
		3	313	75	"	Standby
Jan Meda	JM	1	75	57	Teferi Mekonen Reservoir	Working
		2	75	57	"	"
		3	100	32	AAWSA Main Office Reservoir	"
		4	100	32	"	"
		5	100	32	"	Standby
		6	52	57	Teferi Mekonen	Working
		7	52	57	"	"
		8	52	57	"	Standby
Teferi Mekonnen	TM	1	86	63	Entoto Reservoir	Working
		2	86	63	"	Standby
		3	26	64	Ras Kassa Reservoir	Working
		4	26	64	"	Working
Entoto	EN	1	20	89	Entoto R1	Working
		2	20	89	"	Standby
Entoto R1	R1	1	9	55	Entoto R2	Working
		2	9	55	"	Standby
Entoto R2	R2	1	6	65	Entoto R3	Working
		2	6	65	"	Standby
AAWSA Main Office	MO	1	75	160	Belay Zeleke Reservoir	Working
		2	75	160	"	Standby
Belay Zeleke	BZ	1	5	100	Belay Zeleke Distribution	Working
		2	5	100	"	Working
		3	5	100	"	Standby
Rass Kassa	RK	1	8	130	Ras Kassa Sub-system	Working
		2	8	130		Working

3.3.4 Water Supply

Development of the Addis Ababa water supply system began in 1886 by developing ground water sources. But the intensified increasing of demand due to population increase could not be met with ground sources only. This necessitated surface water developments and water treatment plants at Geferssa in 1942, at Legedadi in 1970, increasing the capacity of Legadadi water treatment plant under its phase II project in 1985 & rehabilitated in 2008/09. In 1990 the distribution systems of the city were improved and Dire earth dam construction to supplement Lagadadi water treatment plant, from 1995 up to 2015 the Akaki groundwater development project (phase I, II, IIIA, IIIB), from 1995 up to now drilling of deep boreholes for water scarce areas at various pocket areas of the city, Legadadi groundwater development phase-I in 2016, and Koye Fechea & Klinto Condominum Area Water Supply Project in 2018 were among major water supply projects carried out to date on new and existing surface & ground water source development & expansion projects to increase water production capacity of the city and to satisfy the demand of the city (AAWSA "Weha ena Fesash" Magazine, Vol. (10), No.1, 2018).

Currently, the city of Addis Ababa is supplied from both surface water and groundwater sources. The main surface water supply sources for the entire city are the "Gafarsa" , "Lagadadi", and "Dire" dams located 14 km to the west of the city Centre, 17 km east of the city's edge, and an approximately 7km far from Legadadi treatment plant, respectively. Additional supplies from groundwater sources pumped from "Akaki" well field located about 22km to the southeast of the city, Legadadi well field, and a number of wells & springs found in and around of the city. Figure 3.8 shows locations to the major water supply sources of the city.

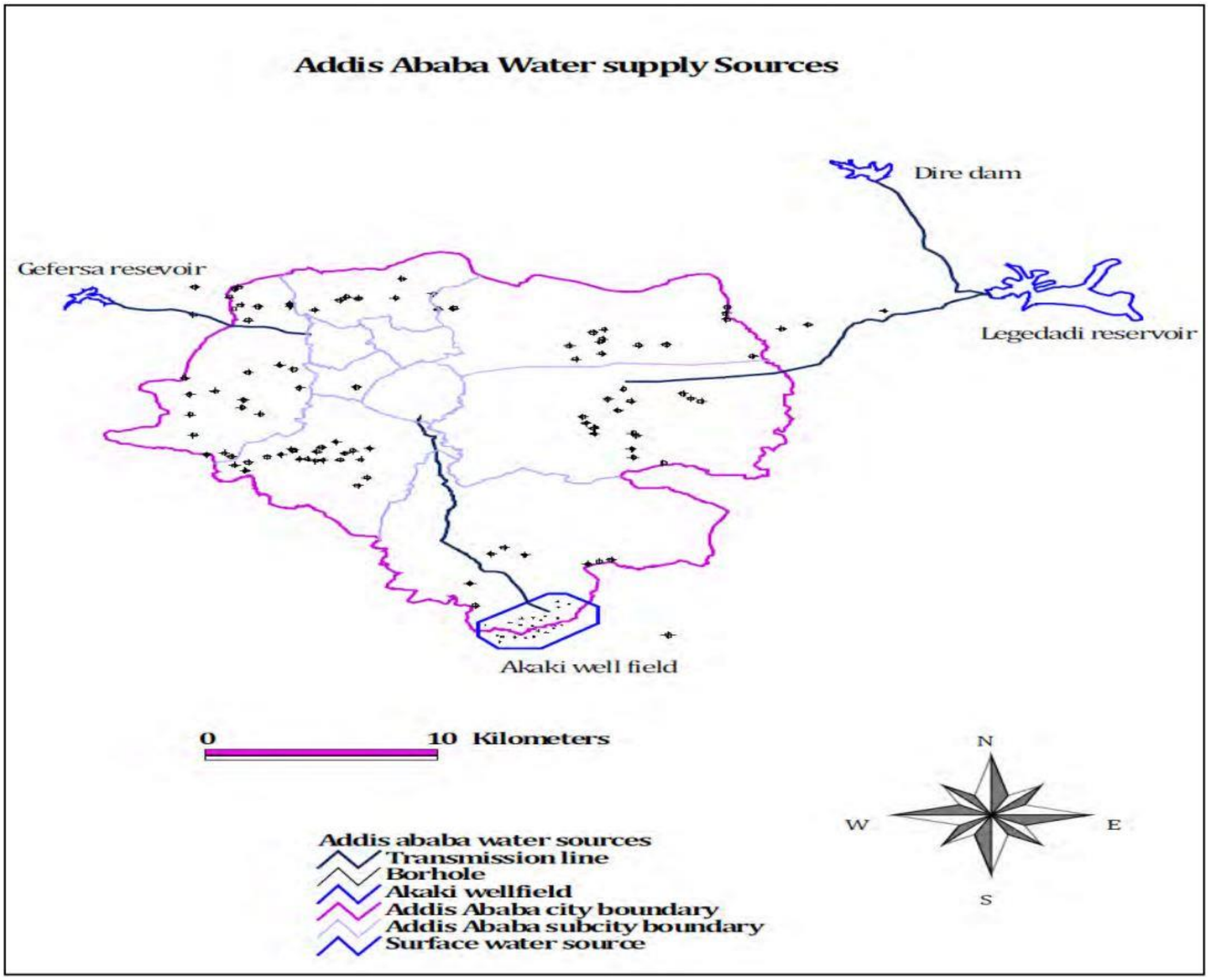


Figure (3.8) Location map of Addis Ababa water supply sources

As shown on Table 3.3 below, the total amount of water produced from existing surface and groundwater sources of the city is 574,000m^3/d at the end of 2018 budget year. However, there are various hindrances encountered in relation to utilizing the entire production potential of 574,000m3 of water per day. Such as underutilizing the maximum production capacity of sources due to frequent power interruptions, a high quantity of water loss, poor chemical content of borehole' water, malfunctioning of well pumps, yield capacity depletion of groundwater sources, and repetitive damages on water transferring mains due to lack of coordination between infrastructure developers. Due to these, currently on average, the amount of water supplied is only **460,000**m^3 per a day (Conference for conscious of short and long-term solutions to the difficulties of water supply services of Addis Ababa, Addis Ababa Water and Sewerage Authority, October, 2018).

This supply is not sufficient to cover the city's needs and supply interruptions have being effected for equitable distribution of water (AAWSA "Weha ena Fesash" Magazine, Vol. (11), No.3, 2018).

Proposed water supply projects: Besides the existing water supply sources, AAWSA has developed a long term business plan with clearly identified short, medium and long term plans to meet the ever increasing demand of the city.

Accordingly, AAWSA has been implementing the planned projects to maximizing supply capacity of the city to 1,000,000m3/d at the ending year of the second GTP. The construction of Siblu and Gerbi dams are among the major projects (AAWSA "Weha ena Fesash" Magazine, Vol. (11), No.3, 2018). Making the community to be beneficiary by completing the projects with in the budget year of 2018/19 – 2021, is the authority's plan to be achieved within short and long-term periods. The projects are Koye-Fechea groundwater development project, Legadadi Deep Well Phase II project, South Ayat North *Fanta* borehole water development project, Study & construction of Gerbi dam & treatment plant project, and Sebeta-Holeta borehole water development project (AAWSA "Weha ena Fesash" Magazine, Vol. (10), No.3, December, 2017) as shown on Table 3.3 along with their production capacity.

Table 3.1: Existing and Future Water Sources for Addis Ababa.

S. No.	Surface Water Sources	Existing Supply Capacity (m^3/d)	Future Production Capacity (m^3/d)	Remark
1	Legadadi water treatment plant & Dire Dam	170,000	195,000	Add 25,000m3/d by upsizing the existing inadequate capacity transfer main to utilize the ultimate production capacity of the legedadi treatment plant in short-term plan.
2	Gefersa water treatment plant	30,000	30,000	
3	Gerbi dam & treatment plant project	-	73,000	Medium-term plan project
4	Siblu surface water development project	-	600,000	Long-term plan project
	Total from Surface water sources	**200,000**	**898,000**	
	Groundwater Sources	**Existing Supply Capacity (m^3/d)**	**Future Production Capacity (m^3/d)**	**Remark**
1	Akaki Groundwater development Phase I	12,000	12,000	
2	Akaki Groundwater development Phase II	70,000	70,000	
3	Akaki Groundwater development Phase IIIA	47,000	47,000	
4	Akaki Groundwater development Phase IIIB	70,000	70,000	
5	Legadadi Deep Well Phase I	40,000	40,000	
6	Various springs, boreholes & wells in the city	91,000	94,000	Add 3,000m3/d from boreholes to be drilled at various pocket areas of the city in Short-term plan
7	Koye Fechea Groundwater development	44,000	50,000	Add 6,000m3/d from Klinto condominium area boreholes drilled in Short-term plan
8	Legadadi Deep Well Phase II	-	86,000	Medium-term plan project
9	South Ayat North *Fanta* Groundwater development	-	68,000	Medium-term plan project
10	Sebeta-Holeta Groundwater development project	-	100,000	Medium-term plan project
	Total from Groundwater sources	**374,000**	**637,000**	
	Total from Surface & Groundwater sources	**574,000**	**1,535,000**	

3.3.5 Water Consumption

The indicator for measuring the level of water consumption is the amount of water consumed per capita per day (l/c/d) and quality of the delivered water. Water consumption is a function of availability, climate conditions, standard of living, and household size. There are three consumption categories in AAWSA namely: Domestic, non-domestic and Public Fountain. The city has over 480,000 registered customers and 400,000 active water connections in the entire city distributed over Weredas and Kebeles during 2017/18. Out of these about 86.8% of the connections are Domestic connections serving household consumers, 0.5% of the connections are public taps for domestic consumers of low income and 12.7% of the connections are non-domestic connections (Short Explanation Brochure of AAWSA, 2017).

People having in-house services use water on average between 90 and 145 liters per capita per day, while the remaining population with access to safe drinking water are served by communal or tap connection and use between 65 and 75litre/capita/day. Non-domestic uses including commercial and industrial water use are about 30% of the average daily domestic demand and 30m^3/day/hectare respectively. Public fountains water use is about 15% of the average daily domestic demand.

3.3.6 Water supply variations

The city water supply network is not continuously pressurized. Supplies are provided intermittently with frequency and length of supply interruptions varying between different areas range from intermittent supply to 24 hrs supply. Currently the city receives water with an average supply time of 14.8 hours per day (Water Audit & Benchmarking Report, P. Antonaropoulos & Associates S.A, 2012). In 2018 Budget year out of 116 woredas; 91 woredas or 78% are received water intermittently, and out of 91 woredas; 14 woredas those found in Gullele & Yeka sub-city are supplied only for 8hrs/day within a week. (Conference for conscious of short and long-term solutions to the difficulties of water supply services of Addis Ababa, Addis Ababa Water and Sewerage Authority, October, 2018).

Table 3.5: Average hours of supply per day for the AAWSA water distribution system.

Situation description	Days of supply per week (min)	Days of supply per week (max)	Estimated average days of supply per week	Hours of supply per day of supply (min)	Hours of supply per day of supply (max)	Estimated average hours of supply per day of supply	Estimated hours of supply per week	Estimated population	Area (%)
No Supply	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17,931	23
Supply for 1 day/week; 7 to 24 hrs/day	1.00	1.00	1.00	7.00	24.00	15.50	15.50	210,768	4
Supply for 2-4 days/week; 7 to 15 hrs/day	2.00	4.00	3.00	7.00	15.00	11.00	22.00	163,247	18
Supply for 5-6 days/week; 10 to 20 hrs/day	5.00	6.00	5.50	10.00	20.00	15.00	75.00	527,972	5
Supply to 7 days/week; 12-24 hrs/day	7.00	7.00	7.00	12.00	24.00	18.00	126.00	2,072,028	50
								2,991,946	100

Total population excluding areas of no supply: 2,974,015
Average hours of supply per week for whole AAWSA system: 103.41
Average hours of supply per day for whole AAWSA system: 14.77

Note: Data used in this Table was obtained from the Addis Ababa Water Supply Situation drawing dated March 2011 and prepared by the AAWSA NRW & SCD team.

3.3.7 Population Data

The water supply in general is an engineering application to meet needs of the consumers. In the case of urban water it is the supply to the inhabitants of a town the quantities they need and could afford. It is therefore that a study of the population size, its development and distribution over the area is necessary.

The main source for the population size is a census that is being carried out at regular period in every country. According to the recent 2007 Central Statistics Authority (CSA) data, the population of Addis Ababa town was 2,739,551. In between censuses some local authorities' data on the population growth gives good data of the Addis Ababa population and its zonal distribution. Nevertheless the rate of growth assumed by CSA (i.e. 3.5%) for the period (1994-2015) is received with reservation by various circles including AAWSA, Addis Ababa University, Office for the Revision of the Addis Ababa Master Plan (ORAAMP), Various consultants (DHV, AE-HBT Agra), and other bodies. while they considers this rate to be 3%-6.3% (AAWSP-Stage IIIA, TAHAL Consulting Engineers Ltd, 2005).

Despite some reservations related to unknown number of temporary/fluctuant residents, death due to AIDS, migratory population; ORAAMP and various consultants made studies for AAWSA base their plans in principle on CSA figures by mentioning their proceedings that "CSA figures are in principle reliable, in both (i) data gathering and (ii) projection methods are principally valid".

Taking into account all above, this Study adapts the rate of growth suggested by CSA and approved by AAWSA (i.e. 3.54%) until the period of 2018, and for the period (2018-2020) the rate of growth of 3.41% is adopted in order to forecast the population of the study area. Projecting the population of Addis Ababa town for the design period of 2 years to year 2020 is computed using the **Geometric increase method** as tabulated below. i.e.:

$$P_N = Pp \times (1 + R)^N \quad \text{………………} (3.1)$$

Where,

P_N is design population at the end of N years

$P_{p.}$ is present population at initial year

R is Population Growth Rate

Table 3.6: Projected Population of Addis Ababa and the Study area.

Year	Base (2007)	(2018)	(2019)	(2020)
Rate of growth, %		3.54	3.47	3.41
Population	2,739,551	4,018,330	4,125,619	4,235,773
The Study area population	217,729	319,361	327,888	336,643

3.3.8 Discussion with Local Experts

Although the study predominantly is planned to be conducted using secondary data, in order to support it qualitatively, also discussion with local experts of AAWSA has been carried out. The main motives behind is to the assignment of confidence limits for the data used for water supply and consumption data, moreover to get the data about the monitored hydraulic parameters including inflows/outflows and water levels of storage tanks, discharge flows and pressure heads of pumps, flows and/or pressure of regulating valves, and pressures at critical points, and to check the pipe layout on the ground, and to assure on accuracy of the data.

3.4 Data Verification

3.4.1 Water Network Data

The data on city water network that has been collected from Water Services Division was in AutoCAD format. While the network was reviewed in its original format, the pipe diameter, length, year of construction and its material type were written as an annotation. These attributes were analyzed thoroughly in conjunction with contour map, cadastral map, road network map and map of former kebele boundaries of the city for consistency.

3.4.2 Water Supply Data

Due to failures in most of the bulk flow meters measuring treated water flow, there was no organized water supply data, the annual treated water production at city level has been collected from water services section and estimated by AAWSA from available data on raw water input to the treatment plants, assuming a reduction of 3-6% due to filter washing and other losses. However, monthly supply data was not available at sub systems level that evaluations at sub systems were not possible.

Meanwhile, when reviewing the data on the current supply capacity of sources collected from various volume' of magazines of AAWSA published during 2018. The data is contradicted to each other and difference in supply capacity of the sources was observed that might be caused due to variations on yield capacity of groundwater sources. This has been also explained by the local experts. For modeling purpose the average daily supply rate of the year 2018 is used. Also the data reported regarding completion dates for the ongoing and planned water development projects is also contradicted to each other.

3.4.3 Water Consumption Data

The consumption data was collected for each month by eight branches and compiled by the IT department in Excel format. The average consumption figures as determined in water demand study conducted for AAWSA by different consultants which is presented on the basis of different levels for each month was also collected.
As the data is very large, verifying its quality before utilizing was necessary.
The data quality checking criteria used were:
a) Comparison with other months data
b) Comparison between respective months of previous years.
c) Evaluation based on expected consumption levels with respect to the season

While the consumption data was reviewed, significant differences between consecutive months were observed that might be caused due to non-regular reading of meters. This has been also explained by the local experts. For modeling purpose, water consumption of the year 2018 is used.

3.5 Model Calibration and Validation

Calibration of a water supply network model requires the need for real time pressure monitoring in critical sections of the distribution system to verify the actual value with respect to modeled parameter values.
Most water supply schemes have some form of data logging systems which allow real-time measurement of system performance. However, in AAWSA this is not the case. Thus, measured pressures at specific time and location were used to verify the model. These calibration runs were conducted on three selected points each measured two times followed by adjustments on hydraulic parameters each time calibration tests are conducted.

Model calibration and validation were undertaken based on the calibration standard criteria for hydraulic network modeling.

3.6 Calibration Criteria

The degree of accuracy (error of difference) criteria is used to verify the calibration results by comparing the observed versus the calculated pressure values in the system. The following criteria are also adopted from (Bhave, 1998 cited by James G. 2002) to verify the calibration results.

a) An pressure average difference of ±1.5m to a maximum of ± 5.0m for a good data set, and
b) The difference between measured and simulated values should be ± 3.0m with a maximum difference of ± 10m for a "poor" data set

3.7 Limitations of the Study

Quantifying, characterizing and modeling the factors that lead to evaluating the hydraulic performance of a city water supply system is by its nature a complex task requiring well managed network and reliable data which is scarce in Addis Ababa city water supply system. As a result, cross checking and verification of data was the most significant problem faced during the study.

Unavailability of that much similar previous local researches studied in other representative zones of the network, impedes the effort to get a better idea about the distribution system of the city.

Availability of reliable data is among the factors that influence the process and out puts of a study. Water supply to a city and to its sub systems is relied on bulk meter reading. In the city of Addis Ababa most bulk flow meters were not functional during the study. This cannot be counter checked using any other method except for cross checking with supplies of other years. Although this method is employed in the study, the issue poses data reliability question.

As part of skeletonization some meandering bends are approximated with straight lines in the system. This will, obviously, have its own conservative effect on the model out puts of pressure values.

On the other hand, the city receives water supply intermittently in shifts due to shortage of supply. Besides, the rationing time is not strictly observed at pumping stations that consistent results could not be obtained at fixed location and fixed time.

Last but not least, the water supply network is interconnected from sub system to sub system that there is no practical boundary between flows of sub systems.

Chapter Four

4. Modeling of the Study Area Water Distribution Network

4.1. Introduction

Modeling the existing water supply system as an intermittent supply system and as a continuous system is carried out in order to study the effects of the two models on the performance of the system. In-here, first the selected study area existing water supply network is modeled as in reality (intermittent water system) depending on the existing situation of operating and managing the system of the network, representing each cluster of houses by one consumption node, to investigate how the system behaves & the hydraulic performance is affected by the local operating conditions.

Then modeling of the selected study area sub system as continuous supply system is carried out depending on assumptions and facts considering with the future water consumption, availability of water, the enhancement of operation and management of the water supply system, and assuming steady state analysis, to verify the ability of the existing system to serve the study area in the future and to cope the future extension.

4.2. Modeling of the Existing distribution network as intermittent system

In the case of Addis Ababa water distribution system, the option of modeling the system as an intermittent supply system was followed to describe the existing system as in reality.

4.2.1 Assumptions of the study

The assumptions and limitations provided below are partly simplifying and are based on actual conditions. However, the assumptions will not alter the goal of obtaining a model close to real situation as long as both temporal and spatial representative testing is conducted during calibration and simulation, that will be verified by comparison of actual versus simulated values.

- Most bulk meters in the systems are not functional during the study. Thus, the reliability of data on the water supply from reservoirs and tanks to sub systems as obtained from the water services section is questionable. Rather it seems approximation of past records by the time the meters were operational.

On the other hand, water consumption data aggregated from customers' bills has some discrepancy from that provided by water services section in summarized form.

- The city is being supplied water currently on intermittent basis. It is estimated that the city is receiving only 49% of the actual demand in 2018. This highly undermines the real demand that the model output may vary from the actual situations by the time of sufficient supply.
- Pipe friction factors are normally considered solely based on age and pipe material. It is well known that as metal pipes age their roughness tends to increase due to encrustation and tuberculation of corrosion products on the pipe walls. This increase in roughness produces a lower Hazen-Williams C-factor. Although, bedding slope, water treatment standard, existence of leakage points and availability of dead ends highly influence friction factors, Hazen-Williams coefficients are applied by measuring the flow of pipelines having different age, diameter and type of materials. The used friction factors are shown in Table 4.1. Note that the Pipe friction factors are taken from standards for the respective pipe characteristic and age.

Table 4.1: Hazen-Williams Coefficients Used (Adopted from AAWSP-Stage IIIA, TAHAL Consulting Engineers LTD, 2005)

Construction Year	Diameter of Pipe (mm)	Type of material	Hazen William Coefficient
After 1980	1200-700	DCI STEEL GSI	100
1955-1979	1200-700	DCI STEEL GSI	90
After 1980	600-150	DCI STEEL GSI	90
1955-1979	600-150	DCI STEEL GSI	80
For all PVC pipes			110

- As part of skeletonization, some meandering bends are approximated with straight lines in the system. This will, obviously, have its own conservative effect on the out puts of pressure in the model. However, this assumption will not alter the real situation as long as both temporal and spatial representative testing is conducted during calibration and simulation.

In modeling this pipe water supply system as intermittent supply system, the following assumptions also have been taken into consideration:

- The demand for each node of consumption was calculated as follows:
  Demand = number of residence * water consumption per capita per day.

The demand of water for domestic uses is assumed to be (86 l/c/d) as a large result of measurements by study the variation of water levels in roof tanks, and to the projected average residential water demand for year 2018 by Tahal Consulting Engineers LTD in the project of developing detail design of Addis Ababa water resources & supply distribution system in stage IIIA. Another study by Shimeles Kabeto (2011) quantifies the average water supply rate per person at city level as 86.59 liter/person/day.

- The industrial, commercial and institutional consumption of water are included in the domestic consumption as its common, a minimum of 28% of the average daily domestic demand is to be considered as being a widely accepted figure. Therefore the domestic consumption enlarges to be (110 l/c/d). The values of the industrial, commercial and institutional consumption depend on the records of the AAWSA & according to their number or built areas assumed on the selected study area of the town (AAWSP-Stage IIIA, TAHAL Consulting Engineers LTD, 2005). Another recent study by Saleamlak Muluken Fitaye (2015) estimates the average Industrial Water Demand as 30% of the Average Domestic Demand (ADD).

- For unaccounted for water (UFW) calculations, according to reports of the Water Audit & Benchmarking Report for AAWSA water supply system in 2012, their data shows a maximum value of 40% as unaccounted for water. The data collected from AAWSA documentation carried out by Tahal Consulting Engineers LTD in 2005, a gap between water produced and billed of 35% has been observed. Recent studies conducted by Shimeles Kabeto (2011) and Saleamlak Muluken Fitaye (2015) indicated the level of UFW as 37.56% and 34.63% respectively. According to AAWSA "Weha ena Fesash" Magazine, Vol. (10), No.4, 2017; about (37-40) % of the total water supply will be lost. The unaccounted for water (UFW) quantity might have various reasons and does not necessarily represent leakages only. But for a well-documented analyze; the means are insufficient as the production is estimated and not measured, a thorough mapping of all consumers is not updated leaving open the possibility of "illegal connections", a comprehensive planned effort to calibrate at fixed periods of time and/or replace defective water meters with all AAWSA procurement efforts is still yet to be accomplished. Also measurement devices are practically lacking from the distribution/transfer network (DTN) making the leakage quantities uncertain and corrective measures difficult to decide upon. Nevertheless an adjusting 35% factor to the present supply is added. A value of (35-40) % of the total water supply as unaccounted for water has been adopted in the modeling of the system, or 30% of the residential demand, and a value of 24% of the total consumption has been adopted to model the technical losses of water in the system.

- The total consumption, which is used in modeling the demand for each node, is 145 (l/c/d) as shown in the table (4.2).

Table 4.2: Assumed water demand for the analysis of the network as intermittent system

Type	Consumption (l/c/d)
Domestic	86
Add industrial, commercial and institutional	110
Technical losses (24%)	35 =(24% * 145)
Total	145(l/c/d)

- It is important to develop a reduced model for convenient analysis of the water network. Skeletonization was used to reduce the model in size, while still preserving the network integrity, thus allowing similar analysis on a reduced model. System isolation was also implemented as a part of the skeletonization process. Accordingly, main pipes in the study area sub systems were sorted and isolated that simplified the complex pipe layout of the city. The skeleton of the pipe layout is provided on fig. 4-2. In this model, the pipes of diameters 150mm and above were considered to limit the length of the network, and due to the difficulty for distinguishing small pipes and their demands as provided on Appendix A2.

- Taking into account that, this amount of water is to be pumped to different zones of the network in different periods of time, A study the way of operation, zoning, and changing valves setting in the distribution system is necessary, in order to calculate the peak factors, especially that the needed demand for consumption nodes will be pumped at high flow rates at shorter times to satisfy the demands of the nodes. This assumption represents the key of difference between the continuous supply systems and the intermittent water supply systems, so there is a need to enlarge the consumption of the nodes where there is not continuous supply to provide their needs of water in short periods of times as it is explained by the following example.

e.g., : A zone in the Addis Ababa water distribution system receives its needs of water for 24 hour each 72 hour, and has a population of 1300 person, then:

Demand = number of residence * water consumption per capita per day
= 1300 person * 145 (l/c/d)
= 188500 l/d
= 188.5 m^3 /d

This gives an hourly average of: 7.88 m^3 /hr.

Taking into account that, this amount of water is to be pumped in 24 hours each 72 hours the peak factor is:
72 hr / 24 hr = 3
Which results a design flow rate of: 3 * 7.88 m^3 /hr = 23.6 m^3 /hr. This is 6.57 l/s.

By this procedure, the demand for each node was calculated and analyzed depending on the number of inhabitants for each consumption node, and the period of supplying water to calculate the peak factor of demand for each node as provided on Appendix A1.

- The demand pattern which has been adopted at the nodes of the distribution system is a roof tank demand pattern (not fixed demand as in the continuous supply systems) to simulate the variations of demands in nodes in the intermittent systems, and the values of this pattern are measured by monitoring flows at the customer's premises in which the daily variations of water demand was recorded as shown in figure (4.1).

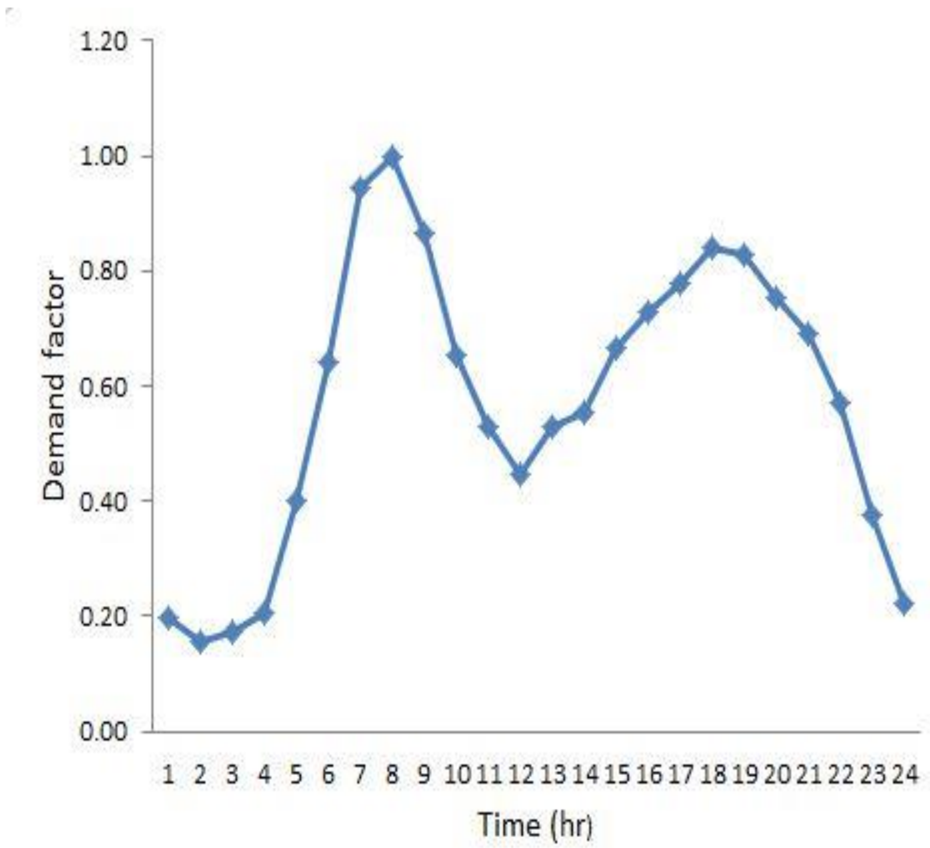


Figure (4.1): Demand Pattern Curve for Daily Water Consumption (Roof tank Pattern):

- The analysis of the water system under these conditions is performed using WaterCAD, which has been developed by the Haestad Methods, and represents a powerful; easy to use that helps in design and analyzes water distribution systems. This package of software enables the designer to model complex hydraulic situations. The input data needed to perform the analysis by the WaterCad Technique comprise the demand in the nodes, their elevations, pipes lengths, diameters, materials, reservoirs and their elevations, demand patterns, valves with different types and their control; also pumps found in the system are modeled depending on their operating curves.

- The population figures, which has been adopted in this model, depend on the statistics of the figures derived from the number of house connections multiplied with the average household size and estimated as 319,361 as provided under Appendix A1.

- Each cluster of houses has been modeled in this model as one consumption node, and its consumption is calculated depending on the number of inhabitants in each of them as shown in figure (4.2)

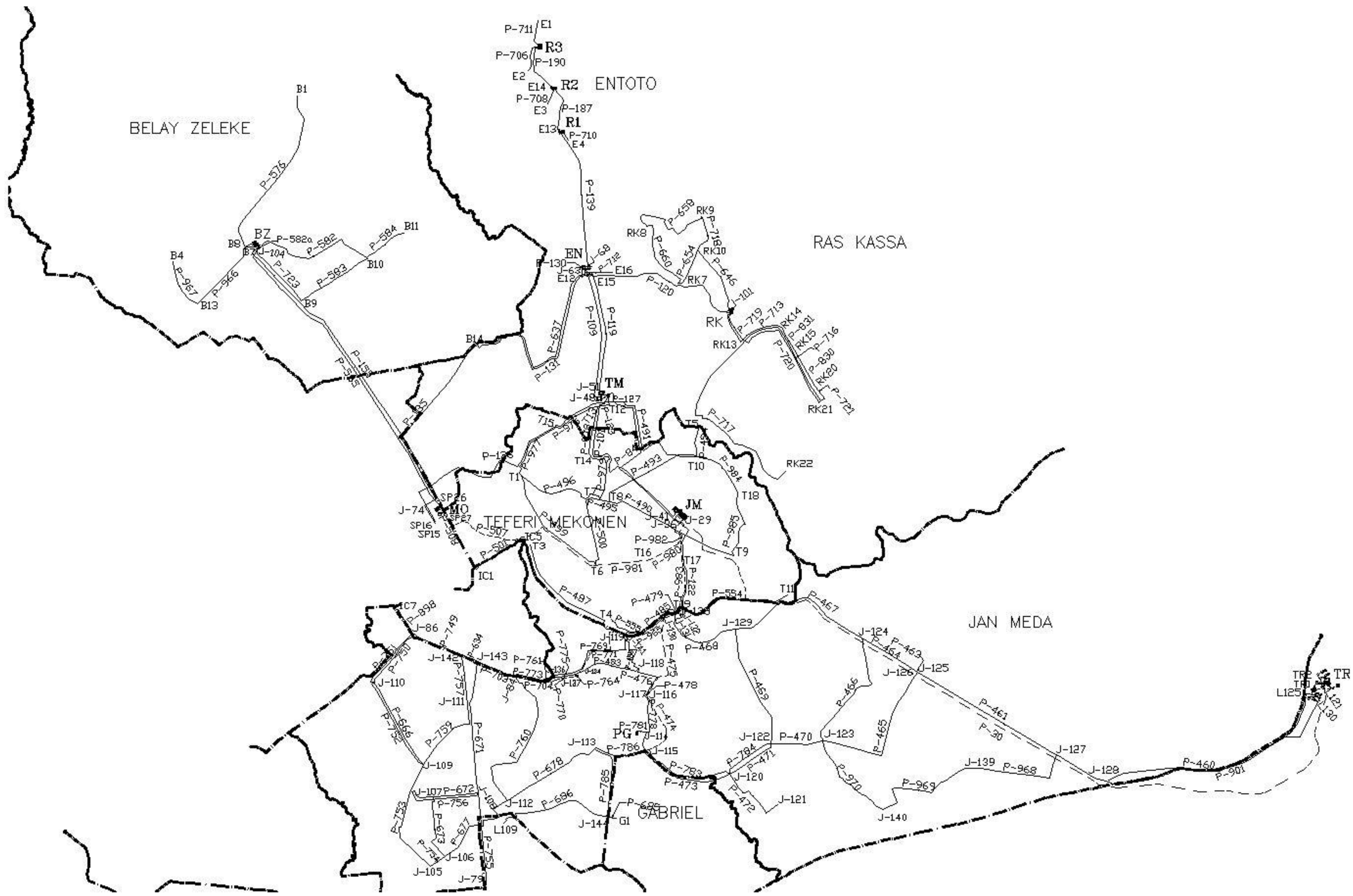


Figure (4.2): Layout of Existing water system of the Study area

- The status of the valves in the model (closed or regulated) was considered according to the site visit made and discussions held with AAWSA personnel.
- It is assumed that the only reservoir supply the study area sub systems is Terminal Reservoir. Accordingly, it is considered as the only source for Jan Meda, Teferi

Mekonnen, Belay Zeleke, Entoto and Ras Kassa sub systems with unlimited supply. Janmeda, Teferi Mekonnen, Belay Zeleke, Entoto, and Ras Kassa reservoirs are considered as tanks since they are simply meant for flow balancing in the sub systems. The limitation, here, is that Terminal reservoir might be in deficit of supply in contrary to the definition of reservoir.

- The Addis Ababa water distribution system has 16 sub-systems, which gets water from three main sources. The study area, namely Janmeda, Teferi Mekonnen, Belay Zeleke, Entoto and Ras Kassa Sub-systems are supplied mainly from Legedadi water treatment plant through Terminal Reservoir. A brief description of the sub-systems is given below.

  - **Janmeda Sub-System:** This area is supplied by gravity from Janmeda reservoir, which is fed via a DN 900 mm line from Terminal reservoir. In addition, there is also supply from Terminal reservoir via a DN 400 mm line directly to the distribution network. It represents a combination of commercial, institutional and domestic consumers.

  - **Teferi Mekonnen Sub-System:** Teferi Mekonnen sub-system lies in one of the most important zones, being the site of the university, many Government offices and much commercial activity. The area is supplied by gravity from Teferi Mekonnen reservoir, which is fed by pumping from Janmeda reservoir.

  - **Entoto and Upper Entoto Sub-System:** This sub-system is situated in the highest part of the city. The area gets water from four reservoirs – Entoto, R1, R2, and R3 – by pumps from Teferi Mekonnen reservoir. From Entoto reservoir pumps feed R1, R1 to R2, and R2 to R3 reservoir respectively.

  - **Ras Kassa Sub-System:** This sub-system is situated in the northeast corner of the city. It is supplied from Rass Kassa (RK) reservoir by gravity and from Teferi Mekonnen reservoir by pumping. The area is mainly residential. Some of the upper parts of the system are supplied by pumping from RK reservoir.

  - **Belay Zeleke Sub-System:** Belay Zeleke is located in one of the highest parts of the city and straddles Belay Zeleke road. The area is supplied by gravity from Belay Zeleke (BZ) reservoir, which is fed by pumping from the AAWSA main office (MO) reservoir. Some of the upper parts of the sub-system are supplied by pumping from BZ reservoir.

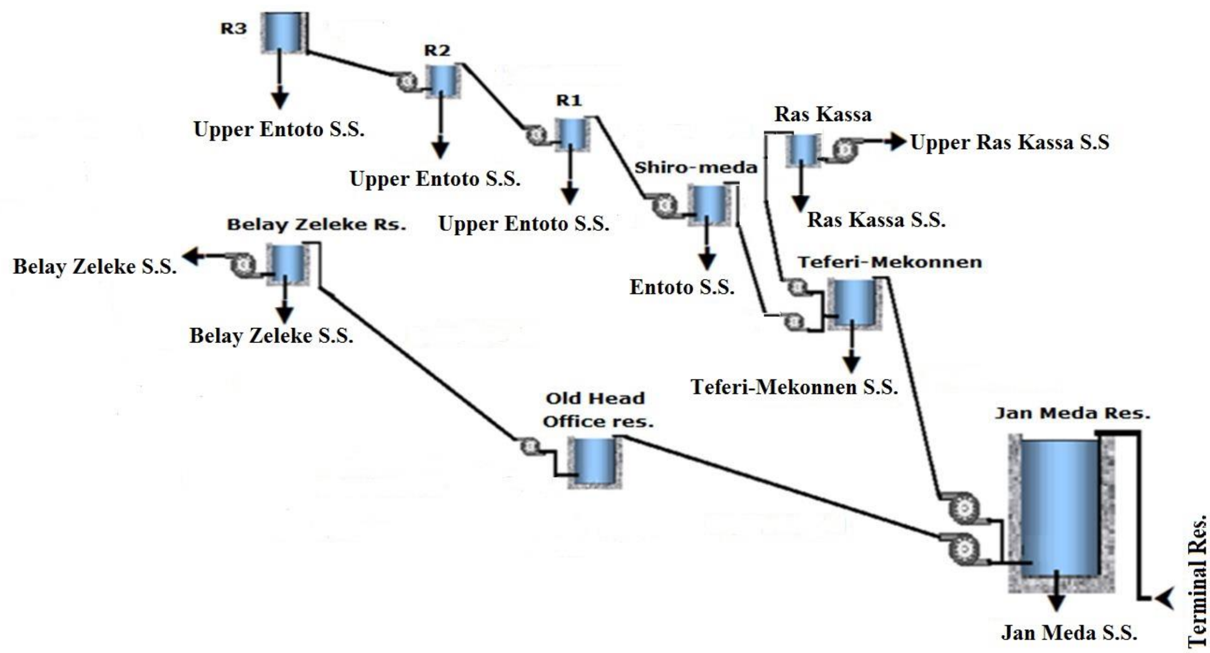


Figure (4.3): Schematic diagram of the study area water distribution system

- Hydraulic Model for intermittent supply condition is developed using WaterCad Software (Vr.5). Despite that this software is utilized mainly for continues supply, the modeler manage by introducing valve control schemes and intermittent supply patterns and peak factors for each operation zone, and flow emitters to overcome such limitation in the hydraulic modeling software.

4.3 Model Calibration and Sensitivity Analysis

Calibration consists of determining the physical and operational characteristics of an existing system and the data, which after being input to the computer model, will yield realistic results. Calibration of a water distribution model is a two-step process consisting of (Walski, 1983):

a) Comparison of pressures and flows predicted with observed pressures and flows for known operating conditions (i.e., pump operation, tank levels, pressure-reducing valve settings), and

b) Adjustment of the input data for the model to improve agreement between observed and predicted values.

It involves the process of fine-tuning a model until it simulates field conditions for a specific time horizon (such as maximum hour conditions) to an established degree of accuracy.

The calibration process for intermittent hydraulic model used in this study involved site measurements of pressure at strategic locations in the water networks, and the model parameters were manipulated in a reasonable range to adjust the model simulated pressure values to the field measured values.

Accordingly, three data sets have been created to keep the consistency between the measured pressures and operation scenarios. To better reflect the system condition for each calibration dataset, demand patterns are adjusted along with pipe roughness and pump operation conditions. Two calibration runs have been conducted for all data sets. Each run has improved gradually the goodness-of-fit between the observed pressures and the simulated pressures after time consuming trials.

The collection of field data provides an opportunity to understand the operation of the real system at a specified number of locations and times. After careful review of the data and the possible sources of error, sensitive parameters are narrowed to three categories that are believed to provide the greatest source for error in the study and therefore, subjected to possible adjustment during the calibration process. The parameters are:

a) Pipe roughness values (Hazen-Williams "C-Factors"),

b) System demand patterns, and

c) Pump operation pattern and pump-characteristic curves (head versus flow values).

A sensitivity analysis confirmed that, variation in "C-Factor" has insignificant influence on system pressures.

The system demand factors are used to distribute the average daily nodal consumption values over hourly time steps of an Extended Period Simulation. Initial estimates of system pattern were obtained from discussions held with AAWSA experts. During the calibration process, the individual hourly factors were modified by a trial and error method using the generalized practical consumption pattern (e.g. peak demand hours and low demand hours). It is important to note, however, that although individual hourly factors were modified, the total system-wide demand was not modified during the calibration process. The spatial (nodal) distribution of consumption in terms of an average daily value derived from records provided by AAWSA was not modified during the calibration process. Rather, as discussed above, the typical system demand factor pattern was used to distribute the average daily consumption value to an hourly time step value.

The third model parameter that was adjusted during the calibration process was the pump operation period and pump-characteristic curves. Initial pump-characteristic curve data were provided by AAWSA. This was a key parameter that was justifiably modified during the calibration process.

Modifications were made to the original data, so that system operations observed values during the tests are as close as possible to the simulated values. Trial and error method was used for two test rounds at three testing locations.

4.4 Correlation of Observed and Simulated Data

Pressure measurements were taken two times at the selected three points and the model is run to assess actual system performance against model outputs. Through each successive runs the correlation between the measured and computed data gradually improves and fulfilled the correlation criteria with correlation between observed and simulated values finally being 0.953. Table 4.3 summarizes the pressure readings at the selected test points.

Table 4.3: Calibration readings at selected nodes

No.	Node Label	Location	Date	Time (hr)	Pressure Reading (m)
1	B4	Belay Zeleke S.S.	May 17, 2018	8:45:00 AM	23
2	RK8	Ras Kassa S.S.	May 17, 2018	8:45:00 AM	55
3	E2	Entoto S.S.	May 17, 2018	12:00:00 PM	38.6

The criteria for each data and for the mean are also fulfilled. The final correlation result is provided on Table 5.8.

4.5 Evaluating the Existing Water Supply System

4.5.1 Variations of Water Levels in Roof Tanks

A study of variations of the water level in three roof tanks for three different consumers in different areas in Addis Ababa city has been registered during the month May 2017 for a period of fifteen days.
The records give the change in the water level of the storage tanks and thus the water consumption measured each day.

The analysis of these data gives an idea about the peak factors and enables for deriving the daily water consumption in order to compare these results with the study that had been carried by Tahal Consulting Engineers LTD (2005), recent studies conducted on other representative zones of the distribution system, and finally to calculate the actual water consumption.

The study has been implemented by installing three water meters at the outlets of three roof tanks in different areas in the city, and a daily monitoring and recording the readings of the water meters for each of them have been taken.

The daily water consumption for each consumer was calculated by subtracting the readings of the water meter for the next day from the previous day reading as shown in table (4.4).

The installed arrangement consists of a roof tank, water meter, check valve as shown in the following figure (4.4) and photo:

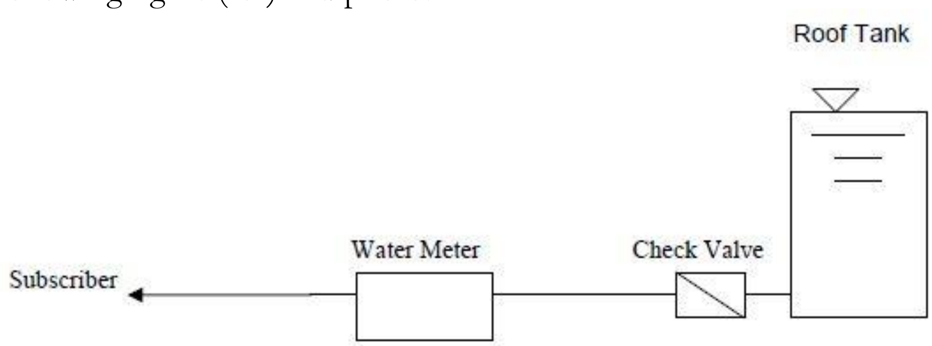


Figure 4.4: Arrangement of water level variations experiment:

Photo: Arrangement of water level variations experiment

Table 4.4: Daily measurements of water level variations in roof tanks:

	Day	Daily Consumption (m3) Home No.1	Home No.2	Home No.3
	1-(21/05/2017)	0.261	0.208	0.332
	2	0.278	0.325	0.198
	3	0.127	0.461	0.252
	4	0.303	0.473	0.167
	5	0.185	0.442	0.229
	6	0.345	0.371	0.182
	7	0.683	0.920	0.474
	8	0.548	0.622	0.355
	9	0.261	0.356	0.177
	10	0.185	0.316	0.308
	11	0.137	0.388	0.249
	12	0.261	0.437	0.197
	13	0.178	0.523	0.189
	14	0.431	0.893	0.323
	15	0.271	0.379	0.166
Total (m3)		**4.454**	**7.11**	**3.799**
No. of inhabitants/Home		**4**	**6**	**3**
Average consumption/day		**0.297**	**0.474**	**0.253**
Peak factor (P.F) = Max./Av.		**2.301**	**1.939**	**1.8719**
Av. P.F = Sum of peaks/no.	**2.037**			

As shown above and by dividing the peak daily water consumption by the average, the daily peak factors for the three different consumers are 2.301, 1.939, and 1.8719 respectively. The average peak factor for these values is 2.037.

The daily water consumption versus time is plotted in figures (4.5), (4.6) and (4.7)

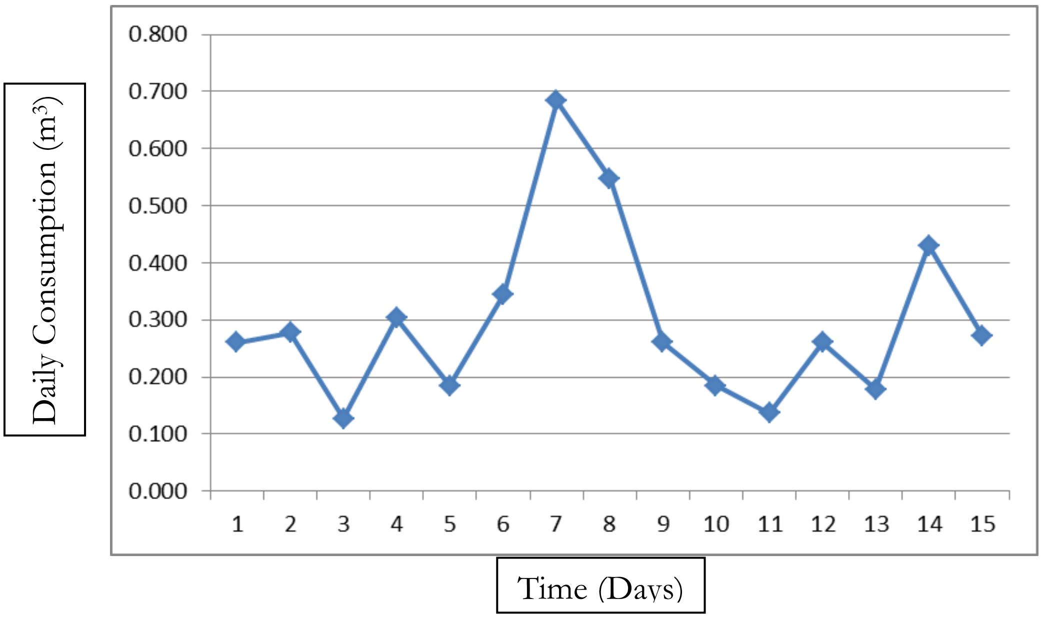


Figure (4.5): Daily water consumption of consumer no.1

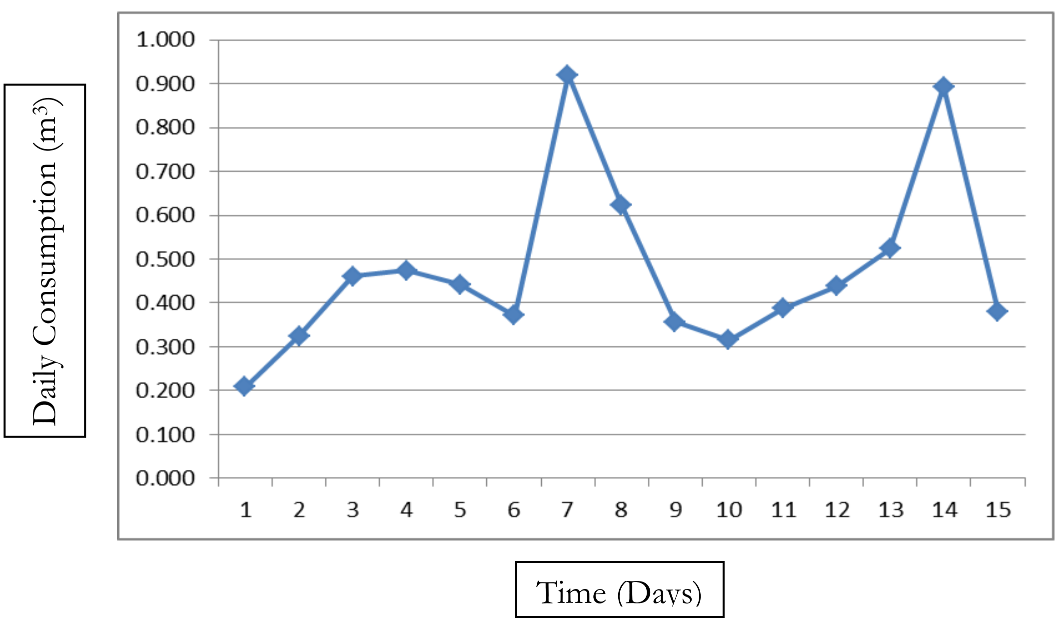


Figure (4.6): Daily water consumption of consumer no.2

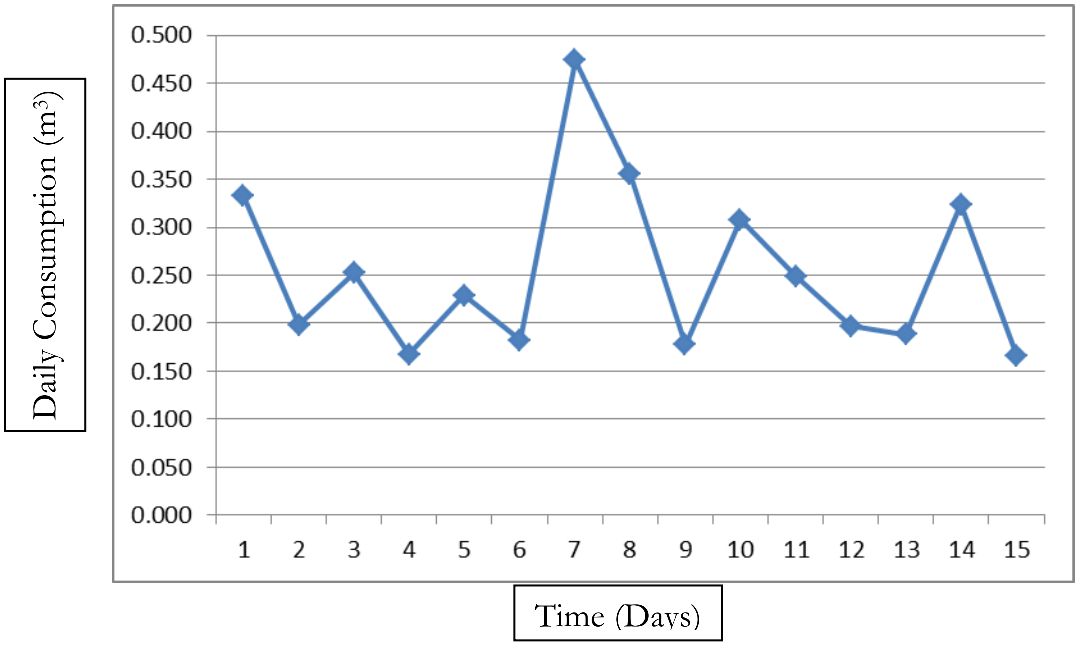


Figure (4.7): Daily water consumption of consumer no.3

The present consumption in terms of per capita and day (L/c/d) for the three different consumers depending on the number of inhabitants and the total consumption in the period of measurements are summarized in the following table:

Table 4.5: Average daily water consumption from measurements of water variations in Roof tanks

No. of Home	No. of Inhabitants	Average Consumption (m3 /day)	Consumption
Home no.1	4	0.296921	74.2
Home no.2	6	0.474	79
Home no.3	3	0.253277	84.4
Average:(L/c/d)	79		

In comparison with measurements that have been implemented in project of developing NRW of Addis Ababa water distribution system by (P.Antonaropoulos & Associates S.A, 2012), in which three sectors in the distribution system were chosen, showed a little difference in the daily water consumption. The sectors located at different areas of the town, with different consumption habits and population figures.

Table 4.6 shows the results achieved for each sector, and the average consumption, which is representative for all Addis Ababa distribution system.

Table 4.6: Water meter readings in three zones - Addis Ababa distribution network

Sector	No. of Person	No. of water meter	Average network pressure (bar)	Supply time (h/d)	Consumption (L/c/d)
Gulele	41,841	11,891	2.04	15	75
Yeka/Megenagna	28,580	7,255	3.06	18	81
Arada	22,317	11,035	2.55	11	65
Total	92,738	30,181	-	-	74

Source: (Water Audit & Benchmarking Report of Addis Ababa Water Supply system Project).

The water meter readings in a pilot zone, which have been implemented by (P. Antonaropoulos & Associates S.A, 2012), showed a daily consumption varied between 65 and 81 liters per person and day.
The results of the study of water level variations for different consumers and the water meter reading measurements in different districts showed a little difference in the daily water consumption. These differences are a result of different in consumption habits; population figures, and standard of living, also the difference of water supply times, and the network pressure will affect the values of the daily water consumption.

4.5.2 Unaccounted for water (UFW) for the study area sub-system

Unaccounted for water is divided into physical and non-physical water losses. Physical water losses are defined as "that amount of water which is lost without being used due to failures and deficiencies in the distribution facilities". Non-physical water loss is defined as "the amount of water which is not registered, due to incorrect reading of the measuring instruments installed (measurement errors) and/or absent or inaccurate estimates in the absence of measuring instruments (estimation errors) (DIN ISO 4064. 1981).

The calculation of the (UFW) for study area sub-system has been implemented by the procedure which depend on the daily quantity of water supplied by the sources of water to the study area sub-system versus the amount of water sold and their value taken from the billing section of the AAWSA, as shown in the table 4.7.

Table 4.7: UFW figure for the study area sub-system in 2018

<table>
<tr><td rowspan="7">System Input Volume
54,000
100%</td><td rowspan="4">Authorized consumption
35,473
65.69%</td><td rowspan="2">Billed Authorized Consumption
35,408
65.57%</td><td>Billed Metered Consumption (including water exported)
35,397
65.55%</td><td rowspan="2">Revenue water
35,408
65.57%</td></tr>
<tr><td>Billed unmetered Consumption
11
0.02%</td></tr>
<tr><td rowspan="2">UnBilled Authorized Consumption
65
0.12%</td><td>Unbilled metered Consumption
38
0.07%</td><td rowspan="5">Non-Revenue water
18,592
34.43%</td></tr>
<tr><td>Unbilled unmetered Consumption
27
0.05%</td></tr>
<tr><td rowspan="3">Water Losses
18,527
34.31%</td><td rowspan="2">Apparent Losses
5,665
10.49%</td><td>Unauthorized use
356
0.66%</td></tr>
<tr><td>Metering inaccuracies
5,308
9.83%</td></tr>
<tr><td colspan="2">Real Losses
12,863
23.82%</td></tr>
</table>

As shown on Table 4.7; 34.31% of UFW indicates the implementation of poor operational practices and leakage control mechanisms. Deteriorated of water distribution pipes and the existence of excessive pressures during supply periods are the main factors for leakage and its frequency. On the other hand, there are many factors that influence deterioration of pipe lines. Generally these factors are categorized under either structural, internal, external or maintenance factors.

It is to be noted that it was difficult to reconcile the water balance components with each other during the Real Losses calculation for the study area. It was also seen that available data on Billed Metered Consumption and Water Supply record in particular may be suspect.

4.5.3 Water Demand and Supply

Following to the accelerated growth of population, economy & urbanization of the city; the demand for water increases dramatically. The accelerated demand of the city necessitates for development of additional water sources and supply infrastructures. However, financial capacity of the city is low to develop additional water sources and supply infrastructures to satisfy the ever growing demand. This constraint results to decrease the water supply coverage of the city and of course to widen the gap between supply & demand. The existing water supply to the study area subsystem was 54,000m^3/day. Hence the total demand including the UFW in the system is 84,588.19m^3/day for supplying water 24hrs. To fill the gap additional 30,588.19m^3/day amount of water is required to fulfill the supply shortage and demand of the study area water supply system. The consumption rate for Addis Ababa is 477 l/d/ service connection; which exhibits that it is under acute shortage of water supply in comparison to other cites of the developing countries in Africa. The city is also receiving only 49% of its demand in 2018. Due to water demand of the system exceeds produced water; rationing of water in the city during the study period was a common phenomenon (AAWSA "Weha ena Fesash" Magazine, Vol. (11), No.3, 2018).

Moreover the reduction on sources' production capacity from their maximum production potential is making the water sources to be unreliable. Among the reasons contributing for the reduction of production capacity are frequent power interruptions, malfunctioning of well pumps, yield depletion of groundwater, poor quality of borehole' water, main break, poor maintenance & flushing practices…

Financial constraint is one of the major factors for the low water coverage of the water supply but poor management of the existing water supply system also has a great impact for the low coverage. Beside to the overall low supply coverage, supply disparity exists among different localities. Therefore evaluating the entire distribution of the water supply system is important in order to identify the problematic areas and intervene accordingly.

4.5.4 Ages of Pipes and Leakage

Addis Ababa is characterized by having old water distribution networks upon which new extensions are linked in order to serve new areas, adding complexity to an aging network where full rehabilitation may not be practical due to economic constraints.

As cause of leakage many of the factors just described are age-dependent and their effect will be greater with time. Consequently, the age of a pipeline can appear to be the most significant factor affecting the likelihood of leakage, but on its own, age is not necessarily a factor.

Most pipelines are replaced after approximately 40 years of continuous service. This lifetime can be extended or shortened significantly depending on the service environment of the pipe. If the pipeline works at the proper operating pressure and is equipped with external and internal protections commensurate with the surroundings and good quality of water is conveyed; it should last for approximately 50 years. However, the service life of the pipe could be shortened considerably if the above conditions are not observed.

As Hazen–Williams Equation relates the flow of water in a pipe with the physical property of the pipe and pressure drop caused by friction. An increase in pipe roughness will lower the value of "C" and causes to drop the system pressure due to the increased frictional loss. (Bhave et al., 1998) states that the Hazen–Williams Equation becomes less accurate for C-values less than 100. Hence, the choice of a proper roughness value is more relevant than the choice of the friction loss equation itself. Which of the values fits the best to the particular case can be confirmed only by field measurements.
Analysis on the physical property of the pipes serving the study area in 2018 is shown on Table (4.8 – 4.10). The data required for the analysis is get from pipe mains layout map obtained from Heavy line section of AAWSA in AutoCAD format.

Table 4.8: Pipe Age Assessment of the Existing Pipes

Construction Year	Age (Year)	Pipes (No.)	Percentage (%)
After 1988	≤30	62	30.39
1969-1987	31-50	132	64.7
Before 1968	>50	10	4.9
Total		**204**	**100**

Table 4.9: Pipe Material Assessment on Existing Pipes

Type of Material	Pipes (No.)	Percentage (%)
PVC	8	3.9
DI/DCI	112	54.90
Steel	67	32.8
GSI	17	8.3
Total	**204**	**100**

Table 4.10: Pipe Roughness Factor Assessment on Existing Pipes

Hazen-Williams C factor	Pipes (No.)	Percentage (%)
less than 80	3	1.47
80-90	10	4.90
90-100	62	30.39
100-110	114	55.9
≥ 110	15	7.35
Total	**204**	**100**

As it is mentioned in Table 4.8; about 4.9% of pipes serving the study area are aged with more than 50 years of continuous service, in addition to that, 64.7% of pipes are also aged with (31 – 50) years of service. While, only 30.39% of pipes are with less than 30 years of operation. From Table 4.9; 54.90% and 32.8% of pipes are made of DI/DCI and Steel material respectively. Thus the value of "C" decreases over time in the case of non-mortar lined cast iron and steel pipes, assuming a given water quality. This means, with more than 30 years of operation, the value of "C" diminishes to become less than 100. As shown on Table 4.10; 36.76% and 55.9% of pipes serving the study area have roughness values of less than 90 and 100 respectively.

4.5.5 Water supply variations

The Addis Ababa water supply network is not continuously pressurized. Supplies are provided intermittently with frequency and length of supply interruptions varying between different areas range from intermittent supply to 24 hrs supply. Currently the city receives water with an average supply time of 14.8 hours per day. In 2018 Budget year out of 116 woredas; 91 woredas or 78% of them are received water intermittently, and out of 91 woredas; 14 woredas those found in Gullele & Yeka sub-city are supplied only for 8hrs per day within a week (Conference for conscious of short and long-term solutions to the difficulties of water supply services of Addis Ababa, Addis Ababa Water and Sewerage Authority, October, 2018).

As Entoto & Upper Entoto, Belay Zeleke, and Ras Kassa sub-systems are found in Gullele & Yeka sub-city; (Woreda-01, 02, 03, 05, 06, 08, 09 of Gulele Sub city) and (Woreda-01 & 08 of Yeka Sub-city) are among the woredas supplied only for 8hrs per day within a week. Whereas (Woreda 07 & 09 of Gulele Sub city) and (Woreda 05 of Arada Sub-city) are supplied for (2 to 3 day/week - 10 to 20hrs/day). (Woreda-04 & 10 of Gulele Sub city), (Woreda-05, 09, 10, 11 of Yeka Sub city) and (Woreda 01, 04, 06, 10 of Arada Sub-city) are supplied for (4 to 6 day/week - 6 to 12hrs/day). (Woreda-02, 03, 04, 06, 07 of Yeka Sub-city) and (Woreda 02, 03, 07, 08, 09 of Arada Sub-city) are supplied for (7 day/week - 12 to 24 hrs/day).

4.5.6 Intermittent supply

The available water sources throughout the world are becoming depleted and this problem is aggravated by the rate at which populations are increasing, especially in developing countries. The problem of water scarcity in urban areas is a particular concern. Migration of the rural population to urban centers has resulted in towns and cities expanding rapidly. Such situations place a strain on existing public services and result in chaotic conditions in many towns and cities throughout the developing world (Vairavamoorthy, K. et al., 2001). Likewise in Addis Ababa, since the water quantity available for supply generally is not sufficient to meet the demands of the population, water conservation measures are employed to control the water demand through the use of intermittent supplies. Therefore it is fair to conclude that intermittent supply is directly connected to the state of unavailability of adequate quantity of water to supply and the inadequate capacity of supply facilities.

Beside to the overall water shortage at the source, the topography conditions preclude supplying the entire distribution area at the same time. In this case, the distribution networks are divided into several pressure zones, through which water is delivered alternately according to an operational schedule; i.e. each supply zone experiences intermittent water delivery by which water is pumped for shorter time periods at higher flow rate to meet the demand of the consumers (i.e. intermittent pumping). Hence, the few supply hours are not sufficient to fill the floating tanks and/or individual storage tanks. During the off-supply time, water is consumed directly from the individual tanks, to be compensated when the distribution network is pressurized again. Thus, the individual storage tanks play a significant role in the hydraulics of water distribution. Since this way of operating & managing of the existing water supply system is employed by necessity rather than design, results the following consequences:

(1) Pumps and pipes failing to carry the required water demand during short periods, thus leading to unreliable service and uneven distribution of water;
(2) Low pressure due to increased hydraulic losses associated with increased flows and undersized pipe diameters;
(3) High energy losses, leading to increased operational costs; and
(4) Increased water leakage

The aforementioned effects indicate that the intermittent service is the procedure of providing water that is followed in operating most of the water distribution systems of Addis Ababa.

Under intermittent-supply conditions, the existing pipelines will have to carry different water quantities depending on the number of supply hours. This leads to increased friction losses (ΔH) or hydraulic gradient (S) and reduced network pressure, and therefore will not fulfill the water demand of all consumers. As a result of reduced network pressure, service will be unreliable: water will fail to reach many consumers, especially those located at higher elevations of the network.

Water distribution systems in large localities are more sensitive to reductions in water supply duration than those in small towns and villages. Similarly, intermittent-supply conditions have a greater impact on the main transmission pipes than the distribution network. In other words, the impact of reduced supply duration increases with proximity to the water source and decreases with proximity to the consumer.

These results prove that reducing the supply duration is a major factor that leads to insufficient water availability for consumers and causes unreliability of the existing distribution systems. These challenges will be exacerbated if the current design practices overlook this fact and assume water availability and appropriateness to provide continuous water supplies. Studying the local conditions of water availability is a necessary step before embarking on the design of new water supply systems to avoid reduced supply duration and the resulting negative impacts. As a result, increased demand multipliers will require increasing the diameters of pipes and capacity of public storage tanks, and thus, construction costs will increase substantially, under the existing conditions of limited financial resources.

4.5.7 Disproportionate Mains

There are some specific technical issues concerning the existing water supply system, in the studied sub distribution systems such as inadequate pipe sizes and disproportional mains spatial distribution is observed.

4.6 Modeling of Study area Distribution Network as Continuous Water Supply System

4.6.1 Introduction

The redesign and analysis of the Study area water distribution system and the extension areas as a continuous supply system is to verify the ability of the existing system to serve the study area in the future is discussed depending on number of assumptions and facts considering with the future water consumption, availability of water, and other factors like the enhancement in operation and management of the water supply system, the development in mode of the water supply to the consumers, and assumed economic development. Design criteria are compiled by following accepted practices and adapt suitably to the specific local conditions in the study area for zoning considerations and other requirements.

The design and analysis of the water distribution system is till the end of the year 2020. According to the adopted rate of growth approved by AAWSA & projected by Tahal Consulting Engineers LTD, the population of the city is expected to be 4,235,773 inhabitants with a rate of growth about 3.41%.

4.6.2 Assumptions of the study

In modeling the Study area water distribution system, the following assumptions have been taken into consideration.

- The water distribution system is designed to cope mainly with the domestic demand. As it is common in Addis Ababa, the consumption for industrial, commercial, and institutional demands is included in the domestic consumption figure to form a total water demand per person and day. According to studies carried out by the AAWSA and Tahal Consulting Engineers LTD (2005), in which the predicted future water consumption till the year 2020/2021 was estimated depending on the future domestic consumption, development of the economy and industry, decreasing the (UFW) and technical losses. The theoretical water demand used in the modeling is as mentioned in Table 4.11:

Table 4.11: Projected demand for design and analysis of the network as continuous system:

Type	Consumption (l/c/d)
Domestic	124
Add industrial, commercial and institutional	161
Technical losses (11%)	20 =(11% * 181)
Total	181(l/c/d)

As mentioned in the above table, the total consumption per capita per a day projected to 181 l/c/d by the year 2020 - 2021.

- The average rate of population growth considered being 3.41%, and according to CSA statistics of the city as base & the projected population number by AAWSA, the population of Study area expected to be 336,643 by the year 2020 – 2021 as provided on Appendix A3.
- Experience from other countries and from Addis Ababa shows that as a result of improved standard of life, improved construction standards, City of Addis Ababa Government & Federal Housing Corporation plans for new massive dwelling units construction on various packet areas of the town; will gradually and permanently shifting from a lower to a higher mode of service occurs over the design period. These also have been taken in consideration as shown in figure (4.8) and provided on Appendix A4.
- The model is limited to a minimum pipe diameter of DN 150 mm in the distribution network. Diameters of smaller size are considered insignificant in terms of the population supplied. The pipes considered in the model are those laid in 1970 and subsequently. These pipes, most of which are of DCI and steel.

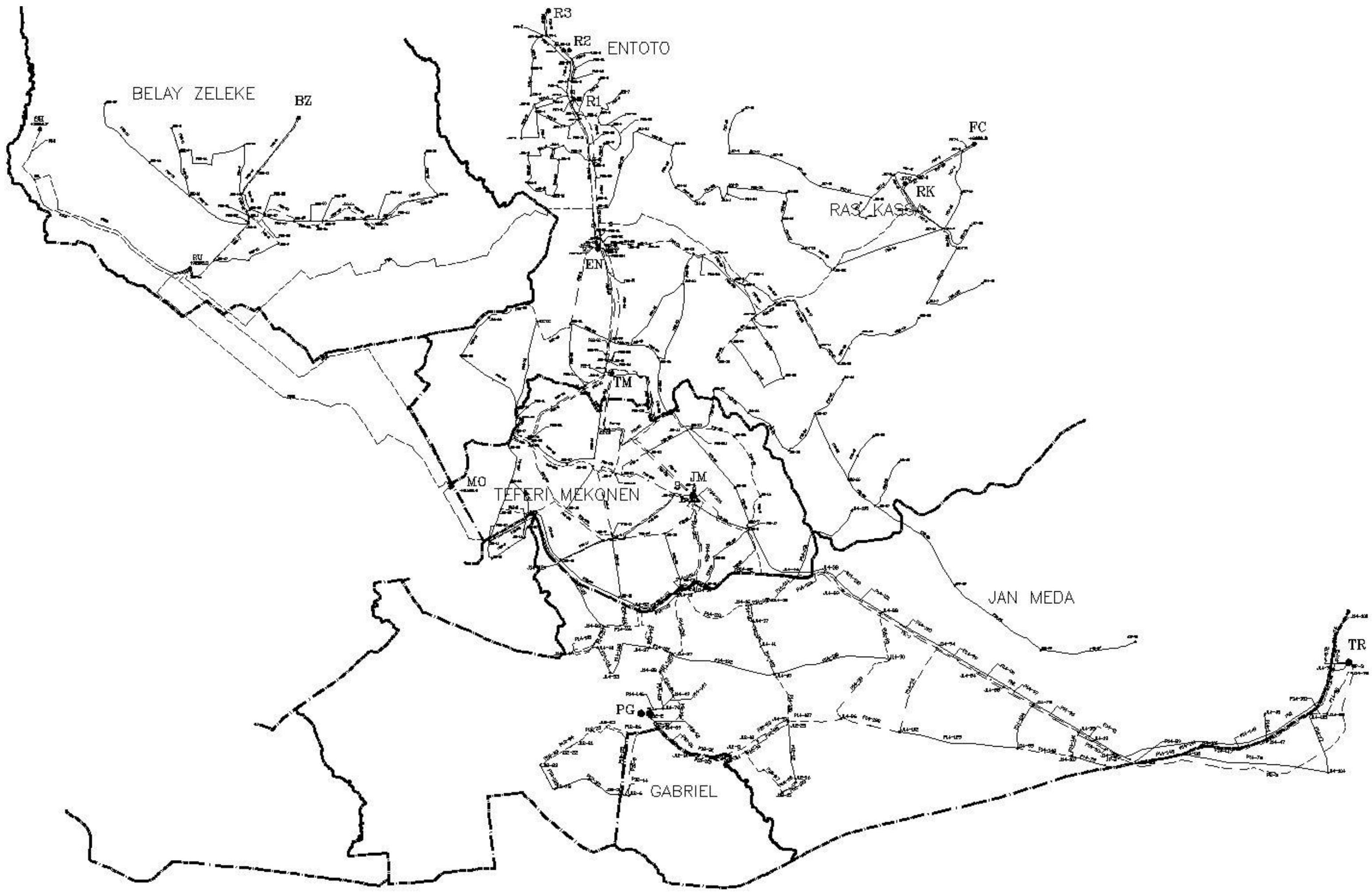


Figure (4.8): Layout of the proposed water system of the Study area

- Currently the water supply to Addis Ababa Metropolitan Area (AAMA) is supplied from the existing surface & ground water sources with a gross supply of 574,000m^3/day.

- AAWSA will have been undertaking a number of programs to provide safe and adequate water to the inhabitants of the city of Addis Ababa which can overcome the acute shortage of water. In this context, the Authority has, therefore, laid out short, medium and long term plans in order to augment the city's water supply and improve the distribution as briefed below:

  - As a short term plan AAWSA is undertaking the remaining ground water exploitation projects under Koye-Fechea groundwater development project (6,000m^3/d) & and drilling of boreholes at various pocket areas of the city (3,000m^3/d), Legedadi Well field phase II (86,000m^3/d), and additional 25,000m^3 of water per day by upsizing the existing inadequate capacity transfer main to utilize the ultimate production capacity of the Legedadi treatment plant. All These projects are expected to be completed by mid of 2019.

  - In the medium term AAWSA has planned to undertake ground and surface water development projects: South Ayat North *Fanta* Groundwater development (68,000m^3/d), Sebeta-Holeta Well field (100,000m^3/d), and Gerbi Dam (73,000m^3/d). These projects are expected to be completed by 2020/2021.

The implementation & completion of these short & medium term projects will improve the water supply situation of the city by providing additional 361,000m^3/day of water. This will increase the daily water supply of the city from 574,000 to 935,000m^3/day by year 2020/2021 (Conference for conscious of short and long-term solutions to the difficulties of water supply services of Addis Ababa, Addis Ababa Water and Sewerage Authority, October, 2018).

- Under the Addis Ababa Deep Wells Water Supply Projects with a major upgrade of the distribution and transfer network within the city, including storage & service reservoirs, submersible pump sets as well as pumping stations, diesel generators, and SCADA system will be occurred.

- The demand for the consumption nodes is approximated depending on the number of inhabitants for each node as provided under Appendix A3. The demand pattern, which has been adopted, is a fixed demand pattern assuming that, there will be availability of water, and enhancement of operation and management of the water supply system.

In considering the design of different elements of each water supply scheme, the following demand conditions are to be taken into consideration:

- *Average Daily Demand* is the sum of the design demand of domestic, commercial, institutional, industrial, public and unaccounted-for water (losses).
- *Maximum Daily Demand* is the highest demand of any one 24-hour period over any specified year. For the purposes of this study, a maximum daily factor of 1.1 is adopted. Thus the transfer mains will be designed for a peak daily flow factor of 1.1.
- *Peak Hourly Demand* is the highest demand of any one hour over a day.

The peak hourly demand is determined by multiplying the average hourly demand by the peak hourly factor. All pipelines except the dedicated transfer mains were modeled using the peak hourly demand.

The peak hourly factor Ph_f is determined from each Subsystem supply zone population using the Harmon equation:

$$Ph_f = 1 + \frac{14}{4 + P^{0.5}} \quad \text{.. (4.1)}$$

Where,

P is the population in thousands.

A summary of peak hourly factors for each Study area supply zone is presented in Table 4.12.

Table 4.12: Summary of Peak hourly factors for each of the study area supply zones

Supply zone	Supply zone ID	Average daily demand	Maximum daily demand	Peak hourly demand	Peak hourly factor
		l/s	l/s	l/s	
Gabriel	12	101	270	423	1.72
Jan Meda	14	152	595	851	1.57
Teferi Mekonnen	18	278	305	472	1.70
Entoto	22	194	214	344	1.77
Ras Kassa	24	42	46	74	1.78
Upper Entoto-1	26	26	28	57	2.24
Upper Ras Kassa	27	30	34	67	2.20
Belay Zeleke	28	88	97	171	1.94
Upper Entoto-2	29	16	18	38	2.37
Upper Entoto-3	30	12	13	28	2.46

As customer service operational criteria, data from previous studies has been considered. Technical specifications of AAWSA specify a minimum pressure at the property boundary to be 10m for residential buildings; whereas, other countries specify correspondingly 20m head. The maximum pressure, however, shall not exceed 80m to limit leakage and stresses on the reticulation system (Hammer, 2003).

Data from more recent studies by TAHAL Consulting Engineers LTD (2005), Liemberger and Partners (2007), Mengistu (2010), and P.Antonaropoulos & Associates S.A (2012) has been mentioned an average operating pressures on 31.4m, 23.8m, (20-30) m, and 25m respectively.
Accordingly, based on discussions with AAWSA network operators, the design criteria used in the design of supply zone boundaries, nodal pressure during the period of peak demand,

and optimum velocities of the transfer and distribution mains are as follows: (AAWSP-Stage IIIA, TAHAL Consulting Engineers LTD, 2005)

- Minimum static head is 20 m, which can supply a 4-storey building from the distribution system.
- Maximum static head within a pressure zone is limited to 80 m.
- Maximum velocities of major transfer mains < 2.5 m/s.
- Maximum velocities on distribution mains < 2 m/s.

The model is limited to a minimum pipe diameter of DN 150 mm in the distribution network. Diameters of smaller size are considered insignificant in terms of the population supplied. The pipes considered in the model are those laid in 1970 and subsequently. These pipes, most of which are of DCI and steel. However, pipelines in excess of 300 mm in diameter, which are known to be in satisfactory condition & are proved of high conveyance following the calibration, are taken into consideration.

In the model roughness coefficients of Hazen-Williams are applied. C-value for existing pipes is suggested based on age and material type. The values are compared with roughness factors calculated based on the results of flow and pressure measurements on Existing Pipes.

Calibration was carried out on the main network and the results are shown in Table 4.13 below. As expected, the table shows that both newer pipes and higher diameter pipes have a better roughness factor.

Some anomalies, however, were encountered, namely:

- In one case pipes of similar age had different roughness factors calculated.
- In another case, pipes with smaller diameters had a better roughness factor than pipes with higher diameters of the same material and same age.

The above contradictory findings could be due to different standards of pipes or errors in measurement.

Many studies show variations in the value of "C" for different materials, wall thickness and pipe age. Thus the value of "C" decreases over time in the case of non-mortar lined cast iron and steel pipes, assuming a given water quality. This means that during 50 years of operation, the value of "C" diminishes.

For the purpose of the model the following roughness coefficients are suggested for existing pipes, depending on age and material: (AAWSP-Stage IIIA, TAHAL Consulting Engineers LTD, 2005)

- All existing PVC pipe: 110-120.
- All existing pipe other than PVC: 90-110.
- All proposed distribution mains equal to or less than 250 mm (PVC, HDPE): 130.
- All proposed distribution and primary transfer lines greater than 250 mm: 120.

Table 4.13: Flow and pressure Measurement on Existing Pipes

Sr. No	Transmission main	Length (m)	Dia (mm)	Material	Year lying	Flow (m3/h)	Pressure (m)		EI of Manometer		Hazen Williams Coefficient
							Delivery	Inlet	Qutlet	Inlet	
1	TR to JM	7516	900	DCI	1985	2210	73	7	2406.6	2464.79	128
2	JM to MO	2741	500	DCI	1985	624	35	5.5	2469	2490.67	91

Chapter Five

5. Results and Discussion

5.1 Results and discussion of the intermittent model

The discussion of results which are produced by the modeling of the study area water distribution system as an intermittent supply system depends on some facts about the behavior of the Addis Ababa water supply system under these conditions of providing water for consumers, design life of the system, taking into consideration some theoretical assumptions about the intermittent water systems.

A well-designed WDS should supply adequate quantities of water to all consumers including fire demands within a certain time through a certain section (VAC, 2002). It is not only important to deliver adequate quantities of water to the consumers but also to ensure that the water is delivered at adequate pressures. The pressure at nodes depends on the adopted minimum and maximum pressures within the network, topographic circumstances, and the size of the network (Masri M, 1997). 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. Pressures less than 20 m under maximum-hour demand conditions are not acceptable for most water systems. Although the upper bound on pressure would depend on the pressure rating of the pipe material or the pipe joints. Many water utilities are mandated to maintain pressures well below the rated capacities of pipes (e.g., 48–55 m) to safeguard the appliances that derive water directly from the distribution network. Limiting the upper bound on pressures would also reduce the leakage losses as well as the pump operating costs (Lingireddy, S. and Wood, D.J, 1998).

Constant problems with low pressure or pressure fluctuations in a portion of a system where the utility is attempting to serve a customer at too high of an elevation. The best solution is to create or move the pressure zone boundary so that those customers experiencing low pressures will be served from the next higher pressure zone. Each succeeding pressure zone shall not be less than 15.2 m and not more than 45.7 m apart in elevation.

For city of Addis Ababa, AWWSA is using operating pressures which ranges from 60m to 80m: However, there was no defined maximum and minimum pressure ranges set by the AWWSA. Therefore, literature based recommendation for optimum operating pressure was used to assess system hydraulic performance.

With regard to the intermittent model simulation of existing water distribution at peak hour demand condition as shown below in tabular and the results for pressure at peak flow is summarized in Table 5.1 and detailed in Appendix B1, pressure on peak hour is the most important for design and improving and expansion of existing system, updating and installation of new water supply distribution schemes.

Table 5.1: Pressure distribution during Peak hour demand conditions

Pressure (m H2O)	Nodes (No.)	Percentage (%)
> 80	8	5.84
60-80	19	13.87
20-60	52	37.96
0-20	41	29.93
< 0.00	17	12.41
Total	**137**	**100**

As depicted in Table 5.1, 42.34% of nodes are below the minimum desirable pressures (20m) during peak hour period. Out of this 12.41% of nodes are with a negative pressure. High pressure is also observed during high consumption period on 19.71% of nodes by exceeding the maximum allowable pressures of 60m. Out of this 5.84% of nodes are with excessive high pressure exceeding the ultimate maximum pressures of 80m. This figure is relatively high. While 37.96% of nodes are in the permissible pressure ranges of minimum 20m and maximum 60m pressure in consideration to the design life of the system.

Estimating pressure distribution at the peak hour demand conditions is the governing parameters for the purposes of design and improving the existing water distribution network in addition to the pressure at minimum consumption hour demand conditions. At peak hour the water consumption or demand expected to be more over all the hour demands. Demand is peak especially at morning and early evening for domestic water consumption or residential use. Therefore from results of the above table, Table 5.1; nodes with pressure less than the minimum desirable pressure must be improved to ensure that consumers' demands are provided at all times. By looking for pipes with high velocities and hydraulic gradient during periods of high demand conditions; nodes located far away from the source with lower elevation, are susceptible to lower pressure due to under sized pipe diameter.

Nodes with negative pressures or pressures that drop off significantly during peak hour period for a pressure zone that is served by a pump and/or if there is no storage in the pressure zone (or the storage is located far from the problem area); indicates a pump capacity problem. A comparison of the pump's production with its rated capacity will indicate the problem. Installing another pump in parallel will correct the problem.

Among the reasons for the occurrence of poor pressure in the water supply distribution system might be as result of the following:

- Elevations difference; properties on high ground,
- Remoteness from the source; Far/ remote properties at the end of long lengths of pipe; downstream side,
- Nodes with high demands greater than the design demand; negative Q demand,
- Pipes of inadequate capacity (too small diameter); pipe size,
- Old & rough pipes (e.g. corroding iron pipes or pipes with a build-up of sediment),
- Inadequate capacity of pumps and equipment failures (e.g. pumps and valves).

In contrary minimum pressures are also observed mainly nodes situated near to tanks. In few instances nodes positioned in middle of network are susceptible to low pressure. Whereas majority of nodes located in relative perfect loop receive optimum pressure which does not violet minimum or maximum allowable pressure range. On the other hand, at night time maximum pressure and minimum velocity and leakage rate are expected to be high because at this time no water outflow occurred at the distribution. Pressure distribution during low consumption hour is shown below on Table 5.2.

Table 5.2: Pressure distribution during off-Peak hour demand conditions

Pressure (m H2O)	Nodes (No.)	Percentage (%)
> 80	29	21.17
60-80	25	18.25
20-60	47	34.31
0-20	36	26.28
< 0.00	0	0.00
Total	**137**	**100.00**

During low flow period typically at mid-night; the study area distribution system is marked by excessive pressure. As portrayed in Table 5.2, and detailed in Appendix B2, 39.42% of nodes are liable to extremely high pressure. Minimum pressure is also observed during low consumption period on 26.28% of nodes of the distribution system. There is no node with negative pressure. Only 34.31% of nodes are received water with optimum pressure during low consumption hour in consideration to the design life of the system. As compared to pressures at peak hour Table 5.1, shows 37.96% nodes are within range of permissible pressure due to excessive demand.

Nodal pressure at the minimum consumption hour is very important. The maximum pressure constraints results from service performance requirements such as 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. Limiting the upper bound on pressures would also reduce the leakage losses as well as the pump operating costs. Therefore from results of the above table, Table 5.2; nodes with pressure greater than the maximum pressure must be improved to maintain pressures well below the rated capacities of pipes in order to reduce the leakage losses, pipe breaks, and to safeguard the appliances that derive water directly from the distribution network. Due to above reasons new and existing water supply distribution systems often are designed by taking considerations it as the base parameters. High Pressures during low demand conditions are usually caused by serving customers at too low an elevation for the pressure zone or due to oversized piping main. This problem can be mitigated by establishing a new pressure zone for the lower elevation using system PRVs and/or downsizing the pipe main by rerunning the model for the critical condition for that oversized piping.

Table 5.3 shows that; 5.11% of nodes are experiencing a constant high pressure problem both during peak and low demand hours. This problem can be mitigated by installing regulating valves (throttling PRVs) at upstream side of the problem area to prevent the downstream hydraulic grade from exceeding a set value in order to avoid pressures that have damaging effects on the system and/or by replacing the problem area piping with a high-pressure rating pipe. Whereas for those 25.55% of nodes experiencing consistent low pressures for the whole day; this problem is to be corrected by moving the pressure zone boundary so that those customers experiencing constant low pressures to be served from the next higher pressure zone of the system.

Table 5.3: Consistent high and low Pressure distribution during Peak & off-Peak hours

Pressure (m H2O)	Nodes (No.)	Percentage (%)
> 80	7	5.11
< 20	35	25.55

- The modeling of the system as an intermittent system shows a high service values of pressure up to 15bar in gravity distribution main and up to 22 bar in pumped distribution main, which is a characteristic of the intermittent water systems. The highest value of pressure in gravity distribution main line was recorded at the node (SP26) with a value of 14.6bar as shown in figure (5.1). This point of demand located below Belay Zeleke (BZ) Reservoir, with a high difference of level up to (143 meter). The highest value of pressure in pumped distribution main was recorded at the node (J-74) with a value of 22.05bar as shown in figure (5.2). This point of demand is located near to the pump station (AAWSA Main Office (MO) Pump station), with a low difference of level up to (3.5 meter). Such high values of pressures are registered at nodes (RK-7, RK-8, B8, E14, RK-21, RK-22), and presented in figures (5.3), (5.4), (5.5), (5.6), (5.7), (5.8). These nodes of demand located at different locations in the distribution system.

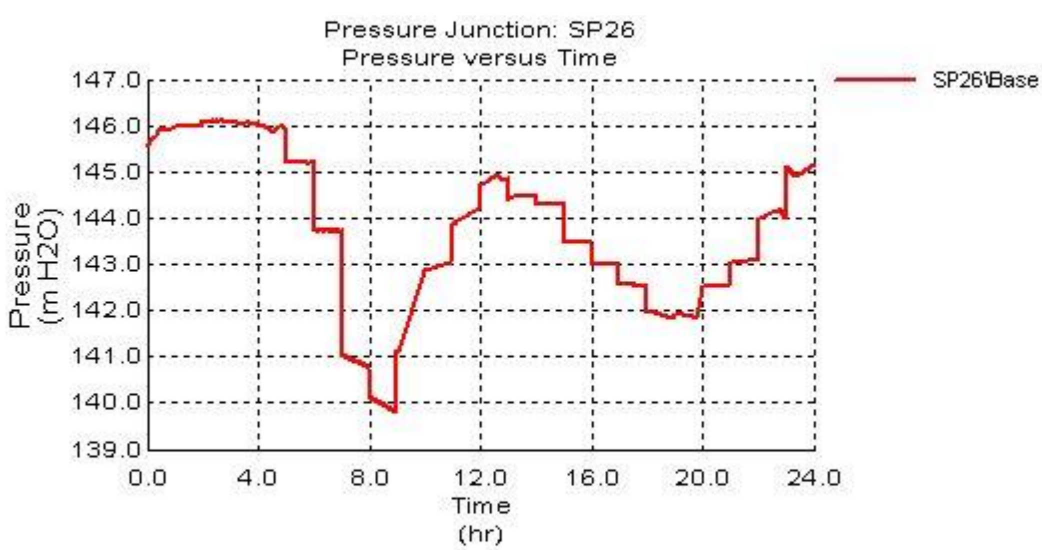


Figure (5.1) Pressure versus Time at Junction: SP26 - along Gravity main of Belay Zeleke Reservoir (BZ) near to AAWSA Main Office Reservoir (MO)

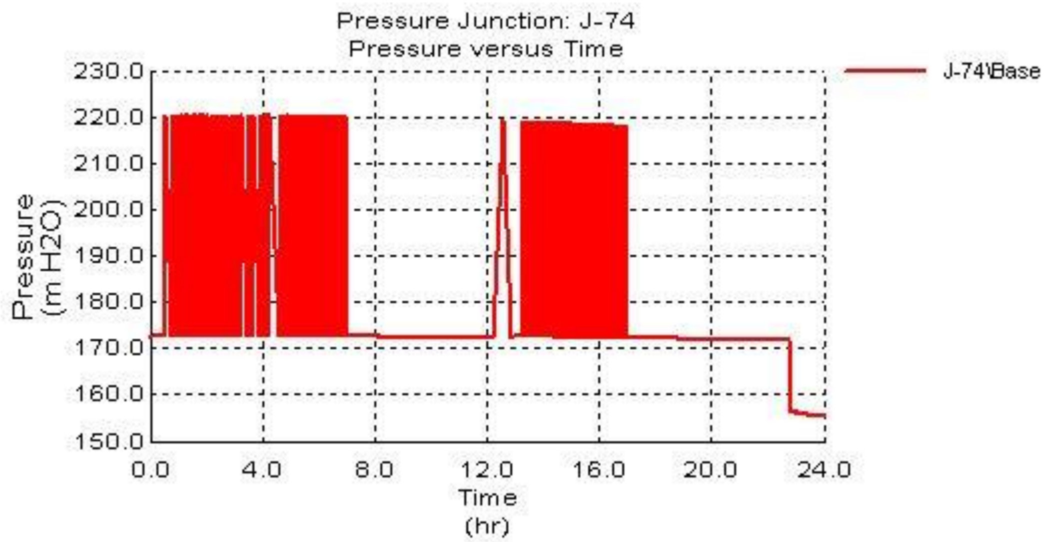


Figure (5.2) Pressure versus Time at Junction: J-74 – near to AAWSA Main Office Reservoir (MO) along Pressurized line from AAWSA Main Office pump station to Belay Zeleke Reservoir (BZ)

- When an evaluation between the pressure values at the nodes illustrated in figures (5.3), (5.4), (5.5), (5.6), (5.7), (5.8) has been done, it is noticeable that the decreasing of pressure at the nodes far away from the source of supplying water is more obvious than for those nodes nearest to the sources, also the range of difference between the maximum and minimum values of pressures at the nodes far away from the sources is large and reaches a value of zero pressure as shown in figures (5.3), (5.4).

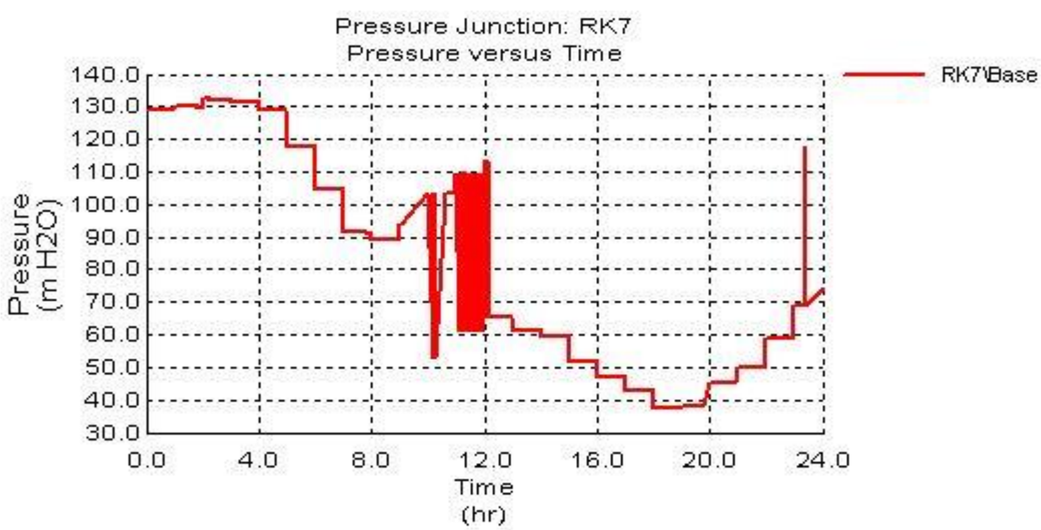


Figure (5.3) Pressure versus Time at Junction: RK7 – along Pressurized line from Ras Kassa Reservoir (RK) to Ras Kassa sub-system far above from Ras Kassa pump station

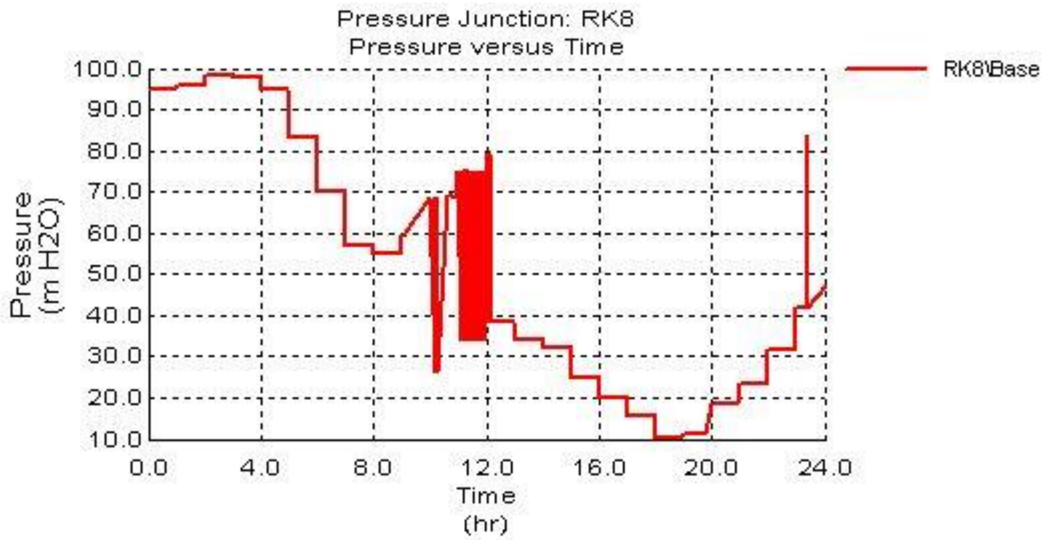


Figure (5.4) Pressure versus Time at Junction: RK8 – along Pressurized line from Ras Kassa Reservoir (RK) to Ras Kassa sub-system far above from Ras Kassa pump station

- The range of difference between the maximum and minimum values of pressure at nodes nearest to the sources is small in comparison to the difference for the farthest nodes, as shown in figures (5.5), (5.6).

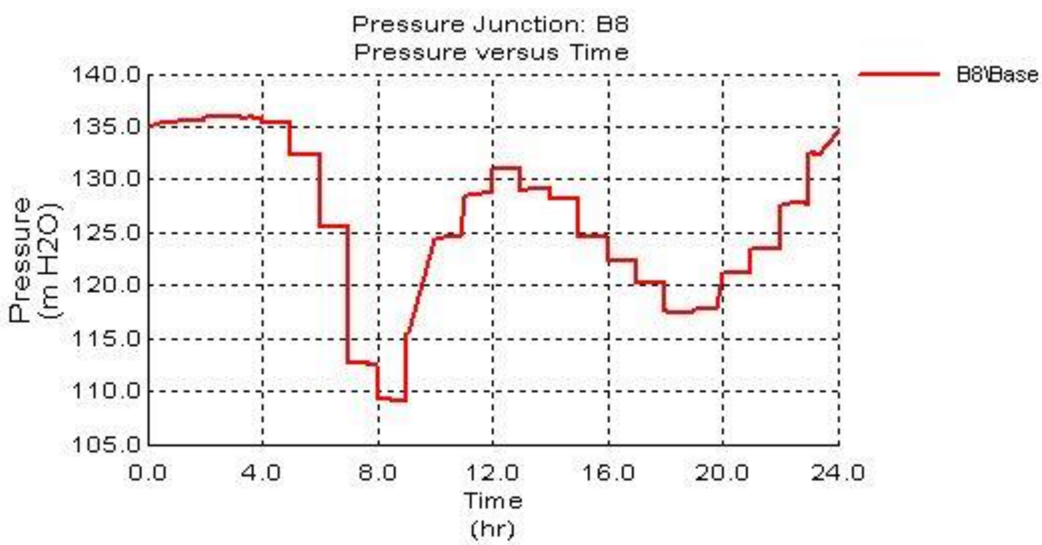


Figure (5.5) Pressure versus Time at Junction: B8- along Pressurized line from Belay Zeleke Reservoir (BZ) to Belay Zeleke sub-system just near to Belay Zeleke pump station (BZ)

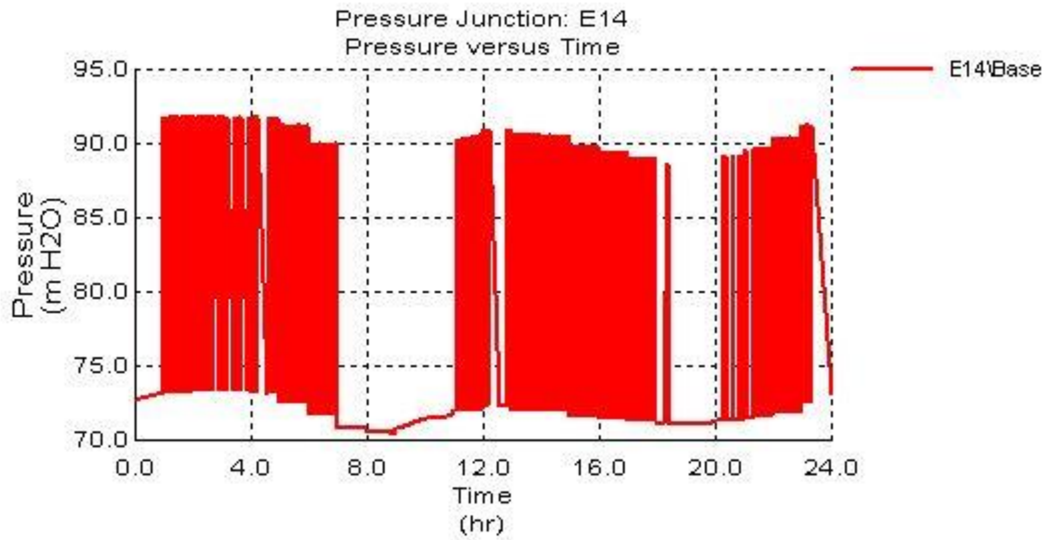


Figure (5.6) Pressure versus Time at Junction: E14– along Pressurized line from Entoto R2 Reservoir to Upper Entoto R3 Reservoir just near to Entoto R2 pump station

- Figures (5.7), (5.8) illustrate the variation of pressures at nodes (RK-21) and (RK-22) which are located far away from the sources, and have a 24 water supply. There is a wide range of difference between pressure values and these values decrease to the levels less than zero.

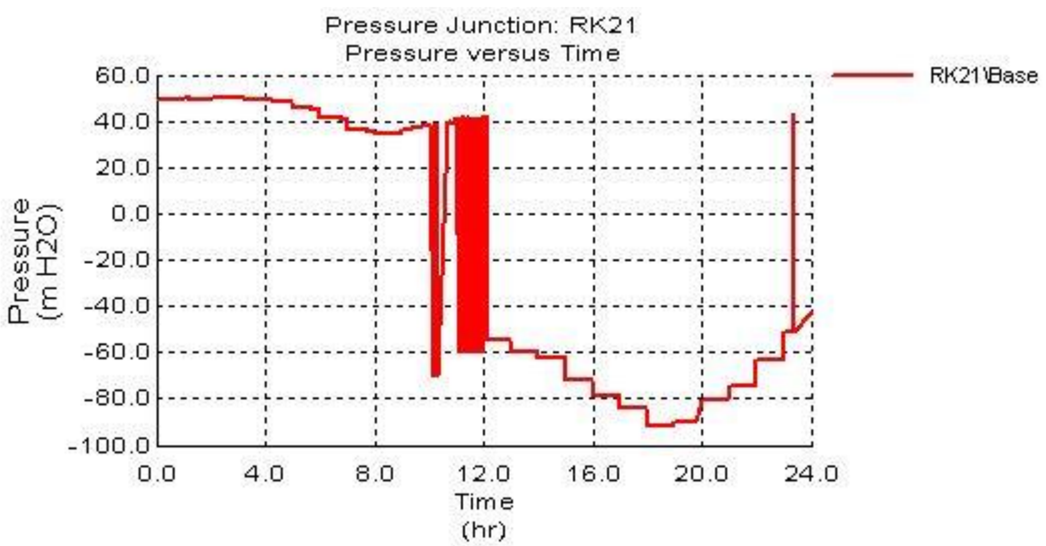


Figure (5.7) Pressure versus Time at Junction: RK21 – along Gravity main from Ras Kassa Reservoir (RK) to Ras Kassa sub-system, far below from Ras Kassa Reservoir (RK)

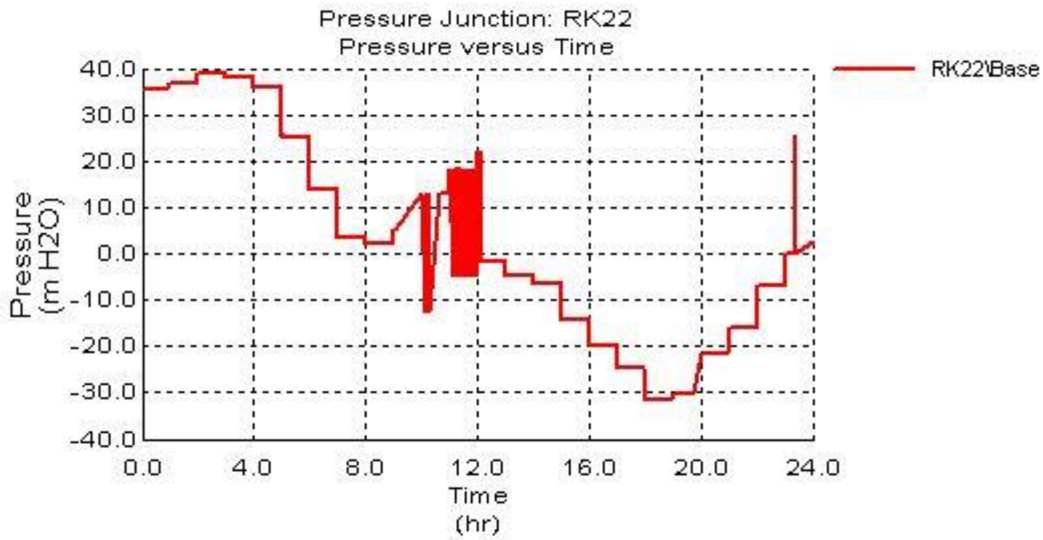


Figure (5.8) Pressure versus Time at Junction: RK22 – along Gravity main from Ras Kassa Reservoir (RK) to Ras Kassa sub-system, far below from Ras Kassa Reservoir (RK)

- Large set of demand points in the distribution system shows a high values of pressures as it is observed under Appendix B1 & B2, which contain the results of consumptions, and pressures at nodes at different times and supply periods.

- One of the main causes of high values of pressure in the system is the wide range of levels between the sources of water (reservoirs) and the consumption nodes; also the absence of pressure reducing valves to counteract the high pressure from the reservoirs and/or pump stations contributes in increasing this problem of high pressures in the system. as shown in figures (5.9), (5.10), which illustrate the pressure at the nodes (J-101), (J-68), that are located near to Ras Kassa (RK) and Entoto (EN) pump stations respectively, with a low difference of level up to (3.0 and 3.5meters) respectively.

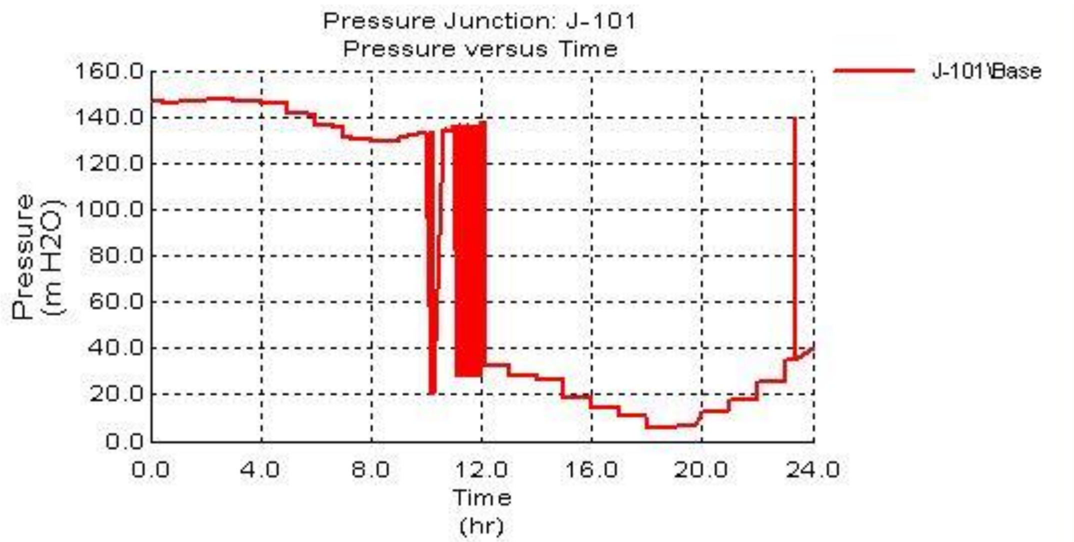


Figure (5.9) Pressure versus Time at Junction: J-101 – along Pressurized line from Ras Kassa Reservoir (RK) to Ras Kassa sub-system just near to Ras Kassa pump station

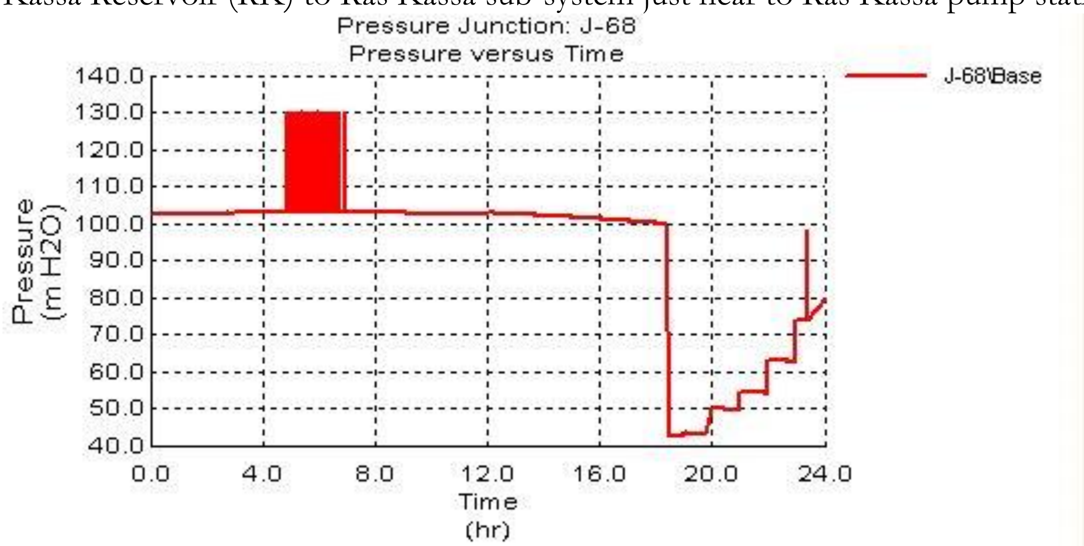


Figure (5.10) Pressure versus Time at Junction: J-68 – along Pressurized line from Entoto Reservoir (EN) to Entoto R1 Reservoir just near to Entoto pump station

- It is obvious from Appendix B1 & B2, that the high values of pressure appear at the nodes nearest to the sources of water, and/or have a clearly difference of levels. Also they have a 24 water supply services.
- The values of pressure at the consumption nodes are not fixed, and varying with time, because the demand pattern, which has been adopted in modeling the

intermittent supply system, is not fixed, and represents the demand at the roof tank. The losses and demands at the system are varying with time due to the demand pattern also.

- The change setting valves in the distribution system to provide the needed amounts of water to the consumers affects the values of pressure in the system, and the closing valves causes increasing the pressure in the system by decreasing the losses in the system.
- These high values of pressure may affect adversely the hydraulic performance of the water distribution network. Also they produce high velocities, which accelerate the deterioration and corrosion of the pipes in the distribution system.
- For the parts of the system that are located far away from the sources, or have high elevation, it is clearly obvious that they are suffering from low-pressure values or even zero values of pressure. This emphasizes the hypothesis (assumption), which states that there is a wide range of variations in pressure values in the intermittent systems.
- The normal pressure values in residential areas ranges between 3.0-4.0 bars. This means that the 14.6 bars recorded at Junction (SP26) at time 2 hr. after the beginning of the supply period is about 4.17 times the normal pressure value in a distribution system. Thus the network will be under excessive pressure during the period of supply and will release to zero pressure during non-supply periods, and this type of loading will affect the life of pipes and increase the leakage and breakage rates.
- When a comparison between the demand figures and the pressure progress has been done, it is concluded that when the demand values increase, there will be a decrease in pressure values as shown in figures (5.11), (5.12), which illustrate the demand and pressure at the nodes (E2).This is because, the increasing of losses and demand in the distribution system will decrease the values of pressure.

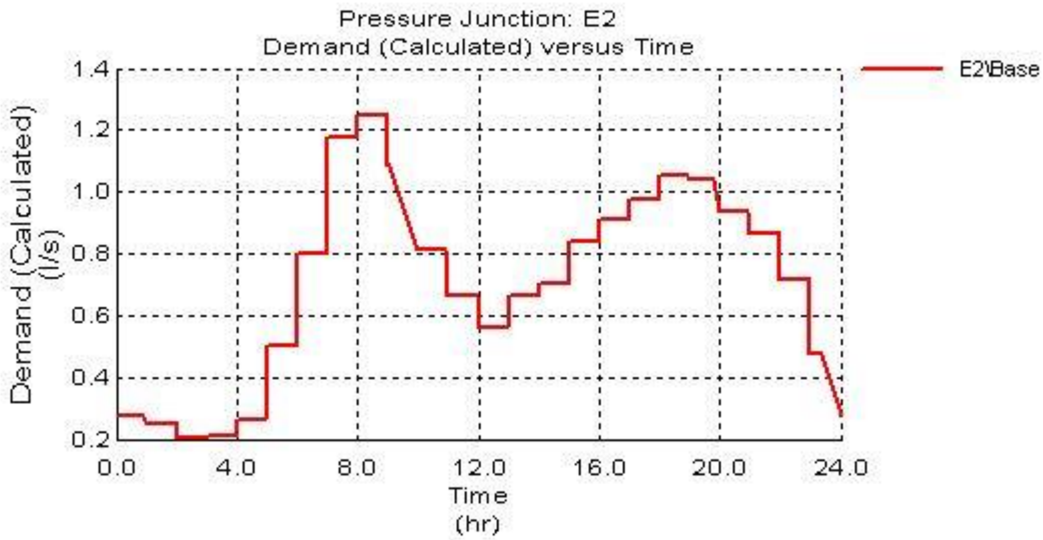


Figure (5.11) Demand versus Time at Junction: E2 – along Gravity main from Upper Entoto R3 Reservoir to Upper Entoto sub-system

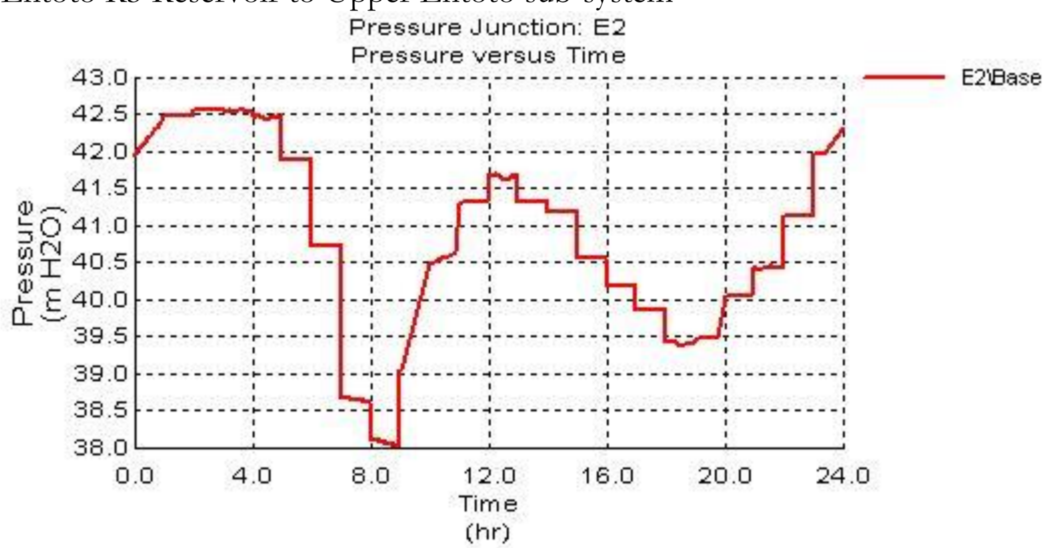


Figure (5.12) Pressure versus Time at Junction: E2 – along Gravity main from Upper Entoto R3 Reservoir to Upper Entoto sub-system, near below Entoto R3 Reservoir

- The local service pressures have a certain influence on demands and losses in the network. Higher pressures lead to increase consumption and losses, and vice versa. Also it is reasonable to conclude that the consumer far away from the supply points will need to be more patient because the refilling of their roof tanks will start later and go slower than for those nearest to the sources points.

- The negative or zero values of pressures at the consumption nodes as shown in Appendix B1 & B2; is an indication of presence control for the pipes supplying these nodes at this moment, e.g., the consumption node (SP27) is closed at time 6hr and will be open at time 24hr, that cause zero or negative value of pressure at this time.

Table 5.4: Pressure versus Time at Junction: SP27

No.	Node Label	Elevation (m)	Demand (l/s)	Demand (Calculated) (l/s)	Calculated Hydraulic Grade (m)	Pressure (m H2O)
78	SP27	2,491.00	0	0	2,491	-0.48
78	SP27	2,491.00	0	0	2,514	23

- Zero values of discharges in the pipes as shown in Appendix B3 & B4, which illustrate the discharges and velocities in the pipes at different times of supplying water, are also indicating to the presence of control for the pipes at this moment. It is obvious at the pipe (P-507) at time 6 hr., which providing water for junction (SP27).

Table 5.5: Discharge versus Time on Link: P-507

No.	Link Label	Length (m)	Diameter (mm)	Material	Initial Status	Control Status	Discharge (l/s)	Headloss Gradient (m/Km)	Velocity (m/s)
109	P-507	1,641.96	500	DI	Open	Temporarily Closed	0.00	0.00	0.00
109	P-507	1,641.96	500	DI	Open	Open	271.68	5.52	1.38

- The negative sign of discharges as shown in Appendix B3 & B4 is an indication to the wrong in assuming direction of flow through pipes in the distribution system.

Velocity of water flow in a pipe is also one of the important parameters in hydraulic modeling performance evaluation of the efficiency of water supply distribution and transmission line. Generally, flow velocity in water supply system shall be in the range of 0.6m/s to 3m/s depending on pipe sizes to avoid stagnation and to limit head loss which varies in squared proportion to velocity. Velocity distribution is also varying with demand pattern changes. At the peak hour demand the values are different as compare to minimum consumption hour. The study area water supply system network velocity distribution during peak hour demand is summarized in the Table 5.6.

Table 5.6: Velocity distribution during Peak hour demand conditions

Velocity (m/s)	Pipes (No.)	Percentage (%)
> 2.5	11	5.39
0.6-2.5	98	48.04
< 0.6	95	46.57
Total	**204**	**100**

As depicted in Table 5.6, during the peak hour demand situations about 5.39% of pipes are failed to satisfy the permissible velocity or maximum velocity in distribution and transmission line (>2.5m/s), in addition to that, 46.57% of pipes also below the minimum velocity of 0.6m/s. While, only 48.04% of pipes are in the permissible velocity ranges. Improving or upgrading the existing water supply distribution is considered through checking of the velocity minimum and maximum limit based criteria. For this study velocity is considered as criteria for resizing the pipe diameter.

- The intermittent model shows high values of velocities, and this result is a suspected outcome of the intermittent systems due to the high pressures in the system. The largest registered velocity is 6.32 m/s at Pipe (P-470), and this value is larger than the design values of velocities (1.2 m/s - 2.0 m/s), which are used to determine the most economic diameters by (5.27-3.16) times, and at the same time it's larger than the absolute minimum velocities (0.1 m/s - 0.3 m/s), that have to be avoided in order to prevent stagnation and water quality problems in the water systems by (63.2 - 21.07) times. These high velocities will affect adversely causing pipe deteriorations.

Table 5.7: High Velocity values registered on Links

Link Label	Length (m)	Diameter (mm)	Material	Initial Status	Control Status	Discharge (l/s)	Head loss Gradient (m/Km)	Velocity (m/s)
P-470	472.74	150	DI	Open	Open	111.68	455.91	6.32
P-465	1,365.20	150	DI	Open	Open	-100.38	374.18	5.68
P-970	868.07	150	DI	Open	Open	-81.83	210.85	4.63
P-582a	15.54	90	DI	Open	Open	28.90	558.52	4.54
P-466	1,165.25	150	DI	Open	Open	-78.53	195.37	4.44
P-755	833.32	200	DI	Open	Open	138.84	168.03	4.42
P-969	996.39	150	DI	Open	Open	-75.89	183.38	4.29
P-968	984.2	150	DI	Open	Open	-67.62	148.12	3.83
P-671	1,195.12	200	PVC	Open	Open	113.10	79.26	3.60
P-481	63.09	350	DI	Open	Open	251.35	27.18	2.61
P-673	617.83	150	Galvanized iron	Open	Open	-45.62	108.02	2.58

Modeling is helpful in pinpointing the cause of hydraulic efficiency problems. In general the study area of water distribution system has the following major problems with respect to hydraulic performance as mentioned below:

- Undersized and oversized service pipe diameter,
- Low and High pressure,
- High and Low velocity.

Undersized pipes can usually be found by looking for pipes with high velocities. Increasing the diameter of the pipe in the model should result in a corresponding decrease in velocity and increase in pressure.

No fixed rule exists regarding the maximum velocity in a main (although some utilities do have guidelines).The optimal velocity in pumped lines can range from 1 to 3 m/s, depending on the relative size of the peak and average flow rates (Desalegn,2005). When checking designs for permissible velocities some engineers use 1.5 m/s as a maximum, other use 2.4m/s, and yet still others use 3.1m/s.

Consistent low pressure problem is due to trying to serve customers at too high an elevation for that pressure zone.

High pressures are usually caused by serving by serving customers at too low an elevation for the pressure zone. Usually, high pressures are easiest to evaluate with model runs at low demands. This range corresponds to minimum night time demands for a typical system. If the pressures are too high, the usual solution is to establish a new pressure zone for the lower elevation using PRVs.

5.2 Model Performance Evaluation

In order to calibrate and validate the models and for comparison purposes, some quantitative information is required to measure model performance. In this study, the pressure data measured at selected three points of the system was used to assess the model performance. The performance assessment was based on the measured and simulated data by model, the agreement of the overall the time series of pressure the value of the statistical performance indices (Vanlewi, 2003., Nash, 1970., Legates, 1999) such as the degree of accuracy (error of difference) and the goodness of fit tests (R^2) are two techniques to be considered for calibration model test as mentioned below.

1. Measure of goodness-of-fit of linear regression

Coefficient of determination (R^2): is a fraction between 0.0 and 1.0, and has no units. R^2 value of 0.0 means, knowing X does not help to predict Y. There is no linear relationship between X and Y, and the best-fit line is a horizontal line going through the mean of all Y values. When R^2 equals 1.0, all points lie exactly on a straight line with no scatter. Knowing X lets you predict Y perfectly (Motulsky, 2007).

Coefficient of determination (R^2) describes the degree of co-linearity between simulated and measured data. The coefficient of determination (R^2) value is determined with Equation (5.1), which ranges between 0 and 1, describes the proportion of the variance in the measured data, which is explained by the model, with higher values indicating less error variance. Typically, $R^2 > 0.5$ is considered acceptable (Singh, 2004, Santhi, 2001).

$$R^2 = \left[\frac{\sum_{i=1}^{n}(O_i-\bar{O})(P_i-\bar{P})}{\sqrt{\sum_{i=1}^{n}(O_i-\bar{O})^2}\sqrt{\sum_{i=1}^{n}(P_i-\bar{P})^2}}\right] \quad , 0\leq R^2 \leq 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5.1)}$$

Where,

n- the number of observations in the period under consideration
O_i-, the i-th observed value
$\bar{O}_i$, - the mean observed value
P, - the i-th model-predicted value and i,
P_i, - the mean model-predicted value.

The linear correlation coefficient (R) of observed versus computed pressures as calculated by Equation 5.1 value is at 0.95. The coefficient of determination (R^2) value is 0.95, it indicates that observed and simulated relation is strongly as values tend to 1.

2. Model Calibration Based on Difference Error

The degree of accuracy varies depending on the size of the system and the amount of field data and testing available to the modeler. The degree of accuracy (error of difference) criteria is used to verify the calibration results by comparing the observed versus the simulated pressure values in the system. The following criteria are also adopted from (Bhave, 1998 cited by James G. 2002) to verify the calibration results.

a) An average pressure difference of ±1.5m to a maximum of ± 5.0m for a good data set, and
b) The difference between measured and simulated values should be ± 3.0m with a maximum difference of ± 10m for a "poor" data set.

Finally, calibration readings are conducted on selected critical nodes in order to check whether the out puts of the model are comply to the outputs of the model at the critical points. Accordingly, table 5.8 elaborates calibration readings at these critical nodes versus the model outputs.

Table 5.8: Comparison of calibration readings with model outputs at critical nodes based on degree of accuracy criteria

Time (hr)	Node Label	x	y	Elevation (m)	Observed Pressure (m)	Simulated Pressure (m)	Difference Pressure Error (m)
8:45:00 AM	B4	0469903	1001398	2560	23	26.3	-3.3
	E2	0475547	0999705	2708	39	38.1	0.9
	RK8	0474873	1003218	2538	55	58.2	-3.2
12:00:00 PM	B4	0469903	1001398	2560	40	41.76	-1.76
	E2	0475547	0999705	2708	38.6	41.7	-3.1
	RK8	0474873	1003218	2538	37	39.1	-2.1
						Average	**-2.09**

As shown in Table 5.8, computed values are within an average error of -2.09m pressure simulated to observed values. Hence, the model is acceptable calibrated which is satisfied the setting pressure calibration and validation criteria under average level (average ± 1.5m to the maximum ± 5m).

5.3 Model Validation

In the model validation, the calibrated model is run under conditions differing from those used for calibration and the results compared to field data .If the model results closely approximate the field results (visually) for an appropriate time period, the calibrated model is considered to be validated. Significant deviations indicate that further calibration is required (USEPA, 2005).

- When a comparison has been done between the outputs of the intermittent model and the field measurements which have been done, some of similarity can be observed as it's shown in figure (5.13) and Table (5.9), which illustrates the pressure versus time at Junction (B4).

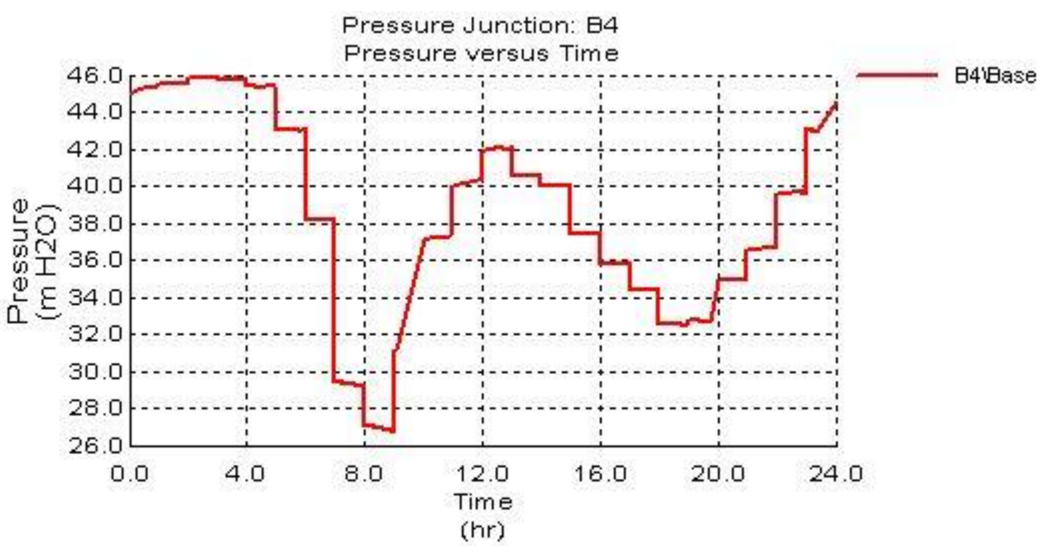


Figure (5.13) Pressure versus Time at Junction: B4 – along Pressurized line from Belay Zeleke Reservoir (BZ) to Belay Zeleke sub-system, far below from Belay Zeleke pump station

Table 5.9: Pressure measurement versus Time (Field measurement) at Junction: B4

Sub System	Gauge Installation Site	Ground Elevation	Gauge Height	Gauge Elevation	Pressure (m)	Time
Belay Zeleke	BZ 1	2560	0.60	2560.60	23	8:45:00 AM

- Generally the outputs of the intermittent model match to some level of accurate with the field measurements from the point view; that the system showing high pressures, and the farthest regions suffering from low pressures, but the complexity of understanding the procedure of managing and operating the Addis Ababa water distribution system, repeated shortcuts of supplying water to the consumers, and the continuous modification and changing of the supplying intervals will appear differences between the field measurements and the theoretical results of modeling the system as intermittent system.

5.4 Results and discussion of the continuous model

The results of continuous model of the study area water distribution network discuss the ability of the existing system with the assumptions and development measures made such as the availability of water, increasing of demand, improving of the low pressure values, reducing the losses and high pressures, to satisfy the requirements of demands, limits of velocities and pressures in order to provide the water by acceptable quantity and quality in the future.

The comparison of results of analysis the proposed model of continuous supply with the assumed limits of velocities which have been established to be (0.1–0.3) m/s. (minimum velocities), and represent the absolute minimum velocities that have to be avoided in order to prevent stagnation and water quality problems, the limits of maximum pressures were set at 80m and the minimum pressure for the main lines at 20m.

The set of design criteria considered for the analysis of pressure and velocity results of the proposed model of continuous supply system is as follows (TAHAL, 2015):

- 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.
- Maximum velocities of major transfer mains < 2.5 m/s.
- Maximum velocities of distribution mains < 2 m/s.
- Head loss gradient (m/km) < 10.
- The absolute minimum velocity of flow in a pipeline is in the range 0.1m/s-0.3m/s, in order to avoid stagnation and water quality problems in the water system (Vairavamoorthy et al 2000).

Ranges of velocity as of Bentley Water CAD/GEMs (2008) are given by

- Typical - 0.6-1.2 m/s
- High - 1.5-2.5 m/s
- Very high - greater than 3 m/s
- Residential - 0.05 m/s

Regarding to the continuous model simulation of the distribution system; detailed results are shown under Appendix B5, and Appendix B6:

- (Appendix B5- Results of Consumptions and Pressures at Nodes, Continuous Model) in detail, and summarized as tabular report on Table 5.10 below.

- (Appendix B6- Results of Pipes Discharge and Velocity, Continuous Model) in detail and summarized as tabular report on Table 5.12 & Table 5.13 below.

Table 5.10: Pressure distribution at nodes in continuous model

Pressure (m H2O)	Nodes (No.)	Percentage (%)
> 80	7	2.98
60-80	49	20.85
20-60	157	66.81
1-20	22	9.36
< 1	0	0.00
Total	**235**	**100**

As depicted in Table 5.10, 87.66% of nodes are under the desirable range for allowable minimum and maximum pressure value (20m-80m) in the system. There is no any node with negative pressure. Excessive high pressure is observed on 2.98% of nodes by exceeding the maximum pressures of 80m. In order to overcome the adverse effect of these high pressures; technical means have been designed. As an economical measure the high pressure effects have been mitigated by use of steel pipes.

There are also a few areas where the static heads are slightly less than 20 m which is equivalent to 9.36% of nodes of the system; these areas include small hills where little or no development has occurred.

- It is obvious from the Table 5.11 and Appendix B5, that high values of pressure appear at the nodes nearest to the sources of water or booster stations as its shown in the intermittent systems which lead us also to conclude that; the consumer far away from the supply points will need to be more patient. Some high values of pressure are specified at the nodes (J28-38:101.4m, J26-13: 90.8m, J22-17: 89.1m, J22-26: 84.1m, J30-4: 82.3m, J22-76: 82.2m, J14-104: 80.9m).
- This type of pressure has a great effect on leakage and water quality degradation; feasible suggestions has been made by replacing the problem area piping with steel pipes, thus eliminating the requirement of high maintenance Pressure Reducing Valves (PRVs), see Table 5.11 for the excessive pressures within the system which is greater than the permissible pressure (80m).

Table 5.11: Excessively high Pressure values in continuous model

Node Label	Elevation (m)	Demand (l/s)	Hydraulic Grade (m/km)	Pressure (m H2O)
J28-38	2590	0	2691.59	101.389
J26-13	2563	0	2653.97	90.785
J22-17	2468	0	2557.23	89.053
J22-26	2473	2.95	2557.31	84.137
J30-4	2664	1.53	2746.42	82.251
J22-76	2475	1.84	2557.36	82.192
J14-104	2370	3.47	2451.04	80.88

- Nodes which are far away from the sources or booster stations and have high levels of elevation are suffered with low pressure values as its shown in Table 5.12, and the registered low pressure values are at the nodes (J12-2: 1.06m, J22-81: 1.1m, J22-6: 1.2m, J12-2: 1.1m, J14-6: 3.0m).

Table 5.12: Excessively Low Pressure values in continuous model

Node Label	Elevation (m)	Demand (l/s)	Hydraulic Grade (m/km)	Pressure (m H2O)
J14-6	2461.5	0	2464.55	3.042
J22-6	2562	0	2563.17	1.172
J22-81	2562	0	2563.1	1.102
J12-2	2417	0	2418.07	1.063

- The results of the pressure values in the whole system as it is detailed under Appendix-B5 and mentioned in the Tables (5.10 - 5.12); show that the ability of the system to satisfy the needed pressures that is necessary with some extreme values neither smaller or larger than the specified values of pressure, and this result leads to suggest the capability of the system to serve the people in the future in the case of adding some developing measures such as: providing the necessary quantities of water, adding new tanks to Entoto & Upper Entoto sub-system near to R1 & R2 tanks, and at Ras Kassa & Upper Ras Kassa sub-systems, put in to operation the existing pumps by adjustments & additions found in the hill areas specifically at Entoto (EN) to feed R1 & RK, at R1 to feed R2, at R2 to feed R3, at RK to feed FC (new tank of the Upper Ras Kassa sub-system), and controlling the high pressures in the system by downsizing of pipelines diameter & using steel pipes.

- The results of the pressure values in the continuous system show the valuable of hydraulic modifications (downsizing of pipelines diameter and adjusting of the pressure zone boundaries) to reduce the high pressure from the reservoirs and limit the pressures in the system to the specified or needed values. This way of managing the system will affect positively the hydraulic performance of the distribution network, especially that it will reduce the losses and velocities in the system and consequently reduce the adverse effects of the high velocities which cause deterioration of the pipes in the system, and save the water meter of the customers from blowing up due to the high pressures.
- The results of velocities in the continuous system, as shown in Table 5.13 and detailed in Appendix-B6, appears a reasonable values of velocities, which are parallel to the assumed limits of velocities to avoid stagnation and quality water problems, also to save the pipes from deterioration due to the high velocities.

Table 5.13: Velocity distribution in continuous model

Velocity (m/s)	Pipes (No.)	Percentage (%)
> 2.5	2	0.59
0.6-2.5	154	45.16
0.3-0.6	97	28.45
0.1-0.3	52	15.25
0.0-0.1	36	10.56
< 0.0	0	0.00
Total	**341**	**100**

As shown on Table 5.13 that shows the evaluation on velocity distribution of water flow in the continuous system, 88.86% of pipes are under allowable maximum and minimum velocity ranges of criteria for transmission, distribution and service main line (0.1m/s-2.5m/s).

Table 5.14: Assessment of Hydraulic gradient in continuous model

Hydraulic Gradient (m/km)	Pipes (No.)	Percentage (%)
≥ 10	7	2.05
< 10	334	97.95
Total	**341**	**100**

Only 2.05% of pipes are failed to satisfy the recommended maximum hydraulic gradient (10 m/km) as summarized on Table 5.14.

All the above results show that by the pipe diameter changing and the adjustments made on the pressure zone boundaries for correcting the impermissible pressure and velocity values to be satisfactory.

- The negative sign of discharges in the pipes shown under Appendix-B6 is an indication to the wrong assumption of direction of flow.

Chapter Six

6. Conclusion and Recommendation

6.1 General

This section gives a detailed emphasis to the conclusions, and proposed solutions that will lead to a better network performance based on results and findings of the studied sub distribution systems.

To assess the current situation of Addis Ababa water supply network; system modeling was found appropriate technique and accordingly modeling efforts were carried out for the case study of Janmeda, Teferi Mekonnen, Belay Zeleke, Entoto and Ras Kassa sub systems. The base of the assessment was evaluating hydraulic performance of the distribution system taking into account the effects of local operating conditions based on results of calibrated and validated model. With intended objectives the study was undertaken and has come with significant outcomes. The research project focused on modeling the study area water supply system as an intermittent supply system and as a continuous system in order to study the effects of the two models on the performance of the system.

6.2 Conclusion

1. For the existing situation of Addis Ababa water distribution system, the following conclusions are extracted from the results presented on the previous chapters:

- **Insufficient availability of water combined with unreliability of sources**

Following to the accelerated growth of population, economy & urbanization of the city; the demand for water increases dramatically. The accelerated demand of the city necessitates for development of additional water sources and supply infrastructures. However, financial capacity of the city is low to develop additional water sources and supply infrastructures to satisfy the ever growing demand. This constraint results to decrease the water supply coverage of the city and of course to widen the gap between supply & demand.

As seen from the computer analysis, the major problem of the existing system is the insufficiency of the water source. The total water use by consumers of the study area sub-system during the year 2018 is estimated to be 84,588.19m^3/d including the UFW, However the study area is supplied with 54,000m^3/day. The demand amounts about 1.57 times the available supply at present. Due to water demand of the system exceeds supplied water quantity; there is a need for additional water to fulfill the supply shortage and demand of the study area water supply system. Also rationing of water in the city during the study period was a common phenomenon.

Moreover, the reduction on production capacity of the sources from their maximum production potential affects the water sources to be unreliable. Among the reasons contributing for this effect are underutilizing the maximum production capacity of sources due to frequent power interruptions, malfunctioning of well pumps, borehole yield depletions, poor quality of boreholes water, repetitive mains break, and poor maintenance practices.

- **Unstructured network made of old pipes**

Addis Ababa is characterized by having old water distribution networks upon which new extensions are linked in order to serve new areas, adding complexity to an aging network. Statistical analysis of the pipe network physical characteristics shows that about 69.6% of the network pipelines serving the study area are older than 30 years, they need be replaced. Moreover, 54.90% and 32.8% of pipes are made of non-mortar lined cast iron and steel pipes respectively, which are easily affected by corrosion. This means, with more than 30 years of continuous operation; increasing the likelihood of leakage, affecting the quality of water conveyed, and diminishes the roughness values of the pipe lines.

- **High level of Unaccounted for Water**

Quantifying the total amount of lost water is achieved by conducting a sub-system-wise water audit, known as a water balance. Audits provide a valuable overall picture about various components of consumption and loss, which is necessary for assessing a utility's efficiency regarding water delivery, finances, and maintenance operations.

The water balance shows 34.31% of UFW, which indicates that, the implementation of poor operational practices and leakage control mechanisms. Deteriorated water distribution pipes and the presence of excessive pressures during supply periods are the main factors for leakage and its frequency. Another cause for water loss is the usage of poor quality of materials and workmanships. Due care should be taken while maintaining existing networks and installation of new ones in this respect. While rehabilitation of any mains is planned, due attention should be given to maintain as well the service connections fed from the mains.

In intermittent supply systems, corrosion, driven by the frequent water/air cycles in high areas seems to weaken the pipes much more than high pressure and results a high water loss in the system even by reduced pressures.

- **Disproportionate Mains**

Inadequate pipe sizes and disproportional mains are spatially distributed in the studied sub distribution system. The undersized pipe diameters and the increased hydraulic losses associated with increased flows are the main reasons for the low pressure problems.

- **Extremely Fluctuation of Pressure**

From the model output; 42.34% of nodes are below the minimum desirable pressures (20m) during peak hour period. Out of this 12.41% of nodes are with a negative pressure. Negative nodal pressures or pressures that drop off significantly during peak hour period indicates a pump capacity problem. Due to this low pressure values the hydraulic performance of the network is affected by precluding the customers to get the desired demand during peak hour periods.

High pressure is also observed during high consumption period on 19.71% of nodes by exceeding the maximum allowable pressures of 60m with respect to the design life of the system. Out of this 5.84% of nodes are with excessive high pressure exceeding the ultimate maximum pressures of 80m. During low flow period typically at mid-night; the study area distribution system is marked by excessive pressure. 39.42% of nodes are liable to extremely high pressure. High pressures are caused by serving customers at too low an elevation for the pressure zone. Due to these high service pressures the hydraulic performance of the network is affected by increasing the rate of main breaks and physical losses (leakage), causing service interruptions, and damaging of valves & water meters.

Also Minimum pressures are observed during low and high consumption periods on 26.28% and 42.34% of nodes of the distribution system respectively. Due to the reduced network pressures water will be failed to reach to customers. Therefore the system hydraulic performance is affected by not fulfilling the water demand of consumers and to have unreliable service.

- **Intermittent supply, which is directly connected to the state of unavailability of water**

Since the water quantity available for supply generally is not sufficient to meet the demands of the population, water conservation measures are practiced to control the water demand through the use of intermittent supplies by operating distribution valves daily to be turned on and off periodically to apportion water in rotation to different areas. The use of intermittent water supplies is usually becoming effect by necessity rather than design. Therefore it is fair to conclude that intermittent supply is directly connected to the state of unavailability of adequate quantity of water to supply and the inadequate capacity of supply facilities.

- **Low service timing /Prolonged period of supply interruption**

Drinking water systems should invariably be operated on continuous pattern for twenty four hours a day. But due to financial constraints it is not practically possible to operate drinking water systems for twenty-four hours a day in developing countries.

The Addis Ababa water supply network is not continuously pressurized. Supplies are provided intermittently with frequency and length of supply interruptions varying between different areas range from intermittent supply to 24hrs supply. The current average service timing of the system ranges (3 – 7) days per week.

The prolonged periods of interruption of supply due to negligible or zero pressures in the system results the system to be affected with high levels of contamination and contributing it part for the current water shortage in the city.

- **Inequitable distribution of the available water**

Experience suggests that implementing a systematic, more focused and integrated water demand management approach/instruments are necessary, but not sufficient to solve the continuous and repeated deficiency in the performance of the Addis Ababa water supply networks in supplying sufficient quantity of water continually & equitably to the consumers which are usually linked to the accelerated demand for water, operational factors, ways of operating and managing the system.

Financial constraint is one of the major factors for the low water coverage of the water supply but poor management of the existing water supply system also has a great impact for the low coverage. Beside to the overall low supply coverage, supply disparity exists among supply zones which creating uneven distribution.

As consequences of operating the water distribution system under intermittent supply conditions; pumps and pipes failing to carry the required water demand during short periods, thus leading to unreliable service and uneven distribution of water.

The water shortage and the topographic conditions of Addis Ababa, forces to divide the water distribution networks in the serving area into several pressure zones through which water is pumped alternatively. The pressure zones division is not designed to operate within a suitably limited range and requiring adjustment. In addition to this, the gradual linking of new extensions on the existing water supply system in order to serve new expansion areas without rehabilitating and upgrading its service components causes the boundaries of the pressure zones to expand beyond their maximum operational static head.

Due to the increased financial and environmental pressures on utilities; efficiency of a Water supply system focuses on better management of the underground assets to improve operational and financial efficiency and reduce leakage and wastage (Larry W. Mays 2004).

Therefore, due to the aforementioned problems of the existing water supply system, the Addis Ababa WDS causes to be less efficient by its high level of UFW and tending the pumps to operate less efficiently & increased the pump operating costs.

2. The intermittent service is the procedure of providing water that is followed in operating most of the water distribution systems in Addis Ababa.

Due to migration of the rural population to urban centers, the city expands rapidly. Such situations result scarcity of water. Since financial capacity of the city is low to develop additional water sources and supply infrastructures to meet the perceived water needs of the inhabitants, necessitate AAWSA to rationing the available water and supply alternatively to different areas with a low per capita supply rate. Therefore the intermittent service is the procedure of providing water that is followed in operating most of the water distribution systems of Addis Ababa.

3. The intermittent supply affects the hydraulic performance of the network and exposes it to high and low pressure and velocities values.

As discussed above, due to the intermittent supply mode of operations (i.e. providing a large number of homes with a high quantity of water in a short period); the system network experiencing oscillating pressure. This fluctuation of pressure affects the distribution system hydraulic performance by causing extended duration of service interruptions, delivering deteriorated quality of water, and service unreliability.

4. The design of water supply systems should consider the effects of intermittent supply on the value of the design factors.

Drinking water systems should invariably be operated on continuous pattern for twenty four hours a day. But due to financial constraints it is not practically possible to operate drinking water systems for twenty-four hours a day in developing countries. Generally a period of eight hours or less is considered adequate to supply the drinking water. Due to present faulty design practice, which is derived from continuous water supply the consumers are deprived of adequate water quantity and pressure. Intermittent water supplies are unique in it-self and need different approach for design and modeling other than the continuous water supplies. Demand of water at particular node is important characteristic in the continuous water supply, but it is SUPPLY of water at a node what drives the intermittent systems. Many factors like charging of water mains at the start of supply each day, ingress of contaminant due to negative pressure, application of peak factors, changing resistance coefficients, equitable water distribution using zoning valves, leakages, etc. are peculiar features of intermittent water supply (World Water & Environmental Resources Congress 2003).

Reduced supply duration is a peculiar feature of the intermittent supply mode of operation, and this factor leads to insufficient water availability for consumers and causes unreliability of the existing distribution systems. These challenges will be exacerbated if the current design practices overlook this fact and assume water availability and appropriateness to provide continuous water supplies. Studying the local conditions of water availability is a necessary step before embarking on the design of new water supply systems to avoid reduced supply duration and the resulting negative impacts. As a result, increased demand multipliers will require increasing the diameters of pipes and capacity of public storage tanks, and thus, construction costs will increase substantially, under the existing conditions of limited financial resources.

Under intermittent-supply conditions, the existing pipelines will have to carry different water quantities depending on the number of supply hours. This leads to increased friction losses (ΔH) or hydraulic gradient (S) and reduced network pressure, and therefore will not fulfill the water demand of all consumers. As a result of reduced network pressure, service will be unreliable: water will fail to reach many consumers, especially those located at higher elevations of the network.

Since it is the storage facilities that provide water during non-supply hours, storage is an important feature of such systems. Because of the low supply rate of water and the intermittent nature of supply, the demand for water at the nodes in the network are not based on notions of diurnal variations of demand related to the consumers behavior (as with networks in developed countries), but on the maximum quantity of water that can be collected during supply hours (Vairavamoorthy, K., Akinpelu, E., Lin,Z., and Ali,M, 2000).

A serious problem arising from intermittent supplies, which is generally ignored, is the associated high levels of contamination. This occurs in networks where there are prolonged periods of interruption of supply due to negligible or zero pressures in the system. The factor that is most related to contamination is duration of supply (Vairavamoorthy, K. et al., 2001).

5. The continuous system shows the ability of the distribution system to cope the future extension in the case of providing the necessary requirements of developing and/or replacing the old pipes, providing the needed quantities of potable water and overcoming the problems of high & low pressures by hydraulic modifications of the distribution system.

The results of the pressure values in continuous system show that about 87.66% of nodes are within the desirable range of allowable minimum and maximum pressure in the system, and the velocity on 88.86% of pipes to satisfy the allowable maximum and minimum range of velocity.

Generally the Pressure based hydraulic performance evaluation of the intermittent system indicates that acceptable minimum and maximum pressure have not been met. During peak hour flow, parts of the distribution system receive water with low pressure and under some circumstances risk of obtaining no water is observed because of the pressure in the distribution system is beyond permissible minimum requirement. In line with this, about one fifth of the distribution system is prone to undesirable pressure which exceeds maximum allowable pressure. As the result, the distribution system is exposed to risks of high leakage and repeated pipe breakage during low flows. Along with this, the intermittent modeling results revealed the existence of both design and operational problems which exceed maximum allowable pressure even during peak hour flow and observed pressures which is lower than the minimum allowable pressure during low flow hours clearly proved the existence of design problems. While the generated excessive negative pressures clearly proved the existence of operational problems.

In general, the simulated hydraulic result indicated that currently the hydraulic performance of study area supply system is not satisfactory. But it doesn’t mean that the supply system is not functional. Rather the frequency of service interruption is relatively high. This interruption is partly contributing for the current water shortage in the city of Addis Ababa.

Therefore, from hydraulic point of view, modeling results showed that, the Janmeda, Teferi Mekonnen, Belay Zeleke, Entoto and Ras Kassa supply system is currently performing in a poor situation. Particularly, the studied subsystems are not maintaining the acceptable minimum and maximum pressure and permissible velocity values.

6.3 Recommendation

6.3.1 General

Performance Evaluation of a water supply system is important to analyze the adequacy and reliability aspect of the complete water supply delivery system for all service areas of a specific community. This means hydraulic performance evaluation of the water delivery system, plus the function of selected components of the water system on its ability to deliver an acceptable quantity and quality of water at suitable pressure to customers with minimum interruption by minimizing the UFW & energy consumptions. Besides measuring the efficiency and effectiveness of the delivery of service, an important part of evaluating water supply systems is to use the results of these assessments to monitor the performance of the water delivery system in relation to the existing/ new water supply services and the constant changes in demand on the water system, and improving the quality of service by determining the water system component which limits the system from meeting its service objectives.

To improve the current situation of the study area supply systems, both design and operational modifications are necessary. From the study undertaken and modeling results the following sets of recommendations are drawn from the above results:

Recommendation for the insufficient availability of water:

Even if AAWSA increases water production capacity of the city from time to time; still there is a huge gap on supply & demand of water due to the supply capacity is not being growing enough in paces with the socioeconomic growth rate of the city.

In order to solve challenges of the water utility like keeping pace with population growth, closing the supply demand gap, ensuring sustainability of existing and news services, and improving the quality of services; AAWSA needs to implement a systematic & integrated approach by giving temporary and permanent solutions through small & big projects to be carried out with in short, medium and long-term periods.

Suggested temporary solutions:

- ✓ Distributing of water to highly water scarce areas by deducting from the areas having supply duration of (12-24) hours.

- ✓ Rehabilitating of the existing reduced yield boreholes found at various pocket areas of the city,
- ✓ Employing an alternative treatment technology for borehole' water with poor chemical content,
- ✓ Drilling new boreholes at different water scarce areas of the city and new settlement areas of the city,
- ✓ Urging major water consumers to develop their own water source (drilling their own borehole) to distribute the city's water equitably to all consumers,
- ✓ Manipulate available supplies to meet perceived water needs & to improve the level of service by install valve regulators in the existing network for equitable distribution,
- ✓ Installing diesel generators on pumping stations and at headwork in order to minimize the situations on production & supply reduction of water due to power interruptions.

Suggested permanent solutions:

In addition to the temporary measures, the authority needs to improve the inadequate quantity of the city's water supply permanently through:-

- ✓ Reducing leakage via continuous leak detection and repair programs, rehabilitating of pipelines & replacing of aged steel pipes, operational & pressure related controls, and implementing an integrated water management hydraulic model by recording of the city water network data with modern GIS database system for decision making on the quantity of water required currently as well as in the future including the pressure required for equitable distribution of water and ensuring healthy of the network.
- ✓ Applying effective water conservation means such as encouraging the community to use water saving rated faucets and flushing mechanisms, and the reuse of wastewater as a source of additional water for outdoor purposes.
- ✓ Implementing various new surface & ground water source development projects and expand on the existing projects, to resolve the shortfall permanently by augmenting the water production capacity of the city to satisfy the demand of the community.
- ✓ By extending the supply hours, etc…

Recommendation for the unstructured network made of old pipes:

Since Performance of a WDS depends on factors like design life of the system; the benchmarks to be considered for performance indicators shall be representative of the system. In this respect, most of the Addis Ababa water distribution pipe networks are put in to operation beyond their life time. The lifetime can be extended or shortened significantly, depending on the service environment and material made of the pipe. If the pipeline works at the proper operating pressure, and is equipped with external and internal protection commensurate with the surroundings and the quality of water conveyed; it should last for approximately 50 years. However, the service life of the pipe is shortened considerably due to the above conditions are not observed. In this context; the 69.6% of pipelines serving the study area for more than 30years, and the 54.90% & 32.8% of non-mortar lined cast iron and steel pipes are definitely not giving a satisfactory service and having a low conveyance capacity due to encrustations, corrosions, and weakened structural integrity all resulting in increasing the likelihood of leakage and affecting the quality of water conveyed. These pipes need to be replaced. Here the rationale being that a change of pipes at this point in time would constitute a considerable burden on the AAWSA budget.

Recommendation for High levels of Unaccounted for Water:

The high levels of Unaccounted for Water (34.31% of System Input Volume) and/or leakage losses (24% of System Input Volume) have a serious impact on AAWSA's finances as well as on available water resources in a water scarce environment.

It is to be noted that it was difficult to reconcile the water balance components with each other during the Real Losses calculation for the study area. It was also seen that available data on Billed Metered Consumption and Water production/supply record in particular may be suspect.

In order to create a database for the statistical analyses of the demand and UFW as a base for further planning and work programming efforts; AAWSA needs to maintain an up to date and correct billing database, water production & supply records, Network map updating, Installation of New bulk flow meters at required locations of the network, regular meter accuracy testing for customer meters & existing bulk flow meters, Periodical network calibration, Implementation of District Metered Areas (DMAs); which in turn are necessary for effective Non-Revenue Water monitoring and control.

Diminishing the UFW with all available means is a major task need to be focused by AAWSA. *It is the cheapest additional water source*. In regard to reducing the present 24% Real (Physical) loss; AAWSA needs to consider pressure management, better active leakage control practices and better network maintenance activities. In addition to this applying other effective water conservation means such as encouraging the use of water saving rated faucets and flushing mechanisms in houses especially that the number of house connection is expected to grow, and the reuse of wastewater as a source of additional water for outdoor purposes are recommended.

Recommendation for Extremely Fluctuation of Pressure:

The pressure at nodes depends on the adopted minimum and maximum pressures within the network, topographic circumstances, and the size of the network (Masri M, 1997). The minimum pressure should be maintained to avoid water column separation and to ensure that consumers' demands are provided at all times. The upper bound on pressure would depend on the pressure rating of the pipe material or the pipe joints. The maximum pressure constraints would also reduce the leakage losses as well as the pump operating costs (Lingireddy, S. and Wood, D.J, 1998).

Based on the established design criteria appropriate technical measures are taken to model the network as continuous system and improving performance of the system as briefed below.

Recommendation for Consistent low Pressure problems:

For the constant problems with low pressure and/or pressure fluctuations in a portion of a system: the best solution is to create or move the pressure zone boundary so that those customers experiencing low pressures will be served from the next higher pressure zone of the system.

Given the topographical layout of the study area and the configuration of the studied sub-systems distribution network; reviewing the pressure zone boundaries for optimal division of the study area existing & extension networks to new expansion areas is required, and pressure zones which serve customers situated in nearly equivalent elevation has to be established. In doing so; each pressure zone will be supplied by an individual dedicated tank sized based on demand calculations, thus eliminating the requirement of high maintenance pressure regulating valves.

Recommendation for low pressure problems:

For nodes with pressure less than the minimum desirable pressure; the pressure needs to improve to ensure that consumers' demands are provided at all times. By looking for pipes with high velocities and hydraulic gradient during periods of high demand conditions; nodes located far away from the source with lower elevations, are susceptible to lower pressure due to under sized pipe diameter.

For nodes located far away from the source with lower elevation and suffered with reduced pressure less than the minimum desirable pressure, by looking for the pipes with high velocities and hydraulic gradient during periods of high demand conditions; the pressure is improved to ensure that consumers' demand is provided at all times by upsizing the pipe diameter serving the respective nodes.

Recommendation for consistent high Pressure problems:

As shown on Table 5.2 for nodes with pressure greater than the maximum pressure must be improved to maintain pressures well below the rated capacities of pipes in order to reduce the leakage losses, pipe breaks, and to safeguard the appliances that derive water directly from the distribution network. Due to the above reasons new and existing water supply distribution systems often are designed by taking considerations the maximum pressure as the base parameter. High Pressures during low demand conditions are usually caused by serving customers at too low an elevation for the pressure zone or due to oversized piping main. This problem can be mitigated by establishing a new pressure zone for the lower elevation areas using system PRVs and/or downsizing the pipe main by re-running the model for the critical condition for that oversized piping.

For those customers located at too low an elevation for the pressure zone and/or having a high elevation difference from the reservoir, and experiencing higher pressure greater than the maximum pressure during low demand conditions; the pressure is improved to maintain pressures well below the rated capacities of pipes in order to reduce the leakage losses, pipe breaks, and to safeguard the appliances that derive water directly from the distribution network. The problem is mitigated by downsizing the pipe main by rerunning the model for the critical condition for the oversized piping. However for the consistent excessive pressure problem both during peak and low demand hours; the adverse effect is solved by replacing the problem area piping with steel pipes, thus eliminating the requirement of high maintenance Pressure Reducing Valves (PRVs).

Recommendation for the effect of water quality due to prolonged period of supply interruption:

AWSA needs to increase it service level by maintaining a high degree of hydraulic integrity through a combination of proper system design, operation, and maintenance. By implementing appropriate measures to improving the negligible or vacuum pressures by extending the supply durations, replacing or improving of pipes, minimizing the unplanned service interruptions due to main breaks or damage to infrastructures, power outages…

AWSA should keep increasing standards for the water supplied to its customers. AAWSA has also the duty to test and preserve the quality of the water, within the WHO Standard, in the reservoirs and in the network.

Regarding to the poor water quality problems resulted due to the prolonged period of supply interruption the following measures may solve the problem:

- ✓ Installing new pipes as to eliminating dead ends and letting water to route in the system is essential. Such an effort contributes reduction in water age. Eliminating dead ends by installing new pipes can significantly reduce the water age.
- ✓ Booster disinfection station has to be established to maintain life guarantee minimum residual chlorine across the distribution system. If implementation of booster disinfection is not possible, local disinfection mechanisms at home level such as use of household chemicals prior to consumption has to be promoted particularly in the rainy season.

6.3.2 System Design

Water supply systems are usually designed and built to make water available under continuous pressure 24 hours a day in order to fully meet demand. In case of water shortage, the supply can be adapted to an intermittent water supply, which serves different users at different times. The components of the water supply system (transport, storage and distribution) have to be designed in order to cope with the strain induced by the shortage of water, but can still deliver the designed flow and pressure.

Designing an intermittent water supply network is often considered when there is a scarcity in total water availability vis-à-vis the net water demand of a considered supply area, or when the hydraulic capacities of the network are too low. Usually water supply networks are designed for continuous conditions: the water system should be operated the way it has been designed to in order to approach equitable and efficient water distribution. However, efforts should go towards transition to continuous systems through technical, social and policy measures, even when water resources are low: less water is wasted with continuous systems, and proper demand management optimizes the resources better than distribution restrictions.

In intermittent systems, the pumping capacities need to be much higher as to run almost continuously with a high rate, and storage capacities also need to be extended. The water transmission system must be adapted to low pressures by enlarging pipe diameters to reduce pressure loss.

6.3.3 Operation and Maintenance

Intermittent water supply requires much more valve operations, requiring more operators to fill the water tanks and direct water towards the appropriate zones. The flow rates are high and the pressures low: more control is also necessary to bring equitable supply. Corrosion and pressure variations make more frequent maintenance necessary on the pipes, joints and valves. Pumps are also more solicited than for continuous supply. Maintaining residual chlorine in water is necessary to try to avoid re-contamination coming with the percolation of extraneous substances out of supply hours.

Other operational difficulties arise and maintaining water quality may be problematic. Poor quality of water through taps at the beginning of supply period due to the intrusion of contaminants by the vacuum pressure created during the non-supply hours. Moreover the water quality problems are associated with infiltration and poor asset conditions. The operation of valves needs to minimize the risk of subjecting parts of the network to vacuum pressures which could cause groundwater infiltration and contamination of the network. This is a specific problem for branch mains off principal feed mains where valves are operated to shut-off or re-open supplies and where a service reservoir is allowed to drain down and empty during each supply cycle resulting in the network also emptying by draining to the lowest point.

6.3.4 Cost Considerations

Maintenance costs are higher in intermittent supply systems: the pipes are alternately exposed to air and water and corrode faster. They need to be repaired and changed more often to control leakage and avoid bursts. Operation costs, i.e. pumping costs, are also higher since pumps work for long hours to fill storages, whereas they only balance consumption when needed in continuous systems.

Because of the poor service provided and the low quantities of water sold, tariffs are often low in such systems. Low tariffs add to problems related to excessive pumping, since utilities that lack funds struggle to meet operating and maintenance costs if there are long pumping hours. No money is then available to invest in adapted infrastructures to extend the network and its supply hours. This cycle is hard to break without reducing leakage and rehabilitating pipelines. Non-revenue water is a major parameter since illegal pumping, leaks and non-metered or free water drastically reduce the income. Planned augmentations should improve the water supply system to meet the total demand and extend supply hours.

When the service improves, higher tariffs can be applied. These are well accepted once consumers are aware that intermittent supplies are not the norm, and that a better service can be achieved.

6.3.5 From intermittent to continuous water supply system

Introducing equitable costs, reducing leakage and installing proper storage can be the beginning of continuous water supply. Higher tariffs are to be set for 24-hours supply zones, as long as they are fully equipped with exact water meters, while the whole network's expansion is stopped. Little by little, 24-hours supply zones are to be enlarged, and the number of connections too. It is to be noticed that technical solutions are not to be addressed before water policy and governance are adapted. A most important thought to bear in mind is that the water quantity does not need to be bigger with a continuous water supply.

This research has generated several significant results. The existing system was modeled to provide deeper understanding of the current situation of water distribution network system. Subsequently valuable suggestions were drawn based on findings to improve the performance and increasing the efficiencies of the water distribution systems. However, for more comprehensive and detailed understanding of the Addis Ababa WDS, future works are suggested:

1. Specialized software should be developed to model the behavior of the intermittent systems of the Addis Ababa water distribution network.
2. More local studies are recommended. This is to understand how the water systems in our city perform under the local conditions of operation and management.
3. The universal peak factors which are used in the design of water distribution systems should be modified and adjusted in the design of new water systems in Addis Ababa according to the local conditions of operating and managing the distribution networks.

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APPENDICES

Appendix A – Model Input Data

Appendix A1 – Current Consumption and Nodes in the Study area water System.

No.	Node Label	Elevation (m)	Population (number)	Consumption per capita	Consumption/node (l/s)	Operation factor
1	L121	2,402.00	0	145	0	1.73
2	L125	2,404.00	0	145	0	1.73
3	L130	2,402.00	0	145	0	1.73
4	J-131	2,427.00	369	145	1.07	1.73
5	J-124	2,420.00	7681	145	22.3	1.73
6	J-27	2,400.00	0	145	0	1.73
7	J-28	2,460.00	0	145	0	1.87
8	J-29	2,460.00	0	145	0	1.87
9	J-30	2,460.00	0	145	0	1.87
10	J-31	2,460.00	0	145	0	1.87
11	J-32	2,460.00	0	145	0	1.87
12	J-33	2,460.00	0	145	0	1.87
13	J-35	2,460.00	0	145	0	1.87
14	J-36	2,460.00	0	145	0	2.05
15	J-37	2,460.00	0	145	0	1.87
16	J-38	2,460.00	0	145	0	1.87

17	J-39	2,460.00	0	145	0	1.87
18	J-40	2,460.00	0	145	0	1.87
19	J-41	2,460.00	0	145	0	1.87
20	J-42	2,460.00	0	145	0	1.87
21	J-43	2,460.00	0	145	0	1.87
22	J-44	2,460.00	0	145	0	1.87
23	J-45	2,507.00	0	145	0	1.95
24	J-46	2,507.00	0	145	0	1.95
25	J-47	2,507.00	0	145	0	1.95
26	J-48	2,507.00	0	145	0	1.95
27	J-49	2,507.00	0	145	0	1.95
28	J-50	2,507.00	0	145	0	1.95
29	J-51	2,507.00	0	145	0	1.95
30	J-52	2,507.00	0	145	0	1.95
31	E15	2,564.00	825	145	2.7	1.95
32	J-133	2,432.00	369	145	1.07	1.73
33	J-132	2,433.00	369	145	1.07	1.73
34	T7	2,473.00	2205	145	6.92	1.87
35	T12	2,512.00	1020	145	3.2	1.87
36	T9	2,459.00	2693	145	8.45	1.87
37	SP15	2,490.00	457	145	1.41	1.84

38	T13	2,510.00	1020	145	3.2	1.87
39	T1	2,469.00	1657	145	5.2	1.87
40	B14	2,536.00	13226	145	47.5	2.14
41	J-63	2,560.00	0	145	0	1.95
42	J-64	2,560.00	0	145	0	1.95
43	J-65	2,560.00	0	145	0	2.47
44	SP16	2,490.00	457	145	1.41	1.84
45	J-67	2,560.00	0	145	0	2.47
46	J-68	2,560.00	0	145	0	2.47
47	J-79	2,340.00	0	145	0	1.73
48	J-90	2,637.00	0	145	0	2.61
49	E13	2,637.00	669	145	2.93	2.61
50	J-92	2,682.00	0	145	0	2.71
51	E14	2,682.00	580	145	2.64	2.71
52	J-118	2,423.00	524	145	1.52	1.73
53	J-138	2,390.00	15706	145	45.6	1.73
54	J-127	2,387.00	58553	145	170	1.73
55	J-123	2,376.00	4305	145	12.5	1.73
56	J-125	2,418.00	34443	145	100	1.73
57	J-126	2,418.00	7894	145	22.92	1.73
58	J-129	2,411.00	2594	145	7.53	1.73

59	J-122	2,386.00	2597	145	7.54	1.73
60	J-120	2,371.00	1991	145	5.78	1.73
61	J-121	2,366.00	1994	145	5.79	1.73
62	J-115	2,405.00	1643	145	4.77	1.73
63	J-130	2,425.00	369	145	1.07	1.73
64	J-116	2,405.00	761	145	2.21	1.73
65	J-117	2,406.00	765	145	2.22	1.73
66	J-84	2,410.00	0	145	0	1.73
67	J-134	2,411.00	465	145	1.35	1.73
68	J-119	2,431.00	530	145	1.54	1.73
69	T3	2,440.00	3833	145	12.03	1.87
70	T11	2,410.00	2693	145	8.45	1.87
71	T4	2,435.00	1877	145	5.89	1.87
72	T8	2,472.00	2205	145	6.92	1.87
73	T10	2,472.00	1743	145	5.47	1.87
74	T5	2,455.00	1743	145	5.47	1.87
75	T6	2,460.00	1877	145	5.89	1.87
76	IC5	2,437.00	1426	145	3.71	1.55
77	IC1	2,472.00	1426	145	3.71	1.55
78	SP27	2,491.00	0	145	0	1.84
79	T19	2,430.00	1877	145	5.89	1.87

80	RK22	2,431.00	4630	145	15.23	1.96
81	J-144	2,364.00	8642	145	25.09	1.73
82	RK7	2,511.00	222	145	0.73	1.96
83	J-87	2,404.00	0	145	0	1.73
84	RK20	2,500.00	459	145	1.51	1.96
85	RK15	2,522.00	237	145	0.78	1.96
86	J-143	2,423.00	1636	145	4.75	1.73
87	J-112	2,346.00	4416	145	12.82	1.73
88	J-106	2,355.00	4812	145	13.97	1.73
89	E1	2,734.00	580	145	2.64	2.71
90	E4	2,635.00	3450	145	14.3	2.47
91	J-128	2,385.00	4240	145	12.31	1.73
92	J-109	2,385.00	1267	145	3.68	1.73
93	E3	2,673.00	874	145	3.83	2.61
94	J-141	2,432.00	524	145	1.52	1.73
95	RK21	2,490.00	2283	145	7.51	1.96
96	J-108	2,353.00	789	145	2.29	1.73
97	J-110	2,417.00	2659	145	7.72	1.73
98	E2	2,708.00	275	145	1.25	2.71
99	RK8	2,538.00	225	145	0.74	1.96
100	E16	2,547.00	1403	145	4.59	1.95

101	RK14	2,523.00	234	145	0.77	1.96
102	RK10	2,553.00	225	145	0.74	1.96
103	J-142	2,424.00	1639	145	4.76	1.73
104	L109	2,345.00	486	145	1.41	1.73
105	J-107	2,379.00	9909	145	28.77	1.73
106	J-86	2,434.00	0	145	0	1.73
107	J-113	2,403.00	2036	145	5.91	1.73
108	G1	2,364.00	4801	145	15.31	1.9
109	RK9	2,588.00	985	145	4	2.42
110	J-137	2,390.00	462	145	1.34	1.73
111	RK13	2,520.00	1064	145	3.5	1.96
112	J-105	2,358.00	5569	145	16.17	1.73
113	J-111	2,397.00	1636	145	4.75	1.73
114	J-135	2,390.00	462	145	1.34	1.73
115	J-136	2,390.00	465	145	1.35	1.73
116	J-114	2,417.00	1646	145	4.78	1.73
117	IC7	2,441.00	3210	145	8.35	1.55
118	J-139	2,373.00	4447	145	12.91	1.73
119	J-140	2,365.00	3196	145	9.28	1.73
120	T15	2,497.00	3524	145	11.06	1.87
121	T14	2,492.00	3524	145	11.06	1.87

122	T16	2,447.00	3744	145	11.75	1.87
123	T17	2,454.00	3744	145	11.75	1.87
124	T18	2,459.00	1743	145	5.47	1.87
125	E12	2,560.00	1830	145	5.99	1.95
126	J-101	2,545.00	0	145	0	1.96
127	J-74	2483.00	0	145	0	2.14
128	B8	2636.00	607	145	2.18	2.14
129	B1	2706.00	1835	145	6.59	2.14
130	B7	2631.00	607	145	2.18	2.14
131	B13	2595.00	1041	145	3.74	2.14
132	B4	2593.00	6716	145	24.12	2.14
133	SP26	2493.00	1392	145	5	2.14
134	B9	2582.00	958	145	3.44	2.14
135	B10	2600.00	11834	145	42.5	2.14
136	J-104	2615.00	0	145	0	2.14
137	B11	2610.00	741	145	2.66	2.14

Appendix A2 – Links in the Study area water distribution system

No.	Link Label	From Node	To Node	Length (m)	Diameter (mm)	Material	Hazen-Williams C	Construction Year
1	P-30	L121	Jan Meda	7,549.90	900	DI	120	1985
2	P-40	TR1	L125	23.77	500	Steel	100	1985
3	P-57	J-27	TR2	15.85	1,000	Steel	100	1985
4	P-62	J-31	JM3	11.58	300	Steel	100	1985
5	P-63	JM3	J-30	14.63	250	Steel	100	1985
6	P-65	J-31	J-32	12.8	600	Steel	100	1985
7	P-66	J-32	J-28	13.11	600	Steel	100	1985
8	P-67	J-29	J-33	12.5	300	Steel	100	1985
9	P-68	J-33	J-30	12.5	300	Steel	100	1985
10	P-69	J-32	JM4	12.19	300	Steel	100	1985
11	P-70	JM4	J-33	14.02	250	Steel	100	1985
12	P-71	J-28	JM5	12.8	300	Steel	100	1985
13	P-72	JM5	J-29	14.02	250	Steel	100	1985
14	P-75	J-35	J-31	16.46	600	Steel	100	1985
15	P-77	JanMeda	J-37	19.51	600	Steel	100	1985
16	P-78	J-37	J-35	15.85	600	Steel	100	1985
17	P-80	J-38	J-36	14.02	250	Steel	100	1985
18	P-79	J-37	JM1	13.11	300	Steel	100	1985
19	P-81	JM1	J-38	15.54	250	Steel	100	1985

20	P-82	J-35	JM2	12.8	300	Steel	100	1985
21	P-83	JM2	J-36	13.72	250	Steel	100	1985
22	P-84	J-36	TM	1,782.47	400	DI	100	1985
23	P-88	JanMeda	J-42	22.86	350	Steel	100	1975
24	P-89	J-42	J-43	16.76	350	Steel	100	1975
25	P-91	J-43	J-39	19.51	350	Steel	100	1975
26	P-92	J-40	J-44	19.81	250	Steel	100	1975
27	P-93	J-44	J-41	17.68	250	Steel	100	1975
28	P-95	J-39	JM9	11.89	200	Steel	100	1975
29	P-96	JM9	J-40	14.63	150	Steel	100	1975
30	P-97	J-43	JM8	12.8	200	Steel	100	1975
31	P-98	JM8	J-44	14.02	150	Steel	100	1975
32	P-99	J-42	JM7	13.41	200	Steel	100	1975
33	P-100	JM7	J-41	13.41	150	Steel	100	1975
34	P-101	J-41	TM	1,730.04	250	DI	100	1975
35	P-102	TM	J-47	85.34	400	Steel	100	1985
36	P-103	J-47	J-45	33.53	400	Steel	100	1985
37	P-104	J-46	TM2	14.63	300	Steel	100	1985
38	P-106	TM2	J-47	15.54	350	Steel	100	1985
39	P-105	J-45	TM1	14.33	350	Steel	100	1985
40	P-107	TM1	J-48	15.24	300	Steel	100	1985
41	P-108	J-46	J-48	34.14	400	DI	100	1985

42	P-109	J-48	EN	1,246.02	400	DI	100	1985
43	P-110	TM	J-50	42.98	200	Steel	100	1974
44	P-111	J-50	J-49	39.62	200	Steel	100	1974
45	P-113	J-52	J-51	38.4	150	Steel	100	1974
46	P-115	J-50	TM4	12.19	150	Steel	100	1974
47	P-116	TM4	J-52	12.19	125	Steel	100	1974
48	P-117	J-49	TM3	12.5	150	Steel	100	1974
49	P-118	TM3	J-51	13.11	125	Steel	100	1974
50	P-119	J-51	E15	1,056.44	200	DI	100	1974
51	P-120	E15	RK	1,435.30	150	DI	100	1989
52	P-122	JanMeda	J-132	1,074.72	350	DI	100	1975
53	P-123	TM	T12	58.83	400	DI	110	1975
54	P-126	T12	SP15	2,450.29	250	DI	100	1975
55	P-127	T12	T13	134.72	400	DI	110	1975
56	P-130	EN	J-63	24.99	400	DI	100	1975
57	P-131	J-63	B14	1,885.19	200	DI	100	1989
58	P-132	J-63	J-65	27.13	200	Steel	100	1975
59	P-135	B14	SP16	2,035.15	150	DI	100	1975
60	P-136	J-65	J-67	21.64	150	Steel	100	1975
61	P-137	J-67	J-64	20.12	150	Steel	100	1975
62	P-139	J-68	R1	1,258.82	150	DI	100	1975
63	P-140	J-67	Entoto1	17.68	150	Steel	100	1975

64	P-141	Entoto1	J-68	16.15	125	Steel	100	1975
65	P-142	J-64	Entoto2	18.9	150	Steel	100	1975
66	P-143	Entoto2	J-68	33.22	125	DI	100	1975
67	P-184	R1	J-90	32	150	DCI	100	1975
68	P-185	J-90	R1(1)	14.02	125	Steel	100	1975
69	P-186	R1(1)	E13	17.37	100	Steel	100	1975
70	P-187	E13	R2	409.65	125	DI	90	1975
71	P-188	R2	J-92	21.95	100	DCI	100	1975
72	P-190	E14	R3	473.66	100	Galvanized iron	90	1975
73	P-189	J-92	R2(1)	15.85	100	Steel	100	1975
74	P-191	R2(1)	E14	16.46	80	Steel	100	1975
75	P-428	J-27	J-138	99.97	150	DI	100	1984
76	P-460	L130	J-127	2,732.23	400	DI	100	1975
77	P-461	J-127	J-125	1,458.16	400	DI	90	1975
78	P-463	J-125	J-126	26.52	400	DI	100	1975
79	P-464	J-126	J-124	555.65	350	DI	90	1975
80	P-465	J-125	J-123	1,365.20	150	DI	90	1975
81	P-466	J-123	J-124	1,165.25	150	DI	100	1989
82	P-467	J-124	J-129	1,369.47	350	DI	110	1989
83	P-468	J-129	J-131	689.15	350	DI	110	1989
84	P-469	J-129	J-122	1,106.73	150	DI	90	1989

85	P-470	J-122	J-123	472.74	150	DI	90	1975
86	P-471	J-122	J-120	477.93	250	DI	100	1989
87	P-472	J-120	J-121	653.8	150	DI	100	1989
88	P-473	J-120	J-115	859.54	300	DI	90	1975
89	P-474	J-115	J-116	629.11	500	DI	100	1989
90	P-475	J-116	J-130	782.73	500	DI	100	1989
91	P-476	J-118	J-117	392.89	200	Steel	100	1989
92	P-478	J-116	J-117	11.28	200	DI	100	1989
93	P-479	J-130	J-133	142.65	800	DI	100	1989
94	P-480	J-133	J-132	44.2	350	DI	100	1989
95	P-481	J-132	J-131	63.09	350	DI	100	1989
96	P-483	J-118	J-134	525.78	150	Steel	90	1970
97	P-485	J-131	J-119	666.6	300	DI	90	1975
98	P-487	J-119	T3	1,366.11	200	DI	80	1955
99	P-488	J-119	J-118	407.21	200	DI	100	1989
100	P-490	T9	T8	1,286.87	250	DI	90	1975
101	P-491	T12	T10	1,222.55	200	DI	100	1989
102	P-493	T8	T10	960.12	150	DI	80	1955
103	P-494	T10	T5	260.3	150	DI	90	1970
104	P-495	T8	T7	84.43	250	DI	90	1975
105	P-496	T7	T1	865.33	250	DI	90	1975
106	P-499	T1	T6	1,130.81	150	DI	90	1975

107	P-500	T6	T7	761.09	250	DI	90	1975
108	P-501	IC5	IC1	529.74	200	DI	80	1955
109	P-507	T6	SP27	1,641.96	500	DI	100	1985
110	P-508	SP27	MO	57	500	DI	100	1985
111	P-554	T11	T19	1,096.98	150	DI	100	1989
112	P-555	T19	T4	716.58	150	DI	100	1989
113	P-556	J-133	T19	30.48	150	DI	100	1989
114	P-666	J-110	J-109	863.8	150	DI	90	1975
115	P-654	RK7	RK10	373.08	50	PVC	110	1975
116	P-673	J-107	J-106	617.83	150	Galvanized iron	80	1955
117	P-831	RK15	RK14	177.39	100	Galvanized iron	90	1975
118	P-634	J-142	J-143	154.23	400	Steel	80	1959
119	P-671	J-143	J-108	1,195.12	200	PVC	110	2001
120	P-660	RK8	RK7	701.34	50	PVC	110	1978
121	P-658	RK9	RK8	811.99	50	PVC	110	1978
122	P-685	G1	J-144	98.45	150	Steel	80	1955
123	P-672	J-108	J-107	403.56	150	DI	90	1970
124	P-830	RK20	RK15	377.04	100	Galvanized iron	90	1975
125	P-678	J-112	J-113	938.17	350	DI	90	1989
126	P-686	J-144	L109	1,043.64	100	Galvanized iron	90	1970

127	P-677	J-106	J-112	900.07	300	DI	90	1989
128	P-703	J-143	J-84	383.74	400	Steel	80	1959
129	P-704	J-84	J-137	455.37	500	DI	90	1989
130	P-706	R3	E2	281.33	50	PVC	110	1975
131	P-708	E3	R2	156.67	100	DI	90	1975
132	P-710	R1	E4	89.61	100	PVC	110	1975
133	P-711	E1	R3	261.82	75	Galvanized iron	90	1979
134	P-712	EN	E16	292.91	100	Galvanized iron	90	1975
135	P-718	RK10	RK9	357.84	75	Galvanized iron	90	1989
136	P-713	RK	RK14	769.01	100	Galvanized iron	90	1975
137	P-716	RK21	RK13	1,100.63	150	DI	90	1989
138	P-717	RK13	RK22	1,944.93	150	DI	50	1984
139	P-719	RK	RK13	306.63	250	DI	15	1989
140	P-720	RK13	RK21	1,122.27	150	DI	90	1989
141	P-721	RK20	RK21	180.14	100	Galvanized iron	90	1975
142	P-749	J-142	J-86	481.58	400	Steel	80	1959
143	P-750	J-86	J-110	580.03	200	DI	90	1989
144	P-751	J-86	J-110	610.82	250	DI	90	1989
145	P-752	J-110	J-109	903.43	250	DI	90	1989

146	P-753	J-109	J-105	1,101.24	250	DI	90	1989
147	P-754	J-105	J-106	164.9	300	DI	90	1989
148	P-755	J-108	J-79	833.32	200	DI	90	2001
149	P-756	J-108	J-107	898.86	150	DI	90	2001
150	P-757	J-142	J-111	360.88	300	DI	90	1975
151	P-759	J-111	J-109	838.5	200	DI	90	1975
152	P-760	J-84	J-112	1,487.12	350	DI	90	1989
153	P-761	J-84	J-135	461.16	150	Steel	90	1989
154	P-764	J-135	J-134	194.77	150	Steel	90	1989
155	P-769	J-141	J-137	897.94	500	DI	90	1989
156	P-770	J-137	J-135	18.29	150	DI	90	1989
157	P-771	J-119	J-136	766.27	300	DI	90	1975
158	P-773	J-136	J-84	468.17	300	DI	90	1975
159	P-775	J-135	J-136	20.73	150	DI	90	1989
160	P-778	J-117	J-114	378.56	200	Steel	100	1989
161	P-781	J-114	PG	108.2	200	Steel	100	1989
162	P-783	J-114	J-120	1,062.53	150	DI	100	1975
163	P-784	J-120	J-122	489.81	150	DI	100	1975
164	P-785	J-144	J-113	715.67	150	DI	100	1989
165	P-786	J-113	J-115	520.9	400	DI	100	1994
166	P-898	IC7	J-86	257.25	400	Steel	90	1975
167	P-901	J-87	J-128	2,182.06	150	Galvanized	90	1984

						iron		
168	P-965	J-141	J-130	384.05	800	DI	100	1970
169	P-968	J-127	J-139	984.2	150	DI	100	1989
170	P-969	J-139	J-140	996.39	150	DI	100	1989
171	P-970	J-140	J-123	868.07	150	DI	100	1989
172	P-976	T13	T15	430.68	150	DI	100	1975
173	P-977	T15	T1	586.74	150	DI	100	1975
174	P-978	T13	T14	427.02	400	DI	110	1975
175	P-979	T14	T7	603.81	400	DI	110	1975
176	P-980	J-29	T16	589.18	500	DI	100	1985
177	P-981	T16	T6	496.82	500	DI	100	1985
178	P-982	JanMeda	T17	539.19	800	DI	100	1989
179	P-983	T17	J-133	442.26	800	DI	100	1989
180	P-984	T10	T18	519.68	200	DI	100	1989
181	P-985	T18	T9	586.44	200	DI	100	1989
182	P-997	L125	J-87	43.28	150	Galvanized iron	90	1984
183	P-636	J-65	E12	99.36	150	DI	100	1975
184	P-637	E12	B14	1,783.38	150	DCI	100	1975
185	P-646	J-101	RK10	621.79	75	Galvanized iron	90	1989
186	P-645	RK	PMP-47	21.03	75	Galvanized iron	90	1989

187	P-647	PMP-47	J-101	18.9	75	Galvanized iron	90	1989
188	P-650	RK	PMP-49	27.43	150	DCI	100	1989
189	P-651	PMP-49	J-101	28.96	150	DCI	100	1989
190	P-155	J-74	T-14	3,030.93	300	DI	100	1985
191	P-585	B7	SP26	2,909.62	150	Galvanized iron	90	1955
192	P-583	B10	B9	730	110	PVC	110	1989
193	P-576	B8	B1	1,649.27	100	PVC	110	1975
194	P-584	B10	B11	404.47	200	DI	90	1989
195	P-722	B7	T-14	62.18	250	DI	80	1989
196	P-723	B7	B9	658.98	125	Galvanized iron	90	1955
197	P-966	B7	B13	794	200	DI	60	1975
198	P-967	B13	B4	464.21	200	DI	90	1989
199	P-648	T-14	PMP-48	22.56	100	DI	90	1975
200	P-649	PMP-48	B8	23.77	100	DI	90	1975
201	P-652	T-14	PMP-50	29.26	100	Steel	100	1975
202	P-653	PMP-50	B8	34.14	100	Steel	100	1975
203	P-582a	B7	J-104	15.54	90	DI	80	1975
204	P-582	J-104	B10	1,160.98	250	DI	90	1989

Appendix A3 – Theoretical population's consumption and nodes in the proposed Study area water supply system.

No.	Node Label	Elevation (m)	Population(number)	Consumption per capita	Consumption/node (l/s)
1	J22-28	2521	3187	157	5.80
2	J22-30	2512	2228	157	4.05
3	J22-36	2535	14995	157	27.29
4	J22-27	2489	2431	157	4.43
5	J22-37	2520	2027	157	3.69
6	J22-35	2496	3647	157	6.64
7	J22-16	2480	3446	157	6.27
8	J22-2	2519	1823	157	3.32
9	J22-32	2520	1620	157	2.95
10	J22-25	2490	4458	157	8.11
11	J22-31	2490	3851	157	7.01
12	J22-33	2490	2027	157	3.69
13	J22-8	2536	1823	157	3.32
14	J22-4	2514	1012	157	1.84
15	J22-17	2468	0	157	0.00
16	J22-21	2514	1620	157	2.95
17	J22-20	2494	4054	157	7.38
18	J22-24	2478	6686	157	12.17
19	J22-26	2473	1620	157	2.95
20	J22-22	2501	3039	157	5.53
21	J22-11	2504	1216	157	2.21
22	J22-19	2494	1620	157	2.95
23	J22-1	2518	1823	157	3.32
24	J22-7	2538	2228	157	4.05
25	J22-23	2517	4863	157	8.85
26	J22-15	2489	3243	157	5.90
27	J22-12	2511	3243	157	5.90
28	J22-29	2536	2431	157	4.43
29	J22-13	2532	4255	157	7.74
30	J22-10	2526	1823	157	3.32
31	J22-3	2511	1216	157	2.21
32	J22-14	2513	4054	157	7.38

33	J22-18	2503	1216	157	2.21
34	J22-34	2510	2027	157	3.69
35	J22-39	2528	3446	157	6.27
36	J22-76	2475	1012	157	1.84
37	J22-81	2,562.00	0	157	0
38	J22-6	2,562.00	0	157	0
39	J22-40	2539	1475	157	2.69
40	J26-4	2589	435	182	0.91
41	J26-11	2587	936	182	1.97
42	J26-13	2563	0	182	0.00
43	J26-12	2606	410	182	0.86
44	J26-3	2613	584	182	1.23
45	J26-9	2579	3079	182	6.47
46	J26-2	2589	652	182	1.37
47	J26-8	2605	1743	182	3.66
48	J26-1	2601	1217	182	2.56
49	J26-10	2568	1066	182	2.24
50	J26-5	2610	310	182	0.65
51	J26-7	2600	1121	182	2.36
52	J26-6	2604	656	182	1.38
53	J29-8	2617	1063	120	1.47679333
54	J29-2	2632	858	120	1.19217498
55	J29-6	2656	944	120	1.31031845
56	J29-21	2638	0	120	0
57	J29-7	2617	1535	120	2.13195256
58	J29-4	2641	959	120	1.33179908
59	J29-3	2648	2042	120	2.8354432
60	J29-1	2636	858	120	1.19217498
61	J29-9	2647	1524	120	2.11584208
62	J29-5	2646	1802	120	2.50249343
63	J30-1	2711	1670	120	2.31990807
64	J30-9	2668	735	120	1.02032994
65	J30-6	2677	1349	120	1.87418499
66	J30-2	2707	1307	120	1.81511326
67	J30-4	2664	1102	120	1.53049491
68	J30-10	2683	0	120	0

69	J30-3	2677	545	120	0.75719222
70	J30-8	2703	1601	120	2.22324523
71	J24-13	2586	1680	115	2.23935571
72	J24-4	2574	2054	115	2.73878036
73	J24-7	2555	3360	115	4.47871141
74	J24-10	2594	2054	115	2.73878036
75	J24-43	2570	2614	115	3.48523226
76	J24-22	2573	2240	115	2.98580761
77	J24-32	2545	4294	115	5.72458797
78	J24-14	2572	1120	115	1.4929038
79	J24-28	2552	2614	115	3.48523226
80	J24-3	2579	2054	115	2.73878036
81	J24-33	2563	3174	115	4.23168417
82	J24-9	2593	0	115	0
83	J24-34	2559	1124	115	1.49827396
84	J24-21	2561	1680	115	2.23935571
85	EN-1	2572	0	115	0
86	J24-34a	2585	1124	115	1.49827396
87	J27-7	2600	886	120	1.22976608
88	J27-15	2592	1586	120	2.2017646
89	J27-6	2599	2766	120	3.83966266
90	J27-10	2640	1845	120	2.56156516
91	J27-8	2629	1555	120	2.15880334
92	J27-12	2614	4034	120	5.60107435
93	J27-3	2627	967	120	1.34253939
94	J27-11	2593	1946	120	2.70118926
95	J27-14	2618	2646	120	3.67318778
96	J27-2	2658	0	120	0
97	J27-9	2625	959	120	1.33179908
98	J27-17	2608	0	120	0
99	J27-13	2597	700	120	0.97199852
100	J27-16	2625	2073	120	2.87840446
101	J18-20	2455	2565	180	5.35007431
102	J18-13	2470	578	180	1.20656241
103	J18-41	2467	2297	180	4.79093563

104	J18-26	2458	3112	180	6.49189434
105	J18-43	2432	2319	180	4.83802099
106	J18-9	2473	996	180	2.07764162
107	J18-36	2469	2740	180	5.71498586
108	J18-27	2464	5432	180	11.3299153
109	J18-21	2484	10437	180	21.7710945
110	J18-35	2481	2396	180	4.99693409
111	J18-14	2470	776	180	1.61855933
112	J18-34	2457	2494	180	5.20293255
113	J18-6	2440	525	180	1.09473468
114	J18-51	2470	17212	180	35.9025888
115	J18-49	2431	8061	180	16.8153601
116	J18-50	2468	1944	180	4.05522684
117	J18-39	2477	1826	180	3.80802869
118	J18-10	2471	2116	180	4.41425273
119	J18-25	2456	1329	180	2.77215071
120	J18-37	2447	2345	180	4.89099202
121	J18-48	2477	6752	180	14.084409
122	J18-16	2440	1955	180	4.07876952
123	J18-40	2469	1958	180	4.08465519
124	J18-15	2428	2249	180	4.69087923
125	J18-18	2461	2579	180	5.37950266
126	J18-17	2463	2362	180	4.92630604
127	J18-12	2442	454	180	0.94759292
128	J18-38	2434	2870	180	5.9857267
129	J18-29	2477	5370	180	11.2004306
130	J18-4	2459	5068	180	10.5706639
131	J18-8	2457	3488	180	7.27468849
132	J18-7	2459	2099	180	4.37893871
133	J18-24	2470	1433	180	2.98992051
134	J18-31	2470	4723	180	9.85261209
135	J18-5	2442	776	180	1.61855933
136	J18-19	2455	2514	180	5.24413224
137	J18-28	2470	2286	180	4.76739295
138	J18-23	2478	2458	180	5.12641883
139	J18-33	2461	2049	180	4.27299664

140	J18-42	2439	1984	180	4.13762622
141	J18-3	2461	2161	180	4.50842345
142	J18-44	2482	2238	180	4.66733655
143	J18-53	2470	0	180	0
144	J18-32	2447	1789	180	3.73151497
145	JP-2	2390	0	191	0
146	JP-3	2404	0	191	0
147	J14-85	2391	1383	191	3.05
148	J14-105	2397	1401	191	3.09
149	J14-106	2387	1206	191	2.66
150	J14-104	2370	1573	191	3.47
151	J14-116	2379	408	191	0.9
152	J14-22	2377	807	191	1.78
153	J14-107	2377	567	191	1.25
154	J14-21	2388	716	191	1.58
155	J14-19	2391	1355	191	2.99
156	J14-18	2389	1609	191	3.55
157	J14-47	2393	1700	191	3.75
158	J14-48	2418	1392	191	3.07
159	J14-99	2414	911	191	2.01
160	J14-100	2422	1092	191	2.41
161	J14-92	2403	911	191	2.01
162	J14-6	2461.5	0	191	0
163	J14-14	2433	1573	191	3.47
164	J14-15	2425	1129	191	2.49
165	J14-82	2432	653	191	1.44
166	J14-83	2416	898	191	1.98
167	J14-112	2424	1646	191	3.63
168	J14-44	2383	1723	191	3.8
169	J14-45	2411	607	191	1.34
170	J14-53	2411	1442	191	3.18

171	J14-37	2421	1215	191	2.68
172	J14-28	2405	1147	191	2.53
173	J14-27	2414	1428	191	3.15
174	J14-79	2416	961	191	2.12
175	J14-49	2403	866	191	1.91
176	J14-69	2405	1478	191	3.26
177	J14-60	2397	2199	191	4.85
178	J14-90	2409	1686	191	3.72
179	J14-16	2411	1496	191	3.3
180	J14-30	2422	1505	191	3.32
181	J14-46	2410	3432	191	7.57
182	J14-115	2436	3364	191	7.42
183	J14-17	2407	1151	191	2.54
184	J14-41	2403	1174	191	2.59
185	J14-91	2386	757	191	1.67
186	J14-96	2377	1550	191	3.42
187	J14-102	2378	1777	191	3.92
188	J14-89	2377	1015	191	2.24
189	J14-38	2405	1840	191	4.06
190	J14-39	2410	1487	191	3.28
191	J14-88	2420	2752	191	6.07
192	J14-94	2418	2443	191	5.39
193	J14-54	2406	2371	191	5.23
194	J14-55	2403	1482	191	3.27
195	J14-75	2393	1804	191	3.98
196	J12-2	2417	0	221	0
197	J12-10	2404	1109	221	2.83
198	J12-12	2376	6369	221	16.26
199	J12-29	2386	3600	221	9.19
200	J12-14	2379	1109	221	2.83
201	J12-34	2369	3075	221	7.85
202	J12-11	2371	6925	221	17.68
203	J12-15	2363	3047	221	7.78
204	J12-16	2366	3326	221	8.49
205	J12-25	2403.5	1661	221	4.24

206	J12-5	2364	1939	221	4.95
207	J12-6	2364	2217	221	5.66
208	J12-21	2373	1387	221	3.54
209	J12-22	2361	1387	221	3.54
210	J12-23	2350	1387	221	3.54
211	J12-78	2344	1109	221	2.83
212	J28-22	2635	0	120	0.00
213	J28-7	2603	4420	120	6.14
214	J28-8	2619	5666	120	7.87
215	J28-13	2654	862	120	1.20
216	J28-12	2650	8512	120	11.82
217	J28-11	2607	4935	120	6.85
218	J28-1	2631	2177	120	3.02
219	J28-7a	2601	0	120	0.00
220	J28-23	2616	0	120	0.00
221	J28-15	2633	2912	120	4.04
222	J28-5	2645	3009	120	4.18
223	J28-17	2604	3910	120	5.43
224	J28-16	2611	1767	120	2.45
225	J28-20	2651	2788	120	3.87
226	J28-10	2594	3848	120	5.34
227	J28-25	2633	0	120	0.00
228	J28-8a	2614	0	120	0.00
229	J28-6a	2627	0	120	0.00
230	J28-4	2621	2800	120	3.89
231	J28-38	2590	0	120	0.00
232	J28-6	2609	4544	120	6.31
233	J28-14	2645	2680	120	3.72
234	J28-3	2627	2672	120	3.71
235	J28-9	2606	5766	120	8.01

Appendix A4 – Links in the proposed design of Study area water distribution system.

No.	Link Label	From Node	To Node	Length (m)	Diameter (mm)	Material	Hazen-Williams C
1	P22-4	J22-7	J22-8	92.66	150	PVC	130
2	P22-29	J22-12	J22-13	206.04	150	DCI	90
3	P22-12	J22-21	J22-11	606.25	150	PVC	130
4	P22-21	J22-18	J22-3	227.08	150	DCI	90
5	P22-41	J22-27	J22-25	521.21	150	PVC	130
6	P22-8	J22-26	J22-18	688.85	150	DCI	90
7	P22-15	J22-14	J22-15	227.99	350	DCI	120
8	P22-25	J22-22	J22-29	582.47	200	DCI	90
9	P22-7	J22-3	J22-11	193.55	250	DCI	90
10	P22-31	J22-19	J22-20	758.04	200	PVC	130
11	P22-9	J22-3	J22-4	57.91	350	DCI	120
12	P22-13	J22-26	J22-27	405.69	150	PVC	130
13	P22-33	J22-31	J22-19	500.79	200	PVC	130
14	P22-43	J22-15	J22-24	334.67	300	DCI	120
15	P22-39	J22-13	J22-7	299.92	150	DCI	90
16	P22-34	J22-25	J22-18	395.33	150	PVC	130
17	P22-42	J22-24	J22-36	526.69	300	DCI	120
18	P22-40	J22-28	J22-12	422.15	150	DCI	90
19	P22-36	J22-16	J22-22	787.91	100	PVC	130
20	P22-16	J22-20	J22-10	736.4	450	DCI	120
21	P22-32	J22-10	J22-19	281.03	250	PVC	130
22	P22-38	J22-30	J22-16	719.02	150	PVC	130
23	P22-17	J22-35	J22-37	594.66	150	PVC	130
24	P22-11	J22-16	J22-17	237.13	200	PVC	130
25	P22-10	J22-29	J22-30	422.76	150	PVC	130
26	P22-23	J22-1	J22-2	36.27	150	PVC	130
27	P22-5	J22-23	J22-14	654.1	150	DCI	90
28	P22-24	J22-21	J22-22	462.08	200	DCI	90
29	P22-30	J22-20	J22-12	289.26	450	DCI	120
30	P22-20	J22-25	J22-31	877.52	150	PVC	130
31	P22-18	J22-34	J22-35	705.92	100	PVC	130

32	P22-86	J22-1	J22-4	80.16	400	DCI	90
33	P22-87	J22-32	J22-37	47.24	200	PVC	130
34	P22-88	J22-37	J22-34	269.75	150	DCI	90
35	P22-89	J22-34	J22-33	204.22	150	DCI	90
36	P22-91	EN1	J22-39	865.33	400	DCI	90
37	P22-92	J22-39	J22-1	170.38	400	DCI	90
38	P22-93	J22-21	J22-39	386.79	200	PVC	130
39	P22-94	J22-39	J22-10	197.51	500	DCI	120
40	P22-95	EN1	J22-39	851	700	DCI	120
41	P22-96	J22-39	J22-4	252.07	500	DCI	120
42	P22-97	J22-4	FCV-1	59.44	500	DCI	120
43	P22-98	FCV-1	TM	18.29	500	DCI	120
44	P22-99	J22-11	J22-76	732.43	250	DCI	90
45	P22-100	J22-76	J22-17	142.34	250	DCI	90
46	P22-101	J22-26	J22-76	17.37	150	PVC	130
47	P22-104	J22-8	J22-23	442.87	250	DCI	90
48	P22-103	J22-12	J22-32	811.38	450	DCI	120
49	P22-105	J22-32	J22-23	207.87	450	DCI	120
50	P22-106	J22-23	J22-14	647.4	350	DCI	120
51	P24-31	J24-33	J24-34	340.77	150	PVC	130
52	P24-56	J24-10	J24-7	560.83	200	PVC	130
53	P24-17	J24-28	J24-21	356.92	250	PVC	130
54	P24-35	J24-9	J24-10	209.7	200	PVC	130
55	P24-15	RS1	J24-9	572.11	350	DCI	120
56	P24-53	J24-13	J24-14	214.27	200	PVC	130
57	P24-38	J24-32	J24-28	356.62	250	PVC	130
58	P24-34	J24-22	J24-3	516.64	250	PVC	130
59	P24-33	J24-4	J24-13	352.96	200	PVC	130
60	P24-122	J24-43	J24-7	541.02	150	PVC	130
61	P24-16	J24-9	J24-32	1,042.72	300	DCI	120
62	P24-32	J24-14	J24-33	396.24	200	PVC	130
63	P24-55	J24-21	J24-22	248.41	250	PVC	130
64	P24-54	J24-3	J24-4	117.04	200	PVC	130
65	P22-108	EN-1	RS	3,913.33	300	DCI	120
66	EN-6	EN1	PMP-1	16.46	250	Steel	120
67	EN-5	PMP-1	EN-1	15.54	200	Steel	120

68	EN-3	EN-1	PMP-2	21.95	200	Steel	120
69	EN-4	PMP-2	EN1	19.51	250	Steel	120
70	P27-15	J27-14	J27-11	352.96	200	PVC	130
71	P27-3	J27-7	J27-8	260.3	100	PVC	130
72	P27-7	J27-6	J27-15	372.47	200	PVC	130
73	P27-9	J27-2	J27-3	460.55	250	PVC	130
74	P27-16	J27-9	J27-13	374.29	150	PVC	130
75	P27-6	J27-8	J27-9	280.72	250	PVC	130
76	P27-8	J27-13	J27-11	290.17	150	PVC	130
77	P27-11	J27-11	J27-12	416.66	150	PVC	130
78	P27-5	J27-3	J27-9	226.16	250	PVC	130
79	P27-4	J27-2	J27-14	410.57	200	PVC	130
80	P27-1	FC1	J27-2	103.02	300	DCI	120
81	P27-33	J27-17	FC	647.4	200	PVC	130
82	P27-13	J27-15	J27-16	514.2	200	PVC	130
83	P27-31	J27-10	J27-6	429.16	150	PVC	130
84	P27-14	J27-16	J27-8	460.55	200	PVC	130
85	RS-1	RS1	PMP-3	22.25	250	Steel	120
86	RS-2	PMP-3	J27-17	24.38	200	Steel	120
87	P29-3	J29-5	J29-3	318.21	150	PVC	130
88	P29-9	J29-5	J29-6	167.64	250	PVC	130
89	P29-2	J29-9	J29-1	371.25	150	PVC	130
90	P30-3	J30-2	J30-8	300.84	150	PVC	130
91	P29-5	J29-4	J29-7	277.67	150	PVC	130
92	P26-33	PMP-5	EN1	22.56	250	Steel	120
93	P29-23	J29-21	R2	444.7	200	PVC	130
94	P29-7	J29-4	J29-8	379.78	150	PVC	130
95	P26-34	J26-12	J26-6	45.11	150	PVC	130
96	P26-5	J26-6	J26-3	226.77	150	PVC	130
97	P30-16	R2a	PMP-7	20.12	150	Steel	120
98	P29-8	J29-1	J29-5	170.38	200	PVC	130
99	P26-13	J26-4	J26-5	265.79	150	PVC	130
100	P26-4	J26-1	J26-2	144.17	150	PVC	130
101	P26-10	J26-8	J26-9	261.52	150	PVC	130
102	P26-28	R1a	J26-12	573.94	250	DCI	120
103	P26-6	J26-7	J26-5	257.56	150	PVC	130

104	P26-11	J26-10	J26-9	306.32	150	PVC	130
105	P29-4	J29-3	J29-4	67.06	150	PVC	130
106	P26-30	J26-13	R1	1,309.73	250	Steel	120
107	P30-18	PMP-7	J30-10	17.37	150	Steel	120
108	P29-21	R2a	J29-6	303.89	250	PVC	130
109	P26-3	J26-12	J26-1	374.29	250	PVC	130
110	P30-19	J30-10	R3	392.28	150	DCI	120
111	P26-2	R1a	J26-6	598.63	150	DCI	90
112	P30-2	J30-1	J30-2	64.92	200	PVC	130
113	P29-10	J29-8	J29-3	334.06	150	PVC	130
114	P26-29	EN1	PMP-6	24.99	250	Steel	120
115	P29-11	J29-7	J29-2	162.76	150	PVC	130
116	P29-24	PMP-4	J29-21	22.25	200	Steel	120
117	P26-12	J26-3	J26-4	374.6	150	PVC	130
118	P26-7	J26-6	J26-11	327.36	150	DCI	90
119	P29-6	J29-1	J29-2	59.44	152	PVC	130
120	P30-7	J30-8	J30-9	139.9	100	PVC	130
121	P26-9	J26-1	J26-8	306.32	200	PVC	130
122	P26-32	J26-13	PMP-5	26.82	200	Steel	120
123	P30-4	J30-3	J30-4	153.01	100	PVC	130
124	P26-31	PMP-6	J26-13	23.16	200	Steel	120
125	P30-1	J30-2	J30-3	356.01	150	PVC	130
126	P29-22	R1a	PMP-4	14.63	200	Steel	120
127	P26-14	J26-2	J26-10	328.57	150	PVC	130
128	P30-8	J30-1	R3a	221.59	200	PVC	130
129	P30-6	J30-3	J30-6	217.32	100	PVC	130
130	P18-123	J18-23	J18-44	395.33	300	DCI	120
131	P18-9	J18-12	J18-13	342.6	100	PVC	130
132	P18-14	J18-42	J18-4	500.18	150	PVC	130
133	P18-4	J18-9	J18-3	689.46	250	DCI	90
134	P18-34	J18-24	J18-25	354.18	150	PVC	130
135	P18-41	J18-6	J18-24	363.02	100	PVC	130
136	P18-52	J18-37	J18-21	405.69	250	PVC	130
137	P18-23	J18-8	J18-20	396.54	150	PVC	130
138	P18-21	J18-26	J18-29	451.71	200	PVC	130
139	P18-127	J18-50	J18-40	681.53	150	DCI	90

140	P18-19	J18-44	J18-28	662.03	250	PVC	130
141	P18-37	J18-13	J18-14	172.52	100	PVC	130
142	P18-125	J18-25	J18-50	292.91	200	DCI	90
143	P18-126	J18-50	J18-39	652.27	200	DCI	90
144	P18-119	J18-9	J18-10	84.73	250	DCI	90
145	P18-118	J18-39	J18-9	234.09	200	DCI	90
146	P18-59	J18-28	J18-7	328.57	250	PVC	130
147	P18-15	J18-43	J18-15	658.37	150	PVC	130
148	P18-56	J18-48	J18-49	957.07	350	DCI	120
149	P18-49	J18-35	J18-36	385.57	200	DCI	90
150	P18-13	J18-3	J18-4	49.99	250	PVC	130
151	P18-6	J18-10	J18-23	338.94	150	DCI	90
152	P18-135	J18-23	J18-41	508.41	400	DCI	90
153	P18-50	J18-35	J18-33	451.71	500	DCI	120
154	P18-131	J18-18	J18-8	576.68	250	DCI	90
155	P18-48	J18-36	J18-19	593.14	200	DCI	90
156	P18-40	J18-33	J18-34	382.52	500	DCI	120
157	P18-35	J18-26	J18-27	331.62	450	DCI	120
158	P18-27	J18-5	J18-12	146.3	100	PVC	130
159	P18-11	J18-5	J18-6	80.77	150	PVC	130
160	P18-2	J18-23	J18-41	478.84	250	DCI	90
161	P18-45	J18-17	J18-18	154.23	250	DCI	90
162	P18-58	J18-20	J18-16	261.52	150	PVC	130
163	P18-122	J18-10	J18-17	515.42	250	DCI	90
164	P18-55	J18-31	J18-27	455.07	200	PVC	130
165	P18-31	J18-16	J18-8	770.84	150	PVC	130
166	P18-8	J18-19	J18-7	261.52	200	DCI	90
167	P18-28	J18-42	J18-6	549.55	150	PVC	130
168	P18-12	J18-39	J18-40	443.18	150	PVC	130
169	P18-18	TM1	J18-23	1,113.74	250	DCI	90
170	P18-47	J18-7	J18-8	76.2	200	DCI	90
171	P18-36	J18-27	J18-48	1,031.44	350	DCI	120
172	P18-128	J18-40	J18-3	482.19	150	DCI	90
173	P18-39	J18-38	J18-37	416.97	500	DCI	120
174	P18-26	J18-14	J18-5	360.27	100	PVC	130
175	P18-51	J18-34	J18-38	520.29	500	DCI	120

176	P18-17	J18-15	J18-16	252.68	150	PVC	130
177	P18-42	J18-4	J18-43	518.46	150	PVC	130
178	P18-20	J18-37	J18-26	658.37	450	DCI	120
179	P18-124	J18-44	J18-35	48.77	500	DCI	120
180	P18-129	J18-9	TM1	1,075.33	400	DCI	90
181	P18-57	J18-49	J18-51	984.81	300	DI	120
182	P18-29	J18-43	J18-42	622.4	150	PVC	130
183	P18-130	TM1	J18-35	1,154.58	200	DCI	90
184	P18-133	TM1	J18-44	1,210.06	500	DCI	120
185	P18-134	TM1	J18-23	1,151.84	400	DCI	90
186	P15-102	FCV-4	JM	15.54	1,400.00	DCI	120
187	P15-101	MO1	FCV-4	3,044.34	1,400.00	DCI	120
188	PRU1	RU1	FCV-8	4,909.41	800	DCI	120
189	PRU1a	FCV-8	EN	23.47	800	DCI	120
190	PSH1	SH1	SH1	517.86	1,400.00	DCI	120
191	PSH2	SH1	FCV-10	1,767.54	1,200.00	DCI	120
192	PSH2a	FCV-10	RU	18.9	1,200.00	DCI	120
193	PSH3a	RU	FCV-11	24.08	1,200.00	DCI	120
194	PSH3	FCV-11	SH1	1,727.00	1,200.00	DCI	120
195	PRU3	RU1	FCV-12	3,763.67	900	DCI	120
196	PRU3a	FCV-12	MO	39.62	1,200.00	DCI	120
197	PRU2	RU1	FCV-13	3,530.80	1,200.00	DCI	120
198	PRU2a	FCV-13	MO	38.4	1,200.00	DCI	120
199	P24-121	J24-34	J24-34a	683.06	150	PVC	130
200	P18-10	J18-14	J18-53	303.58	100	PVC	130
201	P18-10a	J18-53	J18-24	252.37	100	PVC	130
202	P18-63	J18-4	J18-53	1,142.39	500	DCI	90
203	P18-61	J18-18	J18-32	456.59	500	DCI	90
204	P18-62	J18-32	J18-4	465.12	500	DCI	90
205	P18-30	J18-15	J18-32	478.54	150	PVC	130
206	P18-22	J18-17	J18-4	704.39	100	PVC	130

207	P22-26	J22-6	J22-2	979.02	200	DCI	90
208	P22-119	EN1	J22-81	97.84	200	PVC	130
209	P22-1	J22-81	J22-21	706.22	200	DCI	90
210	P22-3	J22-28	J22-40	173.43	150	DCI	90
211	P22-124	J22-6	EN1	90.53	200	PVC	130
212	P22-118(2)	RS1	J22-79(3)	68.88	350	Ductile Iron	120
213	*PN1*	*JM1*	*FCV-11*	*6,939.08*	*1,000.00*	*DI*	*120*
214	*PN-2*	*FCV-11*	*TR*	*31.7*	*1,000.00*	*DI*	*120*
215	PE-1	JM1	JP-2	4,756.40	900	DI	100
216	PE-2	JP-2	JP-3	2,688.95	900	DI	100
217	P-372	JP-3	TR	51.51	800	DI	120
218	P14-151	J14-105	J14-85	135.03	400	DCI	90
219	*P14-77*	*J14-104*	*J14-105*	*565.4*	*150*	*PVC*	*130*
220	*P14-78*	*J14-104*	*J14-116*	*1,324.66*	*150*	*PVC*	*130*
221	P14-149	J14-106	J14-105	1,063.14	400	DCI	90
222	P14-144	J14-116	J14-106	202.39	400	DCI	90
223	P14-143	J14-22	J14-116	366.06	400	DCI	90
224	*P14-79*	*J14-107*	*J14-22*	*607.77*	*100*	*PVC*	*130*
225	P14-142	J14-107	J14-89	483.72	150	DCI	90
226	P14-89	J14-21	J14-22	179.53	400	DCI	90
227	P14-90	J14-19	J14-21	281.03	400	DCI	90
228	P14-91	J14-18	J14-19	153.62	400	DCI	90
229	P14-96	J14-75	J14-18	465.43	400	DCI	90
230	P14-141	J14-18	J14-107	217.02	150	DCI	90
231	P14-147	J14-106	J14-47	599.24	150	GS	90
232	*P14-1*	*J14-47*	*J14-48*	*237.74*	*150*	*DI*	*120*
233	P14-148	J14-47	J14-99	908.3	150	GS	90
234	P14-76	J14-99	J14-100	411.18	150	GS	90
235	P14-86	J14-85	J14-92	449.88	400	DCI	90
236	P14-126	JM1	J14-6	54.56	800	DI	120
237	P14-125	J14-6	J14-14	840.03	800	DCI	90
238	P14-124	J14-6	J14-14	907.69	350	DCI	90
239	P14-123	J14-14	J14-15	158.8	800	DCI	90
240	*P14-119*	*J14-15*	*J14-82*	*402.64*	*200*	*PVC*	*130*

241	P14-111	J14-14	J14-82	613.56	300	DCI	90
242	P14-118	J14-82	J14-83	494.39	500	DCI	90
243	*P14-135*	*J14-83*	*J14-112*	*809.55*	*150*	*PVC*	*130*
244	P14-117	J14-83	J14-44	424.28	500	DCI	90
245	P14-116	J14-82	J14-44	862.89	300	DCI	90
246	P14-112	J14-82	J14-37	466.34	200	DCI	90
247	P14-115	J14-44	J14-45	239.88	200	DCI	90
248	P14-114	J14-45	J14-53	246.89	200	DCI	90
249	*P14-133*	*J14-53*	*J14-37*	*549.55*	*200*	*PVC*	*130*
250	P14-113	J14-37	J14-28	377.95	200	DCI	90
251	P14-158	J14-15	J14-27	596.19	500	DCI	90
252	P14-157	J14-27	J14-28	191.11	500	DCI	90
253	P14-120	J14-28	J14-79	352.04	200	DCI	90
254	P14-85	J14-28	J14-49	242.01	500	DCI	90
255	*P14-145*	*J14-49*	*J14-79*	*157.58*	*400*	*DI*	*120*
256	*P21-100*	*J14-79*	*FCV-5*	*132.59*	*400*	*DI*	*120*
257	*P21-101*	*FCV-5*	*PG*	*18.59*	*400*	*DI*	*120*
258	P14-84	J14-49	J14-69	386.49	500	DCI	90
259	*P14-132*	*J14-27*	*J14-60*	*932.69*	*250*	*PVC*	*130*
260	*P14-130*	*J14-90*	*J14-60*	*1,041.81*	*200*	*PVC*	*130*
261	P14-110	J14-14	J14-16	779.07	350	DCI	90
262	P14-105	J14-16	J14-30	193.85	350	DCI	90
263	P14-104	J14-30	J14-46	311.51	350	DCI	90
264	*P14-131*	*J14-46*	*J14-115*	*848.56*	*150*	*PVC*	*130*
265	P14-82	J14-14	J14-46	1,044.85	150	DCI	90
266	P14-107	J14-16	J14-17	149.66	150	DCI	90
267	P14-106	J14-17	J14-41	237.44	150	DCI	90
268	P14-109	J14-41	J14-60	273.71	150	DCI	90
269	P14-108	J14-60	J14-91	445.01	150	DCI	90
270	P14-127	J14-91	J14-96	472.44	150	DCI	90
271	P14-128	J14-102	J14-96	534.62	150	DCI	90
272	*P14-129*	*J14-102*	*J14-89*	*1,058.57*	*150*	*PVC*	*130*
273	*P14-134*	*J14-75*	*J14-89*	*423.06*	*100*	*PVC*	*130*
274	P14-103	J14-46	J14-38	244.75	350	DCI	90
275	P14-102	J14-38	J14-39	235.31	350	DCI	90
276	P14-101	J14-39	J14-88	384.66	350	DCI	90

277	P14-100	J14-88	J14-94	583.69	350	DCI	90
278	P14-99	J14-94	J14-54	431.29	400	DCI	90
279	P14-98	J14-54	J14-55	250.24	400	DCI	90
280	P14-97	J14-55	J14-75	309.07	400	DCI	90
281	P14-93	J14-88	J14-90	418.19	150	DCI	90
282	P14-92	J14-90	J14-96	756.51	150	DCI	90
283	P14-94	J14-94	J14-102	819.91	150	DCI	90
284	*P12-38*	*PG1*	*J12-2*	*25.6*	*600*	*DI*	*120*
285	*P12-50*	*J12-2*	*J12-10*	*145.69*	*600*	*DI*	*120*
286	P12-31	J12-10	J12-12	998.52	150	DCI	90
287	P12-29	J12-12	J12-29	344.42	150	DCI	90
288	P12-51	J12-10	J12-14	385.57	300	DCI	90
289	P12-113	J12-14	J12-34	244.14	300	DCI	90
290	P12-114	J12-34	J12-11	266.7	300	DI	120
291	P12-30	J12-11	J12-12	165.81	250	DCI	90
292	P12-27	J12-11	J12-15	518.77	150	DCI	90
293	P12-28	J12-12	J12-29	353.87	250	DCI	90
294	P12-26	J12-15	J12-16	149.05	150	DCI	90
295	*P12-125*	*J12-15*	*J12-16*	*154.23*	*250*	*PVC*	*130*
296	*P12-12*	*J12-29*	*J12-16*	*539.5*	*250*	*PVC*	*130*
297	P12-36	J12-25	J12-10	483.72	400	DCI	90
298	P12-115	J12-25	J12-5	704.39	150	DCI	90
299	*P12-44*	*J12-5*	*J12-6*	*89.92*	*200*	*PVC*	*130*
300	P12-8	J12-2	J12-6	865.33	200	DCI	90
301	*P12-121*	*J12-78*	*J12-5*	*621.18*	*200*	*PVC*	*130*
302	P12-35	J12-25	J12-21	286.21	350	DCI	90
303	P12-34	J12-21	J12-22	187.45	350	DCI	90
304	P12-33	J12-22	J12-23	227.08	350	DCI	90
305	*P12-120*	*J12-23*	*J12-78*	*254.2*	*200*	*PVC*	*130*
306	*P28-61*	*J28-6a*	*J28-6*	*171.3*	*250*	*DCI*	*90*
307	*P28-48*	*J28-14*	*J28-22*	*167.94*	*400*	*DCI*	*120*
308	*P28-53*	*J28-1*	*J28-25*	*171.6*	*250*	*DCI*	*90*
309	*P28-57*	*J28-25*	*J28-23*	*270.36*	*350*	*DCI*	*120*
310	*P28-54*	*J28-25*	*J28-23*	*325.22*	*250*	*DCI*	*90*
311	*P28-40*	*J28-14*	*J28-13*	*252.98*	*450*	*DCI*	*120*
312	*P28-9*	*J28-14*	*J28-15*	*435.25*	*200*	*PVC*	*130*

313	P28-11	J28-4	J28-5	220.68	150	PVC	130
314	P28-56	J28-23	J28-8a	211.23	250	DCI	90
315	P28-7	J28-1	J28-17	513.59	200	DCI	90
316	P28-51	J28-22	J28-1	102.11	300	DCI	120
317	P28-58	J28-8a	J28-8	85.04	250	DCI	90
318	P28-12	J28-10	J28-16	457.5	200	PVC	130
319	P28-44	RU(Ex)	PMP-8	23.47	300	DCI	120
320	P28-63	J28-8	J28-6	340.46	300	DCI	120
321	P28-62	J28-6	J28-7a	123.75	250	DCI	90
322	P28-39	J28-1	J28-3	69.8	200	PVC	130
323	P28-14	J28-11	J28-12	416.36	200	PVC	130
324	P28-16	J28-15	J28-4	772.06	200	PVC	130
325	P28-42	J28-38	GR	1,805.33	300	DCI	120
326	P28-10	J28-4	J28-10	403.86	100	PVC	130
327	P28-65	J28-7	J28-11	514.81	200	DCI	90
328	P28-3	GR1	J28-13	582.47	450	DCI	120
329	P28-45	PMP-8	J28-38	29.57	250	DCI	120
330	P28-59	J28-8	J28-6a	239.57	250	DCI	90
331	P28-18	J28-16	J28-20	705.61	150	PVC	130
332	P28-17	J28-10	J28-3	600.15	200	PVC	130
333	P28-66	J28-6	J28-7	195.99	300	DCI	120
334	P28-64	J28-7a	J28-7	106.07	200	DCI	90
335	P28-46	RU(Ex)	PMP-9	31.39	300	Steel	120
336	P28-47	PMP-9	J28-38	28.96	250	Steel	120
337	P28-67	J28-7	J28-11	513.59	250	PVC	130
338	P28-15	J28-17	J28-9	620.88	100	PVC	130
339	P28-60	J28-23	J28-8	275.23	350	DCI	120
340	P28-2	J28-1	J28-9	345.95	300	DCI	90
341	P28-55	J28-22	J28-25	143.56	350	DCI	120

Appendix B – Model Outputs

Appendix B1 – Results of Nodal Consumptions and Pressures at Peak hour, Intermittent Model

No.	Node Label	Elevation (m)	Demand (l/s)	Demand (Calculated) (l/s)	Calculated Hydraulic Grade (m)	Pressure (m H2O)
1	L121	2,402.00	0	0	2,465	63
2	L125	2,404.00	0	0	1,611.16	-91.243
3	L130	2,402.00	0	0	1,711.15	-89.454
4	J-131	2,427.00	1.07	0.68	2,461.49	34.418
5	J-124	2,420.00	22.3	14.27	2,450.32	30.259
6	J-27	2,400.00	0	0	-11,037.22	-10.13
7	J-28	2,460.00	0	0	2,465.27	5.258
8	J-29	2,460.00	0	0	2,502.85	42.763
9	J-30	2,460.00	0	0	2,503.13	43.04
10	J-31	2,460.00	0	0	2,465.28	5.268
11	J-32	2,460.00	0	0	2,465.27	5.26
12	J-33	2,460.00	0	0	2,503.07	42.98
13	J-35	2,460.00	0	0	2,465.30	5.289
14	J-36	2,460.00	0	0	2,522.68	62.553
15	J-37	2,460.00	0	0	2,465.33	5.324
16	J-38	2,460.00	0	0	2,522.86	62.732
17	J-39	2,460.00	0	0	2,465.32	5.305

18	J-40	2,460.00	0	0	2,537.22	77.062
19	J-41	2,460.00	0	0	2,537.08	76.921
20	J-42	2,460.00	0	0	2,465.34	5.332
21	J-43	2,460.00	0	0	2,465.32	5.312
22	J-44	2,460.00	0	0	2,537.18	77
23	J-45	2,507.00	0	0	2,514.04	7
24	J-46	2,507.00	0	0	2,574.48	67
25	J-47	2,507.00	0	0	2,514.12	7
26	J-48	2,507.00	0	0	2,574.48	67
27	J-49	2,507.00	0	0	2,514	7
28	J-50	2,507.00	0	0	2,514	7
29	J-51	2,507.00	0	0	2,581.32	74.168
30	J-52	2,507.00	0	0	2,581.32	74.168
31	E15	2,564.00	2.7	1.73	2,576.01	11.984
32	J-133	2,432.00	1.07	0.68	2,463.92	31.852
33	J-132	2,433.00	1.07	0.68	2,463.20	30.141
34	T7	2,473.00	6.92	4.43	2,511.61	38.535
35	T12	2,512.00	3.2	2.05	2,514.09	2
36	T9	2,459.00	8.45	5.4	2,511.52	52
37	SP15	2,490.00	1.41	0.9	2,514.08	24
38	T13	2,510.00	3.2	2.05	2,513.72	4
39	T1	2,469.00	5.2	3.33	2,510.96	42

40	B14	2,536.00	47.5	30.4	2,563.57	28
41	J-63	2,560.00	0	0	2,571.79	11.766
42	J-64	2,560.00	0	0	2,571.74	11.716
43	J-65	2,560.00	0	0	2,571.74	11.716
44	SP16	2,490.00	1.41	0.9	2,563.47	73.318
45	J-67	2,560.00	0	0	2,571.74	11.716
46	J-68	2,560.00	0	0	2,690	130
47	J-79	2,340.00	0	0	2,198	-142
48	J-90	2,637.00	0	0	2,646	9
49	E13	2,637.00	2.93	1.88	2,691.36	54.246
50	J-92	2,682.00	0	0	2,687.37	5.363
51	E14	2,682.00	2.64	1.69	2,772.15	89.964
52	J-118	2,423.00	1.52	0.98	2,447.21	24.164
53	J-138	2,390.00	45.6	0.06	-11,037.22	-134.151
54	J-127	2,387.00	170	108.8	1,711.13	-74.509
55	J-123	2,376.00	12.5	8	2,222.66	-153.03
56	J-125	2,418.00	100	64	1,712	-74.747
57	J-126	2,418.00	22.92	14.67	2,450	32
58	J-129	2,411.00	7.53	4.82	2,457	46
59	J-122	2,386.00	7.54	4.82	2,438	52
60	J-120	2,371.00	5.78	3.7	2,446	75
61	J-121	2,366.00	5.79	3.71	2,445.35	79.19

62	J-115	2,405.00	4.77	3.05	2,456.91	51.81
63	J-130	2,425.00	1.07	0.68	2,463.84	38.766
64	J-116	2,405.00	2.21	1.41	2,460	55
65	J-117	2,406.00	2.22	1.42	2,447	41
66	J-84	2,410.00	0	0	2,438	28
67	J-134	2,411.00	1.35	0.86	2,441	29
68	J-119	2,431.00	1.54	0.98	2,450	19
69	T3	2,440.00	12.03	7.7	2,448	8
70	T11	2,410.00	8.45	5.4	2,462	52
71	T4	2,435.00	5.89	3.77	2,463	28
72	T8	2,472.00	6.92	4.43	2,512	40
73	T10	2,472.00	5.47	3.5	2,512	40
74	T5	2,455.00	5.47	3.5	2,512	56
75	T6	2,460.00	5.89	3.77	2,500	40
76	IC5	2,437.00	3.71	2.37	2,490	53
77	IC1	2,472.00	3.71	2.37	2,490	18
78	SP27	2,491.00	0	0	2,491	-0.48
79	T19	2,430.00	5.89	3.77	2463.7	33.637
80	RK22	2,431.00	15.23	17.67	2444.78	13.75
81	J-144	2,364.00	25.09	16.06	2420.77	56.656
82	RK7	2,511.00	0.73	0.47	2615.93	104.719
83	J-87	2,404.00	0	0	1611.22	-91.186

84	RK20	2,500.00	1.51	0.97	2532.7	32.63
85	RK15	2,522.00	0.78	0.5	2536.78	14.75
86	J-143	2,423.00	4.75	3.04	2432.76	9.74
87	J-112	2,346.00	12.82	8.2	2447.36	101.154
88	J-106	2,355.00	13.97	8.94	2410.11	54.997
89	E1	2,734.00	2.64	1.69	2749.31	15.281
90	E4	2,635.00	14.3	9.15	2644.23	9.207
91	J-128	2,385.00	12.31	-4.8	1614.14	-69.306
92	J-109	2,385.00	3.68	2.35	2426.05	40.971
93	E3	2,673.00	3.83	2.45	2686.96	13.935
94	J-141	2,432.00	1.52	0.98	2463.84	31.78
95	RK21	2,490.00	7.51	4.81	2531.37	41.291
96	J-108	2,353.00	2.29	1.47	2338.04	-14.933
97	J-110	2,417.00	7.72	4.94	2429.72	12.693
98	E2	2,708.00	1.25	0.8	2748.81	40.729
99	RK8	2,538.00	0.74	0.48	2608.18	70.038
100	E16	2,547.00	4.59	2.94	2570.66	23.611
101	RK14	2,523.00	0.77	0.49	2539.06	16.032
102	RK10	2,553.00	0.74	0.48	2624.25	71.102
103	J-142	2,424.00	4.76	3.04	2432.33	8.312
104	L109	2,345.00	1.41	0.9	2420.31	75.159
105	J-107	2,379.00	28.77	18.41	2343.37	-35.561

106	J-86	2,434.00	0	0	2431.76	-2.237
107	J-113	2,403.00	5.91	3.78	2454.07	50.971
108	G1	2,364.00	15.31	9.8	2418.62	54.513
109	RK9	2,588.00	4	6.17	2605.39	17.354
110	J-137	2,390.00	1.34	0.86	2438.14	48.048
111	RK13	2,520.00	3.5	6.11	2531.39	11.362
112	J-105	2,358.00	16.17	10.35	2410.79	52.683
113	J-111	2,397.00	4.75	3.04	2431.9	34.827
114	J-135	2,390.00	1.34	0.86	2438.28	48.186
115	J-136	2,390.00	1.35	0.86	2442.47	52.364
116	J-114	2,417.00	4.78	3.06	2446.68	29.621
117	IC7	2,441.00	8.35	5.35	2431.75	-9.227
118	J-139	2,373.00	12.91	8.26	1856.91	-55.05
119	J-140	2,365.00	9.28	5.94	2039.63	-34.717
120	T15	2,497.00	11.06	7.08	2511.44	14.414
121	T14	2,492.00	11.06	7.08	2512.78	20.734
122	T16	2,447.00	11.75	7.52	2501.02	53.911
123	T17	2,454.00	11.75	7.52	2464.57	10.553
124	T18	2,459.00	5.47	3.5	2511.55	52.447
125	E12	2,560.00	5.99	3.83	2570.98	10.957
126	J-101	2,545.00	0	0	2681.29	136.018
127	J-74	2,483.00	0	0	2703.53	220.088

128	SP26	2,493.00	5	3.2	2637.01	143.717
129	B9	2,582.00	3.44	2.2	2638.34	56.227
130	B4	2,593.00	24.12	15.44	2631.2	38.122
131	B7	2,631.00	2.18	1.4	2638.85	7.834
132	B8	2,636.00	2.18	1.4	2761.82	125.562
133	B11	2,610.00	2.66	1.7	2626.55	16.518
134	B10	2,600.00	42.5	27.2	2626.57	26.517
135	B1	2,706.00	6.59	4.22	2753.16	47.065
136	B13	2,595.00	3.74	2.39	2632.53	37.458
137	J-104	2,615.00	0	0	2630.17	15.137

Appendix B2 – Results of Nodal Consumptions and Pressures at off-Peak hour, Intermittent Model

No.	Node Label	Elevation (m)	Demand (l/s)	Demand (Calculated) (l/s)	Calculated Hydraulic Grade (m)	Pressure (m H2O)
1	L121	2,402.00	0	0	2,511	108
2	L125	2,404.00	0	0	2,409.18	5.17
3	L130	2,402.00	0	0	2,507.56	105.344
4	J-131	2,427.00	1.07	0.24	2,469.41	42.325
5	J-124	2,420.00	22.3	4.91	2,469.40	49.304
6	J-27	2,400.00	0	0	2,409.20	9.182
7	J-28	2,460.00	0	0	2,470.10	10.08
8	J-29	2,460.00	0	0	2,514.19	54.081
9	J-30	2,460.00	0	0	2,514.19	54.081
10	J-31	2,460.00	0	0	2,470.10	10.08
11	J-32	2,460.00	0	0	2,470.10	10.08
12	J-33	2,460.00	0	0	2,514.19	54.081
13	J-35	2,460.00	0	0	2,470.10	10.08
14	J-36	2,460.00	0	0	2,543.43	83.265
15	J-37	2,460.00	0	0	2,470.10	10.08
16	J-38	2,460.00	0	0	2,543.43	83.265
17	J-39	2,460.00	0	0	2,470.10	10.08
18	J-40	2,460.00	0	0	2,546.10	85.926

19	J-41	2,460.00	0	0	2,546.10	85.926
20	J-42	2,460.00	0	0	2,470.10	10.08
21	J-43	2,460.00	0	0	2,470.10	10.08
22	J-44	2,460.00	0	0	2,546.10	86
23	J-45	2,507.00	0	0	2,514.04	7
24	J-46	2,507.00	0	0	2,574.12	67
25	J-47	2,507.00	0	0	2,514.11	7
26	J-48	2,507.00	0	0	2,574.12	67
27	J-49	2,507.00	0	0	2,514	7
28	J-50	2,507.00	0	0	2,514	7
29	J-51	2,507.00	0	0	2,582.86	75.704
30	J-52	2,507.00	0	0	2,582.86	75.704
31	E15	2,564.00	2.7	0.59	2,577.98	13.953
32	J-133	2,432.00	1.07	0.24	2,469.81	37.731
33	J-132	2,433.00	1.07	0.24	2,469.69	36.62
34	T7	2,473.00	6.92	1.52	2,514.24	41.152
35	T12	2,512.00	3.2	0.7	2,514.29	2
36	T9	2,459.00	8.45	1.86	2,514.19	55
37	SP15	2,490.00	1.41	0.31	2,514.29	24
38	T13	2,510.00	3.2	0.7	2,514.28	4
39	T1	2,469.00	5.2	1.14	2,514.21	45
40	B14	2,536.00	47.5	10.45	2,570.21	34

41	J-63	2,560.00	0	0	2,571.39	11.37
42	J-64	2,560.00	0	0	2,570.97	10.944
43	J-65	2,560.00	0	0	2,571.26	11.235
44	SP16	2,490.00	1.41	0.31	2,570.20	80.037
45	J-67	2,560.00	0	0	2,570.97	10.944
46	J-68	2,560.00	0	0	2,663	102
47	J-79	2,340.00	0	0	2,395	55
48	J-90	2,637.00	0	0	2,645	8
49	E13	2,637.00	2.93	0.64	2,691.78	54.672
50	J-92	2,682.00	0	0	2,686.69	4.68
51	E14	2,682.00	2.64	0.58	2,754.76	72.61
52	J-118	2,423.00	1.52	0.34	2,454.03	30.962
53	J-138	2,390.00	45.6	11.12	2,408.68	18.64
54	J-127	2,387.00	170	37.4	2,501.03	113.796
55	J-123	2,376.00	12.5	2.75	2,475.57	99.372
56	J-125	2,418.00	100	22	2,500	82
57	J-126	2,418.00	22.92	5.04	2,469	51
58	J-129	2,411.00	7.53	1.66	2,469	58
59	J-122	2,386.00	7.54	1.66	2,468	82
60	J-120	2,371.00	5.78	1.27	2,468	97
61	J-121	2,366.00	5.79	1.27	2,467.85	101.644
62	J-115	2,405.00	4.77	1.05	2,468.18	63.049

63	J-130	2,425.00	1.07	0.24	2,469.79	44.7
64	J-116	2,405.00	2.21	0.49	2,469	64
65	J-117	2,406.00	2.22	0.49	2,442	36
66	J-84	2,410.00	0	0	2,460	50
67	J-134	2,411.00	1.35	0.3	2,458	47
68	J-119	2,431.00	1.54	0.34	2,462	31
69	T3	2,440.00	12.03	2.65	2,462	22
70	T11	2,410.00	8.45	1.86	2,470	59
71	T4	2,435.00	5.89	1.29	2,470	35
72	T8	2,472.00	6.92	1.52	2,514	42
73	T10	2,472.00	5.47	1.2	2,514	42
74	T5	2,455.00	5.47	1.2	2,514	59
75	T6	2,460.00	5.89	1.29	2,514	54
76	IC5	2,437.00	3.71	0.82	2,490	53
77	IC1	2,472.00	3.71	0.82	2,490	18
78	SP27	2,491.00	0	0	2,514	23
79	T19	2,430.00	5.89	1.29	2469.78	39.698
80	RK22	2,431.00	15.23	16.1	2466.68	35.611
81	J-144	2,364.00	25.09	5.52	2441.78	77.624
82	RK7	2,511.00	0.73	0.16	2640.18	128.917
83	J-87	2,404.00	0	0	2409.12	5.111
84	RK20	2,500.00	1.51	0.33	2540.92	40.837

85	RK15	2,522.00	0.78	0.17	2543.9	21.854
86	J-143	2,423.00	4.75	1.04	2458.58	35.507
87	J-112	2,346.00	12.82	2.82	2463.97	117.734
88	J-106	2,355.00	13.97	3.07	2453.62	98.417
89	E1	2,734.00	2.64	0.58	2750.09	16.062
90	E4	2,635.00	14.3	3.15	2645.33	10.306
91	J-128	2,385.00	12.31	4.81	2406.18	21.141
92	J-109	2,385.00	3.68	0.81	2457.15	72.002
93	E3	2,673.00	3.83	0.84	2686.84	13.812
94	J-141	2,432.00	1.52	0.34	2469.79	37.715
95	RK21	2,490.00	7.51	1.65	2539.69	49.594
96	J-108	2,353.00	2.29	0.5	2434.28	81.112
97	J-110	2,417.00	7.72	1.7	2457.95	40.867
98	E2	2,708.00	1.25	0.28	2750.02	41.94
99	RK8	2,538.00	0.74	0.16	2633.06	94.866
100	E16	2,547.00	4.59	1.01	2571.24	24.193
101	RK14	2,523.00	0.77	0.17	2545.41	22.36
102	RK10	2,553.00	0.74	0.16	2645.21	92.022
103	J-142	2,424.00	4.76	1.05	2458.49	34.423
104	L109	2,345.00	1.41	0.31	2441.72	96.523
105	J-107	2,379.00	28.77	6.33	2436.21	57.097
106	J-86	2,434.00	0	0	2458.38	24.328

107	J-113	2,403.00	5.91	1.3	2466.8	63.673
108	G1	2,364.00	15.31	3.37	2438.24	74.093
109	RK9	2,588.00	4	6.3	2627.2	39.12
110	J-137	2,390.00	1.34	0.29	2459.81	69.669
111	RK13	2,520.00	3.5	5.85	2539.59	19.547
112	J-105	2,358.00	16.17	3.56	2453.78	95.585
113	J-111	2,397.00	4.75	1.04	2458.4	61.28
114	J-135	2,390.00	1.34	0.29	2459.7	69.556
115	J-136	2,390.00	1.35	0.3	2460.79	70.642
116	J-114	2,417.00	4.78	1.05	2430.48	13.45
117	IC7	2,441.00	8.35	1.84	2458.38	17.342
118	J-139	2,373.00	12.91	2.84	2489.46	116.224
119	J-140	2,365.00	9.28	2.04	2481.07	115.839
120	T15	2,497.00	11.06	2.43	2514.2	17.165
121	T14	2,492.00	11.06	2.43	2514.26	22.214
122	T16	2,447.00	11.75	2.58	2514.19	67.054
123	T17	2,454.00	11.75	2.58	2469.94	15.905
124	T18	2,459.00	5.47	1.2	2514.19	55.076
125	E12	2,560.00	5.99	1.32	2571.16	11.136
126	J-101	2,545.00	0	0	2691.57	146.277
127	J-74	2,483.00	0	0	2655.83	172.478
128	SP26	2,493.00	5	1.1	2638.84	145.547

129	B9	2,582.00	3.44	0.76	2639.03	56.911
130	B4	2,593.00	24.12	5.31	2638.04	44.946
131	B7	2,631.00	2.18	0.48	2639.1	8.08
132	B8	2,636.00	2.18	0.48	2771.22	134.943
133	B11	2,610.00	2.66	0.59	2637.39	27.339
134	B10	2,600.00	42.5	9.35	2637.4	37.321
135	B1	2,706.00	6.59	1.45	2770.02	63.889
136	B13	2,595.00	3.74	0.82	2638.22	43.135
137	J-104	2,615.00	0	0	2637.89	22.848

Appendix B3 – Results of Pipes Discharge and Velocity at Peak hour, Intermittent Model

No.	Link Label	Length (m)	Diameter (mm)	Material	Initial Status	Control Status	Discharge (l/s)	Headloss Gradient (m/Km)	Velocity (m/s)
1	P-30	7,549.90	900	DI	Open	Open	-0.04	0.00	0.00
2	P-40	23.77	500	Steel	Open	Temporarily Closed	0.00	0.00	0.00
3	P-57	15.85	1,000	Steel	Open	Temporarily Closed	0.00	0.00	0.00
4	P-62	11.58	300	Steel	Open	Open	65.62	4.79	0.93
5	P-63	14.63	250	Steel	Open	Open	65.62	11.64	1.34
6	P-65	12.8	600	Steel	Open	Open	133.43	0.60	0.47
7	P-66	13.11	600	Steel	Open	Open	67.43	0.17	0.24
8	P-67	12.5	300	Steel	Open	Open	-131.62	17.36	1.86
9	P-68	12.5	300	Steel	Open	Open	-65.62	4.79	0.93
10	P-69	12.19	300	Steel	Open	Open	66.00	4.85	0.93
11	P-70	14.02	250	Steel	Open	Open	66.00	11.76	1.34
12	P-71	12.8	300	Steel	Open	Open	67.43	5.05	0.95
13	P-72	14.02	250	Steel	Open	Open	67.43	12.23	1.37
14	P-75	16.46	600	Steel	Open	Open	199.04	1.27	0.70
15	P-77	19.51	600	Steel	Open	Open	337.52	3.40	1.19
16	P-78	15.85	600	Steel	Open	Open	268.47	2.23	0.95
17	P-80	14.02	250	Steel	Open	Open	69.05	12.80	1.41
18	P-79	13.11	300	Steel	Open	Open	69.05	5.26	0.98
19	P-81	15.54	250	Steel	Open	Open	69.05	12.79	1.41
20	P-82	12.8	300	Steel	Open	Open	69.42	5.31	0.98
21	P-83	13.72	250	Steel	Open	Open	69.42	12.91	1.41
22	P-84	1,782.47	400	DI	Open	Open	138.48	4.70	1.10
23	P-88	22.86	350	Steel	Open	Open	70.14	2.55	0.73
24	P-89	16.76	350	Steel	Open	Open	46.46	1.20	0.48
25	P-91	19.51	350	Steel	Open	Open	23.16	0.33	0.24
26	P-92	19.81	250	Steel	Open	Open	23.16	1.68	0.47
27	P-93	17.68	250	Steel	Open	Open	46.46	6.15	0.95
28	P-95	11.89	200	Steel	Open	Open	23.16	5.01	0.74
29	P-96	14.63	150	Steel	Open	Open	23.16	20.37	1.31

30	P-97	12.8	200	Steel	Open	Open	23.30	5.07	0.74
31	P-98	14.02	150	Steel	Open	Open	23.30	20.57	1.32
32	P-99	13.41	200	Steel	Open	Open	23.69	5.23	0.75
33	P-100	13.41	150	Steel	Open	Open	23.69	21.22	1.34
34	P-101	1,730.04	250	DI	Open	Open	70.14	13.17	1.43
35	P-102	85.34	400	Steel	Open	Open	90.83	2.15	0.72
36	P-103	33.53	400	Steel	Open	Open	90.83	2.16	0.72
37	P-104	14.63	300	Steel	Open	Open	0.00	0.00	0.00
38	P-106	15.54	350	Steel	Open	Open	0.00	0.00	0.00
39	P-105	14.33	350	Steel	Open	Open	90.83	4.11	0.94
40	P-107	15.24	300	Steel	Open	Open	90.83	8.73	1.28
41	P-108	34.14	400	DI	Open	Open	0.00	0.00	0.00
42	P-109	1,246.02	400	DI	Open	Open	90.83	2.15	0.72
43	P-110	42.98	200	Steel	Open	Open	23.19	5.03	0.74
44	P-111	39.62	200	Steel	Open	Open	23.19	5.03	0.74
45	P-113	38.4	150	Steel	Open	Open	0.00	0.00	0.00
46	P-115	12.19	150	Steel	Open	Open	0.00	0.00	0.00
47	P-116	12.19	125	Steel	Open	Open	0.00	0.00	0.00
48	P-117	12.5	150	Steel	Open	Open	23.19	20.39	1.31
49	P-118	13.11	125	Steel	Open	Open	23.19	49.58	1.89
50	P-119	1,056.44	200	DI	Open	Open	23.19	5.03	0.74
51	P-120	1,435.30	150	DI	Open	Open	21.46	17.68	1.21
52	P-122	1,074.72	350	DI	Open	Open	62.20	2.05	0.65
53	P-123	58.83	400	DI	Open	Open	131.16	3.56	1.04
54	P-126	2,450.29	250	DI	Open	Open	0.90	0.00	0.02
55	P-127	134.72	400	DI	Open	Open	114.40	2.77	0.91
56	P-130	24.99	400	DI	Open	Open	35.13	0.38	0.28
57	P-131	1,885.19	200	DI	Open	Open	21.48	4.36	0.68
58	P-132	27.13	200	Steel	Open	Open	13.65	1.88	0.43
59	P-135	2,035.15	150	DI	Open	Open	0.90	0.05	0.05
60	P-136	21.64	150	Steel	Open	Open	0.00	0.00	0.00
61	P-137	20.12	150	Steel	Open	Open	0.00	0.00	0.00
62	P-139	1,258.82	150	DI	Open	Temporarily Closed	0.00	0.00	0.00
63	P-140	17.68	150	Steel	Open	Open	0.00	0.00	0.00
64	P-141	16.15	125	Steel	Open	Open	0.00	0.00	0.00

65	P-142	18.9	150	Steel	Open	Open	0.00	0.00	0.00
66	P-143	33.22	125	DI	Open	Open	0.00	0.00	0.00
67	P-184	32	150	DCI	Open	Open	10.50	4.72	0.59
68	P-185	14.02	125	Steel	Open	Open	10.50	11.42	0.86
69	P-186	17.37	100	Steel	Open	Open	10.50	33.92	1.34
70	P-187	409.65	125	DI	Open	Open	8.63	9.66	0.70
71	P-188	21.95	100	DCI	Open	Open	1.69	1.15	0.22
72	P-190	473.66	100	Galvani zed iron	Open	Temporarily Closed	0.00	0.00	0.00
73	P-189	15.85	100	Steel	Open	Open	1.69	1.15	0.22
74	P-191	16.46	80	Steel	Open	Open	1.69	3.40	0.34
75	P-428	99.97	150	DI	Open	Open	0.06	0.00	0.00
76	P-460	2,732.23	400	DI	Open	Open	4.80	0.01	0.04
77	P-461	1,458.16	400	DI	Open	Open	-36.38	0.48	0.29
78	P-463	26.52	400	DI	Closed	Closed	0.00	0.00	0.00
79	P-464	555.65	350	DI	Open	Open	-14.67	0.17	0.15
80	P-465	1,365.20	150	DI	Open	Open	-100.38	374.18	5.68
81	P-466	1,165.25	150	DI	Open	Open	-78.53	195.37	4.44
82	P-467	1,369.47	350	DI	Open	Open	-107.46	4.72	1.12
83	P-468	689.15	350	DI	Open	Open	-131.07	6.82	1.36
84	P-469	1,106.73	150	DI	Open	Open	18.79	16.80	1.06
85	P-470	472.74	150	DI	Open	Open	111.68	455.91	6.32
86	P-471	477.93	250	DI	Open	Open	-77.71	15.91	1.58
87	P-472	653.8	150	DI	Open	Open	3.71	0.68	0.21
88	P-473	859.54	300	DI	Open	Open	-101.00	12.93	1.43
89	P-474	629.11	500	DI	Open	Open	-254.09	4.88	1.29
90	P-475	782.73	500	DI	Open	Open	-255.51	4.93	1.30
91	P-476	392.89	200	Steel	Open	Open	8.60	0.80	0.27
92	P-478	11.28	200	DI	Closed	Closed	0.00	0.00	0.00
93	P-479	142.65	800	DI	Open	Open	-257.17	0.50	0.51
94	P-480	44.2	350	DI	Open	Open	189.84	16.16	1.97
95	P-481	63.09	350	DI	Open	Open	251.35	27.18	2.61
96	P-483	525.78	150	Steel	Open	Open	16.17	12.72	0.92
97	P-485	666.6	300	DI	Open	Open	119.60	17.69	1.69
98	P-487	1,366.11	200	DI	Open	Open	7.70	0.99	0.25
99	P-488	407.21	200	DI	Open	Open	25.75	6.10	0.82

100	P-490	1,286.87	250	DI	Open	Open	-3.38	0.06	0.07
101	P-491	1,222.55	200	DI	Open	Open	13.81	1.93	0.44
102	P-493	960.12	150	DI	Open	Open	-1.29	0.15	0.07
103	P-494	260.3	150	DI	Open	Open	3.50	0.75	0.20
104	P-495	84.43	250	DI	Open	Open	-6.52	0.20	0.13
105	P-496	865.33	250	DI	Open	Open	13.48	0.75	0.27
106	P-499	1,130.81	150	DI	Open	Open	14.24	10.06	0.81
107	P-500	761.09	250	DI	Open	Open	-69.67	15.80	1.42
108	P-501	529.74	200	DI	Open	Open	-2.37	0.11	0.08
109	P-507	1,641.96	500	DI	Open	Open	271.68	5.52	1.38
110	P-508	57	500	DI	Open	Open	271.68	5.52	1.38
111	P-554	1,096.98	150	DI	Open	Open	-5.40	1.38	0.31
112	P-555	716.58	150	DI	Open	Open	3.77	0.70	0.21
113	P-556	30.48	150	DI	Open	Open	12.94	6.92	0.73
114	P-666	863.8	150	DI	Open	Open	8.94	4.24	0.51
115	P-654	373.08	50	PVC	Open	Open	-1.49	22.29	0.76
116	P-673	617.83	150	Galvanized iron	Open	Open	-45.62	108.02	2.58
117	P-831	177.39	100	Galvanized iron	Open	Open	-5.60	12.87	0.71
118	P-634	154.23	400	Steel	Open	Open	-83.63	2.79	0.67
119	P-671	1,195.12	200	PVC	Open	Open	113.10	79.26	3.60
120	P-660	701.34	50	PVC	Open	Open	-1.02	11.05	0.52
121	P-658	811.99	50	PVC	Open	Open	-0.54	3.44	0.28
122	P-685	98.45	150	Steel	Open	Open	-19.23	21.80	1.09
123	P-672	403.56	150	DI	Open	Open	-16.50	13.21	0.93
124	P-830	377.04	100	Galvanized iron	Open	Open	-5.10	10.83	0.65
125	P-678	938.17	350	DI	Open	Open	-110.07	7.16	1.14
126	P-686	1,043.64	100	Galvanized iron	Open	Open	0.90	0.44	0.12
127	P-677	900.07	300	DI	Closed	Closed	0.00	0.00	0.00
128	P-703	383.74	400	Steel	Open	Open	-199.77	14.01	1.59
129	P-704	455.37	500	DI	Open	Open	-11.38	0.02	0.06
130	P-706	281.33	50	PVC	Open	Open	0.80	7.07	0.41
131	P-708	156.67	100	DI	Open	Open	-2.45	2.79	0.31
132	P-710	89.61	100	PVC	Open	Open	9.15	22.04	1.17

133	P-711	261.82	75	Galvanized iron	Open	Open	-1.69	5.68	0.38
134	P-712	292.91	100	Galvanized iron	Open	Open	2.94	3.90	0.37
135	P-718	357.84	75	Galvanized iron	Open	Open	5.63	52.70	1.27
136	P-713	769.01	100	Galvanized iron	Open	Open	6.09	15.04	0.78
137	P-716	1,100.63	150	DI	Open	Open	-0.34	0.01	0.02
138	P-717	1,944.93	150	DI	Open	Open	17.67	44.53	1.00
139	P-719	306.63	250	DI	Open	Open	24.45	62.77	0.50
140	P-720	1,122.27	150	DI	Open	Open	0.33	0.01	0.02
141	P-721	180.14	100	Galvanized iron	Open	Open	4.14	7.34	0.53
142	P-749	481.58	400	Steel	Open	Open	52.65	1.19	0.42
143	P-750	580.03	200	DI	Open	Open	17.21	3.52	0.55
144	P-751	610.82	250	DI	Open	Open	30.10	3.34	0.61
145	P-752	903.43	250	DI	Open	Open	33.43	4.06	0.68
146	P-753	1,101.24	250	DI	Open	Open	64.91	13.86	1.32
147	P-754	164.9	300	DI	Open	Open	54.56	4.13	0.77
148	P-755	833.32	200	DI	Open	Open	138.84	168.03	4.42
149	P-756	898.86	150	DI	Open	Open	-10.71	5.93	0.61
150	P-757	360.88	300	DI	Open	Open	27.93	1.20	0.40
151	P-759	838.5	200	DI	Open	Open	24.90	6.97	0.79
152	P-760	1,487.12	350	DI	Open	Open	-101.87	6.20	1.06
153	P-761	461.16	150	Steel	Open	Open	-2.21	0.32	0.13
154	P-764	194.77	150	Steel	Open	Open	-15.31	11.49	0.87
155	P-769	897.94	500	DI	Closed	Closed	0.00	0.00	0.00
156	P-770	18.29	150	DI	Open	Open	-12.24	7.60	0.69
157	P-771	766.27	300	DI	Open	Open	85.17	9.43	1.20
158	P-773	468.17	300	DI	Open	Open	84.31	9.26	1.19
159	P-775	20.73	150	DI	Closed	Closed	0.00	0.00	0.00
160	P-778	378.56	200	Steel	Open	Open	7.18	0.57	0.23
161	P-781	108.2	200	Steel	Open	Temporarily Closed	0.00	0.00	0.00
162	P-783	1,062.53	150	DI	Open	Open	4.12	0.83	0.23
163	P-784	489.81	150	DI	Open	Open	20.01	15.53	1.13
164	P-785	715.67	150	DI	Open	Open	-36.19	46.54	2.05

165	P-786	520.9	400	DI	Open	Open	-150.04	5.45	1.19
166	P-898	257.25	400	Steel	Open	Open	-5.35	0.01	0.04
167	P-901	2,182.06	150	Galvanized iron	Open	Open	-4.80	1.34	0.27
168	P-965	384.05	800	DI	Open	Open	-0.98	0.00	0.00
169	P-968	984.2	150	DI	Open	Open	-67.62	148.12	3.83
170	P-969	996.39	150	DI	Open	Open	-75.89	183.38	4.29
171	P-970	868.07	150	DI	Open	Open	-81.83	210.85	4.63
172	P-976	430.68	150	DI	Open	Open	11.18	5.28	0.63
173	P-977	586.74	150	DI	Open	Open	4.10	0.82	0.23
174	P-978	427.02	400	DI	Open	Open	101.18	2.20	0.81
175	P-979	603.81	400	DI	Open	Open	94.10	1.93	0.75
176	P-980	589.18	500	DI	Open	Open	199.04	3.10	1.01
177	P-981	496.82	500	DI	Open	Open	191.53	2.89	0.98
178	P-982	539.19	800	DI	Open	Open	468.15	1.53	0.93
179	P-983	442.26	800	DI	Open	Open	460.63	1.49	0.92
180	P-984	519.68	200	DI	Open	Open	5.52	0.35	0.18
181	P-985	586.44	200	DI	Open	Open	2.02	0.05	0.06
182	P-997	43.28	150	Galvanized iron	Open	Open	-4.80	1.34	0.27
183	P-636	99.36	150	DI	Open	Open	13.65	7.65	0.77
184	P-637	1,783.38	150	DCI	Open	Open	9.82	4.16	0.56
185	P-646	621.79	75	Galvanized iron	Open	Open	7.59	91.75	1.72
186	P-645	21.03	75	Galvanized iron	Open	Open	7.59	91.75	1.72
187	P-647	18.9	75	Galvanized iron	Open	Open	7.59	91.73	1.72
188	P-650	27.43	150	DCI	Open	Open	0.00	0.00	0.00
189	P-651	28.96	150	DCI	Open	Open	0.00	0.00	0.00
190	P-155	3,030.93	300	DI	Open	Temporarily Closed	0.00	0.00	0.00
191	P-585	2,909.62	150	Galvanized iron	Open	Open	3.20	0.63	0.18
192	P-583	730	110	PVC	Closed	Closed	0.00	0.00	0.00
193	P-576	1,649.27	100	PVC	Open	Open	4.22	5.25	0.54
194	P-584	404.47	200	DI	Open	Open	1.70	0.05	0.05
195	P-722	62.18	250	DI	Open	Open	-53.53	12.07	1.09

196	P-723	658.98	125	Galvanized iron	Open	Open	2.20	0.77	0.18
197	P-966	794	200	DI	Open	Open	17.83	7.95	0.57
198	P-967	464.21	200	DI	Open	Open	15.44	2.88	0.49
199	P-648	22.56	100	DI	Open	Open	2.81	3.59	0.36
200	P-649	23.77	100	DI	Open	Open	2.81	3.59	0.36
201	P-652	29.26	100	Steel	Open	Open	2.81	2.95	0.36
202	P-653	34.14	100	Steel	Open	Open	2.81	2.95	0.36
203	P-582a	15.54	90	DI	Open	Open	28.90	558.52	4.54
204	P-582	1,160.98	250	DI	Open	Open	28.90	3.10	0.59

Appendix B4 – Results of Pipes Discharge and Velocity at off-Peak hour, Intermittent Model

No.	Link Label	Length (m)	Diameter (mm)	Material	Initial Status	Control Status	Discharge (l/s)	Headloss Gradient (m/Km)	Velocity (m/s)
1	P-30	7,549.90	900	DI	Open	Temporarily Closed	0.00	0.00	0.00
2	P-40	23.77	500	Steel	Open	Open	98.15	0.84	0.50
3	P-57	15.85	1,000	Steel	Open	Open	-11.12	0.00	0.01
4	P-62	11.58	300	Steel	Open	Open	0.00	0.00	0.00
5	P-63	14.63	250	Steel	Open	Open	0.00	0.00	0.00
6	P-65	12.8	600	Steel	Open	Open	0.00	0.00	0.00
7	P-66	13.11	600	Steel	Open	Open	0.00	0.00	0.00
8	P-67	12.5	300	Steel	Open	Open	0.00	0.00	0.00
9	P-68	12.5	300	Steel	Open	Open	0.00	0.00	0.00
10	P-69	12.19	300	Steel	Open	Open	0.00	0.00	0.00
11	P-70	14.02	250	Steel	Open	Open	0.00	0.00	0.00
12	P-71	12.8	300	Steel	Open	Open	0.00	0.00	0.00
13	P-72	14.02	250	Steel	Open	Open	0.00	0.00	0.00
14	P-75	16.46	600	Steel	Open	Open	0.00	0.00	0.00
15	P-77	19.51	600	Steel	Open	Open	0.00	0.00	0.00
16	P-78	15.85	600	Steel	Open	Open	-0.30	0.00	0.00
17	P-80	14.02	250	Steel	Open	Open	0.30	0.00	0.01
18	P-79	13.11	300	Steel	Open	Open	0.30	0.00	0.00

19	P-81	15.54	250	Steel	Open	Open	0.30	0.00	0.01
20	P-82	12.8	300	Steel	Open	Open	-0.30	0.00	0.00
21	P-83	13.72	250	Steel	Open	Open	-0.30	0.00	0.01
22	P-84	1,782.47	400	DI	Open	Temporarily Closed	0.00	0.00	0.00
23	P-88	22.86	350	Steel	Open	Open	0.00	0.00	0.00
24	P-89	16.76	350	Steel	Open	Open	0.01	0.00	0.00
25	P-91	19.51	350	Steel	Open	Open	0.00	0.00	0.00
26	P-92	19.81	250	Steel	Open	Open	0.00	0.00	0.00
27	P-93	17.68	250	Steel	Open	Open	0.01	0.00	0.00
28	P-95	11.89	200	Steel	Open	Open	0.00	0.00	0.00
29	P-96	14.63	150	Steel	Open	Open	0.00	0.00	0.00
30	P-97	12.8	200	Steel	Open	Open	0.01	0.00	0.00
31	P-98	14.02	150	Steel	Open	Open	0.01	0.00	0.00
32	P-99	13.41	200	Steel	Open	Open	-0.01	0.00	0.00
33	P-100	13.41	150	Steel	Open	Open	-0.01	0.00	0.00
34	P-101	1,730.04	250	DI	Open	Temporarily Closed	0.00	0.00	0.00
35	P-102	85.34	400	Steel	Open	Open	91.52	2.18	0.73
36	P-103	33.53	400	Steel	Open	Open	91.52	2.18	0.73
37	P-104	14.63	300	Steel	Open	Open	0.00	0.00	0.00
38	P-106	15.54	350	Steel	Open	Open	0.00	0.00	0.00
39	P-105	14.33	350	Steel	Open	Open	91.52	4.18	0.95

40	P-107	15.24	300	Steel	Open	Open	91.52	8.87	1.29
41	P-108	34.14	400	DI	Open	Open	0.00	0.00	0.00
42	P-109	1,246.02	400	DI	Open	Open	91.52	2.18	0.73
43	P-110	42.98	200	Steel	Open	Open	22.15	4.61	0.70
44	P-111	39.62	200	Steel	Open	Open	22.15	4.62	0.70
45	P-113	38.4	150	Steel	Open	Open	0.00	0.00	0.00
46	P-115	12.19	150	Steel	Open	Open	0.00	0.00	0.00
47	P-116	12.19	125	Steel	Open	Open	0.00	0.00	0.00
48	P-117	12.5	150	Steel	Open	Open	22.15	18.75	1.25
49	P-118	13.11	125	Steel	Open	Open	22.15	45.56	1.80
50	P-119	1,056.44	200	DI	Open	Open	22.15	4.62	0.70
51	P-120	1,435.30	150	DI	Open	Open	21.55	17.82	1.22
52	P-122	1,074.72	350	DI	Open	Open	24.98	0.38	0.26
53	P-123	58.83	400	DI	Open	Open	20.12	0.11	0.16
54	P-126	2,450.29	250	DI	Open	Open	0.31	0.00	0.01
55	P-127	134.72	400	DI	Open	Open	16.57	0.08	0.13
56	P-130	24.99	400	DI	Open	Open	30.62	0.29	0.24
57	P-131	1,885.19	200	DI	Open	Open	7.53	0.63	0.24
58	P-132	27.13	200	Steel	Open	Open	23.09	4.99	0.74
59	P-135	2,035.15	150	DI	Open	Open	0.31	0.01	0.02
60	P-136	21.64	150	Steel	Open	Open	18.54	13.48	1.05
61	P-137	20.12	150	Steel	Open	Open	0.00	0.00	0.00

62	P-139	1,258.82	150	DI	Open	Open	18.54	13.49	1.05
63	P-140	17.68	150	Steel	Open	Open	18.54	13.49	1.05
64	P-141	16.15	125	Steel	Open	Open	18.54	32.78	1.51
65	P-142	18.9	150	Steel	Open	Open	0.00	0.00	0.00
66	P-143	33.22	125	DI	Open	Open	0.00	0.00	0.00
67	P-184	32	150	DCI	Open	Open	10.31	4.55	0.58
68	P-185	14.02	125	Steel	Open	Open	10.31	11.06	0.84
69	P-186	17.37	100	Steel	Open	Open	10.31	32.77	1.31
70	P-187	409.65	125	DI	Open	Open	9.66	11.92	0.79
71	P-188	21.95	100	DCI	Open	Open	5.31	9.59	0.68
72	P-190	473.66	100	Galvanized iron	Open	Open	4.73	9.41	0.60
73	P-189	15.85	100	Steel	Open	Open	5.31	9.60	0.68
74	P-191	16.46	80	Steel	Open	Open	5.31	28.45	1.06
75	P-428	99.97	150	DI	Open	Open	11.12	5.23	0.63
76	P-460	2,732.23	400	DI	Open	Open	96.11	2.39	0.76
77	P-461	1,458.16	400	DI	Open	Open	41.50	0.61	0.33
78	P-463	26.52	400	DI	Closed	Closed	0.00	0.00	0.00
79	P-464	555.65	350	DI	Open	Open	-5.04	0.02	0.05
80	P-465	1,365.20	150	DI	Open	Open	19.50	17.99	1.10
81	P-466	1,165.25	150	DI	Open	Open	11.19	5.29	0.63
82	P-467	1,369.47	350	DI	Open	Open	1.24	0.00	0.01

83	P-468	689.15	350	DI	Open	Open	-4.45	0.01	0.05
84	P-469	1,106.73	150	DI	Open	Open	4.04	0.97	0.23
85	P-470	472.74	150	DI	Open	Open	-17.89	15.33	1.01
86	P-471	477.93	250	DI	Open	Open	16.11	0.86	0.33
87	P-472	653.8	150	DI	Open	Open	1.27	0.09	0.07
88	P-473	859.54	300	DI	Open	Open	-13.42	0.31	0.19
89	P-474	629.11	500	DI	Open	Open	-115.82	1.14	0.59
90	P-475	782.73	500	DI	Open	Open	-116.31	1.15	0.59
91	P-476	392.89	200	Steel	Open	Open	61.66	30.75	1.96
92	P-478	11.28	200	DI	Closed	Closed	0.00	0.00	0.00
93	P-479	142.65	800	DI	Open	Open	-116.88	0.12	0.23
94	P-480	44.2	350	DI	Open	Open	70.33	2.57	0.73
95	P-481	63.09	350	DI	Open	Open	95.07	4.49	0.99
96	P-483	525.78	150	Steel	Open	Open	-12.40	7.78	0.70
97	P-485	666.6	300	DI	Open	Open	90.39	10.53	1.28
98	P-487	1,366.11	200	DI	Open	Open	2.65	0.14	0.08
99	P-488	407.21	200	DI	Open	Open	49.60	20.55	1.58
100	P-490	1,286.87	250	DI	Open	Open	-2.32	0.03	0.05
101	P-491	1,222.55	200	DI	Open	Open	2.53	0.08	0.08
102	P-493	960.12	150	DI	Open	Open	0.61	0.04	0.03
103	P-494	260.3	150	DI	Open	Open	1.20	0.10	0.07
104	P-495	84.43	250	DI	Open	Open	-4.46	0.10	0.09

105	P-496	865.33	250	DI	Open	Open	2.19	0.03	0.04
106	P-499	1,130.81	150	DI	Open	Open	0.49	0.02	0.03
107	P-500	761.09	250	DI	Open	Open	-3.39	0.06	0.07
108	P-501	529.74	200	DI	Open	Open	-0.82	0.02	0.03
109	P-507	1,641.96	500	DI	Open	Temporarily Closed	0.00	0.00	0.00
110	P-508	57	500	DI	Open	Temporarily Closed	0.00	0.00	0.00
111	P-554	1,096.98	150	DI	Open	Open	-1.86	0.19	0.11
112	P-555	716.58	150	DI	Open	Open	1.29	0.10	0.07
113	P-556	30.48	150	DI	Open	Open	4.45	0.96	0.25
114	P-666	863.8	150	DI	Open	Open	3.94	0.93	0.22
115	P-654	373.08	50	PVC	Open	Open	-1.13	13.49	0.58
116	P-673	617.83	150	Galvanized iron	Open	Open	-22.08	28.17	1.25
117	P-831	177.39	100	Galvanized iron	Open	Open	-4.48	8.49	0.57
118	P-634	154.23	400	Steel	Open	Open	-35.14	0.56	0.28
119	P-671	1,195.12	200	PVC	Open	Open	54.26	20.34	1.73
120	P-660	701.34	50	PVC	Open	Open	-0.97	10.15	0.50
121	P-658	811.99	50	PVC	Open	Open	-0.81	7.21	0.41
122	P-685	98.45	150	Steel	Open	Open	-25.18	35.94	1.42
123	P-672	403.56	150	DI	Open	Open	-9.55	4.80	0.54
124	P-830	377.04	100	Galvaniz	Open	Open	-4.30	7.90	0.55

				ed iron					
125	P-678	938.17	350	DI	Open	Open	-69.04	3.02	0.72
126	P-686	1,043.64	100	Galvanized iron	Open	Open	0.31	0.06	0.04
127	P-677	900.07	300	DI	Closed	Closed	0.00	0.00	0.00
128	P-703	383.74	400	Steel	Open	Open	-90.44	3.23	0.72
129	P-704	455.37	500	DI	Open	Open	11.28	0.02	0.06
130	P-706	281.33	50	PVC	Open	Open	0.28	0.98	0.14
131	P-708	156.67	100	DI	Open	Open	-0.84	0.39	0.11
132	P-710	89.61	100	PVC	Open	Open	3.15	3.05	0.40
133	P-711	261.82	75	Galvanized iron	Open	Open	-0.58	0.79	0.13
134	P-712	292.91	100	Galvanized iron	Open	Open	1.01	0.54	0.13
135	P-718	357.84	75	Galvanized iron	Open	Open	5.49	50.33	1.24
136	P-713	769.01	100	Galvanized iron	Open	Open	4.64	9.10	0.59
137	P-716	1,100.63	150	DI	Open	Open	1.17	0.10	0.07
138	P-717	1,944.93	150	DI	Open	Open	16.10	37.48	0.91
139	P-719	306.63	250	DI	Open	Open	19.63	41.79	0.40
140	P-720	1,122.27	150	DI	Open	Open	-1.15	0.10	0.07
141	P-721	180.14	100	Galvanized iron	Open	Open	3.97	6.81	0.51

142	P-749	481.58	400	Steel	Open	Open	22.19	0.24	0.18
143	P-750	580.03	200	DI	Open	Open	7.41	0.74	0.24
144	P-751	610.82	250	DI	Open	Open	12.95	0.70	0.26
145	P-752	903.43	250	DI	Open	Open	14.72	0.89	0.30
146	P-753	1,101.24	250	DI	Open	Open	28.71	3.06	0.58
147	P-754	164.9	300	DI	Open	Open	25.15	0.98	0.36
148	P-755	833.32	200	DI	Open	Open	69.50	46.65	2.21
149	P-756	898.86	150	DI	Open	Open	-6.20	2.15	0.35
150	P-757	360.88	300	DI	Open	Open	11.90	0.25	0.17
151	P-759	838.5	200	DI	Open	Open	10.86	1.50	0.35
152	P-760	1,487.12	350	DI	Open	Open	-66.22	2.79	0.69
153	P-761	461.16	150	Steel	Open	Open	2.00	0.26	0.11
154	P-764	194.77	150	Steel	Open	Open	12.69	8.13	0.72
155	P-769	897.94	500	DI	Closed	Closed	0.00	0.00	0.00
156	P-770	18.29	150	DI	Open	Open	10.99	6.22	0.62
157	P-771	766.27	300	DI	Open	Open	37.81	2.10	0.53
158	P-773	468.17	300	DI	Open	Open	37.51	2.07	0.53
159	P-775	20.73	150	DI	Closed	Closed	0.00	0.00	0.00
160	P-778	378.56	200	Steel	Open	Open	61.17	30.30	1.95
161	P-781	108.2	200	Steel	Open	Open	91.26	63.55	2.90
162	P-783	1,062.53	150	DI	Open	Open	-31.14	35.23	1.76

163	P-784	489.81	150	DI	Open	Open	-4.15	0.84	0.23
164	P-785	715.67	150	DI	Open	Open	-31.01	34.96	1.75
165	P-786	520.9	400	DI	Open	Open	-101.35	2.64	0.81
166	P-898	257.25	400	Steel	Open	Open	-1.84	0.00	0.01
167	P-901	2,182.06	150	Galvanized iron	Open	Open	4.81	1.35	0.27
168	P-965	384.05	800	DI	Open	Open	-0.34	0.00	0.00
169	P-968	984.2	150	DI	Open	Open	17.21	11.75	0.97
170	P-969	996.39	150	DI	Open	Open	14.37	8.42	0.81
171	P-970	868.07	150	DI	Open	Open	12.33	6.34	0.70
172	P-976	430.68	150	DI	Open	Open	1.87	0.19	0.11
173	P-977	586.74	150	DI	Open	Open	-0.56	0.02	0.03
174	P-978	427.02	400	DI	Open	Open	14.00	0.06	0.11
175	P-979	603.81	400	DI	Open	Open	11.57	0.04	0.09
176	P-980	589.18	500	DI	Open	Open	0.00	0.00	0.00
177	P-981	496.82	500	DI	Open	Open	-2.59	0.00	0.01
178	P-982	539.19	800	DI	Open	Open	194.47	0.30	0.39
179	P-983	442.26	800	DI	Open	Open	191.89	0.29	0.38
180	P-984	519.68	200	DI	Open	Open	0.74	0.01	0.02
181	P-985	586.44	200	DI	Open	Open	-0.46	0.00	0.01
182	P-997	43.28	150	Galvanized iron	Open	Open	4.81	1.35	0.27
183	P-636	99.36	150	DI	Open	Open	4.55	1.00	0.26

184	P-637	1,783.38	150	DCI	Open	Open	3.23	0.53	0.18
185	P-646	621.79	75	Galvanized iron	Open	Open	6.79	74.57	1.54
186	P-645	21.03	75	Galvanized iron	Open	Open	6.79	74.57	1.54
187	P-647	18.9	75	Galvanized iron	Open	Open	6.79	74.57	1.54
188	P-650	27.43	150	DCI	Open	Open	0.00	0.00	0.00
189	P-651	28.96	150	DCI	Open	Open	0.00	0.00	0.00
190	P-155	3,030.93	300	DI	Open	Open	70.62	5.49	1.00
191	P-585	2,909.62	150	Galvanized iron	Open	Open	1.10	0.09	0.06
192	P-583	730	110	PVC	Closed	Closed	0.00	0.00	0.00
193	P-576	1,649.27	100	PVC	Open	Open	1.45	0.73	0.18
194	P-584	404.47	200	DI	Open	Open	0.59	0.01	0.02
195	P-722	62.18	250	DI	Open	Open	-18.40	1.67	0.37
196	P-723	658.98	125	Galvanized iron	Open	Open	0.76	0.11	0.06
197	P-966	794	200	DI	Open	Open	6.13	1.10	0.20
198	P-967	464.21	200	DI	Open	Open	5.31	0.40	0.17
199	P-648	22.56	100	DI	Open	Open	0.97	0.50	0.12
200	P-649	23.77	100	DI	Open	Open	0.97	0.49	0.12
201	P-652	29.26	100	Steel	Open	Open	0.96	0.41	0.12
202	P-653	34.14	100	Steel	Open	Open	0.96	0.40	0.12

203	P-582a	15.54	90	DI	Open	Open	9.94	77.30	1.56
204	P-582	1,160.98	250	DI	Open	Open	9.94	0.43	0.20

Appendix B5 – Results of Consumptions and Pressures at Nodes, Steady State Analysis, Continuous Model

No.	Node Label	Elevation (m)	Demand (l/s)	Hydraulic Grade (m)	Pressure (m H2O)
1	J22-28	2521	5.80	2551.17	30.113
2	J22-30	2512	4.05	2556.46	44.371
3	J22-36	2535	27.29	2548.84	13.815
4	J22-27	2489	4.43	2556.71	67.571
5	J22-37	2520	3.69	2553.92	33.853
6	J22-35	2496	6.64	2551.5	55.383
7	J22-16	2480	6.27	2556.92	76.766
8	J22-2	2519	3.32	2560.48	41.398
9	J22-32	2520	2.95	2554.2	34.132
10	J22-25	2490	8.11	2556.72	66.59
11	J22-31	2490	7.01	2558.03	67.892
12	J22-33	2490	3.69	2550.95	60.823
13	J22-8	2536	3.32	2553.61	17.577
14	J22-4	2514	1.84	2560.13	46.034
15	J22-17	2468	0.00	2557.23	89.053
16	J22-21	2514	2.95	2560.31	46.213
17	J22-20	2494	7.38	2557.48	63.353
18	J22-24	2478	12.17	2549.96	71.819
19	J22-26	2473	2.95	2557.31	84.137
20	J22-22	2501	5.53	2557.49	56.375
21	J22-11	2504	2.21	2559.58	55.468
22	J22-19	2494	2.95	2559.25	65.116
23	J22-1	2518	3.32	2560.4	42.319
24	J22-7	2538	4.05	2553.53	15.499
25	J22-23	2517	8.85	2553.87	36.795
26	J22-15	2489	5.90	2551.37	62.248

27	J22-12	2511	5.90	2556.32	45.227
28	J22-29	2536	4.43	2556.57	20.532
29	J22-13	2532	7.74	2553.61	21.569
30	J22-10	2526	3.32	2560.28	34.211
31	J22-3	2511	2.21	2560.08	48.98
32	J22-14	2513	7.38	2551.96	38.882
33	J22-18	2503	2.21	2557.54	54.425
34	J22-34	2510	3.69	2551.48	41.394
35	J22-39	2528	6.27	2560.97	32.9
36	J22-76	2475	1.84	2557.36	82.192
37	J22-81	2,562.00	0	2,563.10	1.102
38	J22-6	2,562.00	0	2,563.17	1.172
39	J22-40	2539	2.69	2550.92	11.899
40	J26-4	2589	0.91	2636.65	47.551
41	J26-11	2587	1.97	2637.83	50.731
42	J26-13	2563	0.00	2653.97	90.785
43	J26-12	2606	0.86	2638.32	32.255
44	J26-3	2613	1.23	2637.43	24.378
45	J26-9	2579	6.47	2636.02	56.901
46	J26-2	2589	1.37	2636.88	47.779
47	J26-8	2605	3.66	2636.78	31.713
48	J26-1	2601	2.56	2637.41	36.341
49	J26-10	2568	2.24	2636.16	68.025
50	J26-5	2610	0.65	2636.31	26.256
51	J26-7	2600	2.36	2636.1	36.028
52	J26-6	2604	1.38	2638.21	34.14
53	J29-8	2617	1.48	2682.65	65.521
54	J29-2	2632	1.19	2682.91	50.81
55	J29-6	2656	1.31	2683.49	27.436
56	J29-21	2638	0.00	2691.67	53.56
57	J29-7	2617	2.13	2682.73	65.594
58	J29-4	2641	1.33	2682.67	41.591
59	J29-3	2648	2.84	2682.68	34.609
60	J29-1	2636	1.19	2683.02	46.929
61	J29-9	2647	2.12	2682.85	35.777
62	J29-5	2646	2.50	2683.25	37.176

63	J30-1	2711	2.32	2747.4	36.331
64	J30-9	2668	1.02	2746.85	78.694
65	J30-6	2677	1.87	2746.11	68.975
66	J30-2	2707	1.82	2747.29	40.209
67	J30-4	2664	1.53	2746.42	82.251
68	J30-10	2683	0.00	2752.01	68.867
69	J30-3	2677	0.76	2746.7	69.562
70	J30-8	2703	2.22	2746.98	43.888
71	J24-13	2586	2.24	2601.77	15.738
72	J24-4	2574	2.74	2602.63	28.574
73	J24-7	2555	4.48	2608.5	53.389
74	J24-10	2594	2.74	2609.25	15.224
75	J24-43	2570	3.49	2607.86	37.779
76	J24-22	2573	2.99	2603.96	30.902
77	J24-32	2545	5.72	2606.96	61.833
78	J24-14	2572	1.49	2601.43	29.368
79	J24-28	2552	3.49	2605.59	53.483
80	J24-3	2579	2.74	2603.06	24.015
81	J24-33	2563	4.23	2600.98	37.903
82	J24-9	2593	0.00	2609.74	16.71
83	J24-34	2559	1.50	2600.67	41.589
84	J24-21	2561	2.24	2604.55	43.466
85	EN-1	2572	0.00	2635.34	63.207
86	J24-34a	2585	1.50	2600.5	15.472
87	J27-7	2600	1.23	2663.51	63.384
88	J27-15	2592	2.20	2661.81	69.669
89	J27-6	2599	3.84	2661.47	62.349
90	J27-10	2640	2.56	2661.19	21.144
91	J27-8	2629	2.16	2663.84	34.766
92	J27-12	2614	5.60	2662.96	48.865
93	J27-3	2627	1.34	2664.69	37.613
94	J27-11	2593	2.70	2664.16	71.012
95	J27-14	2618	3.67	2664.62	46.53
96	J27-2	2658	0.00	2665.73	7.715
97	J27-9	2625	1.33	2664.24	39.163
98	J27-17	2608	0.00	2665.18	57.069

99	J27-13	2597	0.97	2664.16	67.027
100	J27-16	2625	2.88	2662.61	37.535
101	J18-20	2455	5.35	2499.52	44.428
102	J18-13	2470	1.21	2498.99	28.929
103	J18-41	2467	4.79	2506.13	39.052
104	J18-26	2458	6.49	2496.82	38.738
105	J18-43	2432	4.84	2499.46	67.324
106	J18-9	2473	2.08	2504.37	31.304
107	J18-36	2469	5.71	2502.36	33.289
108	J18-27	2464	11.33	2496.09	32.029
109	J18-21	2484	21.77	2497.82	13.796
110	J18-35	2481	5.00	2504.33	23.279
111	J18-14	2470	1.62	2499.12	29.064
112	J18-34	2457	5.20	2501.55	44.464
113	J18-6	2440	1.09	2499.17	59.054
114	J18-51	2470	35.90	2485.82	15.79
115	J18-49	2431	16.82	2488.76	57.645
116	J18-50	2468	4.06	2500.39	32.329
117	J18-39	2477	3.81	2501.93	24.882
118	J18-10	2471	4.41	2503.96	32.896
119	J18-25	2456	2.77	2500.06	43.976
120	J18-37	2447	4.89	2498.83	51.724
121	J18-48	2477	14.08	2491.51	14.477
122	J18-16	2440	4.08	2499.51	59.392
123	J18-40	2469	4.08	2500.63	31.57
124	J18-15	2428	4.69	2499.51	71.363
125	J18-18	2461	5.38	2500.51	39.434
126	J18-17	2463	4.93	2501.03	37.95
127	J18-12	2442	0.95	2499	56.88
128	J18-38	2434	5.99	2499.99	65.853
129	J18-29	2477	11.20	2495.85	18.809
130	J18-4	2459	10.57	2500.48	41.393
131	J18-8	2457	7.27	2500.54	43.447
132	J18-7	2459	4.38	2501.37	42.281
133	J18-24	2470	2.99	2499.84	29.782
134	J18-31	2470	9.85	2495.32	25.274

135	J18-5	2442	1.62	2499.12	57.007
136	J18-19	2455	5.24	2501.39	46.298
137	J18-28	2470	4.77	2502.17	32.104
138	J18-23	2478	5.13	2506.14	28.084
139	J18-33	2461	4.27	2502.79	41.704
140	J18-42	2439	4.14	2499.4	60.276
141	J18-3	2461	4.51	2500.58	39.497
142	J18-44	2482	4.67	2504.51	22.463
143	J18-53	2470	0.00	2500.47	30.404
144	J18-32	2447	3.73	2500.48	53.373
145	JP-2	2390	0	2454.20	64.069
146	JP-3	2404	0	2451.60	47.507
147	J14-85	2391	3.05	2451.55	60.424
148	J14-105	2397	3.09	2451.55	54.441
149	J14-106	2387	2.66	2451.69	64.564
150	J14-104	2370	3.47	2451.04	80.88
151	J14-116	2379	0.9	2451.77	72.625
152	J14-22	2377	1.78	2451.96	74.805
153	J14-107	2377	1.25	2452.31	75.154
154	J14-21	2388	1.58	2452.05	63.919
155	J14-19	2391	2.99	2452.20	61.08
156	J14-18	2389	3.55	2452.30	63.173
157	J14-47	2393	3.75	2447.81	54.702
158	J14-48	2418	3.07	2447.73	29.671
159	J14-99	2414	2.01	2446.77	32.701
160	J14-100	2422	2.41	2446.61	24.563
161	J14-92	2403	2.01	2451.55	48.447
162	J14-6	2461.5	0	2464.55	3.042
163	J14-14	2433	3.47	2463.43	30.367
164	J14-15	2425	2.49	2463.30	38.221
165	J14-82	2432	1.44	2462.67	30.605
166	J14-83	2416	1.98	2462.64	46.545
167	J14-112	2424	3.63	2462.31	38.235
168	J14-44	2383	3.8	2462.63	79.466
169	J14-45	2411	1.34	2461.92	50.817
170	J14-53	2411	3.18	2461.30	50.203

171	J14-37	2421	2.68	2460.87	39.789
172	J14-28	2405	2.53	2457.91	52.802
173	J14-27	2414	3.15	2459.04	44.945
174	J14-79	2416	2.12	2455.00	38.919
175	J14-49	2403	1.91	2456.52	53.408
176	J14-69	2405	3.26	2456.52	51.411
177	J14-60	2397	4.85	2457.95	60.825
178	J14-90	2409	3.72	2456.36	47.269
179	J14-16	2411	3.3	2459.48	48.381
180	J14-30	2422	3.32	2458.73	36.657
181	J14-46	2410	7.57	2457.62	47.525
182	J14-115	2436	7.42	2456.33	20.289
183	J14-17	2407	2.54	2458.81	51.703
184	J14-41	2403	2.59	2458.22	55.11
185	J14-91	2386	1.67	2456.39	70.244
186	J14-96	2377	3.42	2455.31	78.151
187	J14-102	2378	3.92	2453.51	75.359
188	J14-89	2377	2.24	2452.63	75.478
189	J14-38	2405	4.06	2456.85	51.742
190	J14-39	2410	3.28	2456.18	46.085
191	J14-88	2420	6.07	2455.18	35.112
192	J14-94	2418	5.39	2453.62	35.552
193	J14-54	2406	5.23	2453.13	47.04
194	J14-55	2403	3.27	2452.90	49.796
195	J14-75	2393	3.98	2452.63	59.515
196	J12-2	2417	0	2418.07	1.063
197	J12-10	2404	2.83	2417.90	13.87
198	J12-12	2376	16.26	2415.42	39.34
199	J12-29	2386	9.19	2415.09	29.035
200	J12-14	2379	2.83	2417.09	38.016
201	J12-34	2369	7.85	2416.44	47.343
202	J12-11	2371	17.68	2415.92	44.832
203	J12-15	2363	7.78	2415.78	52.673
204	J12-16	2366	8.49	2415.59	49.488
205	J12-25	2403.5	4.24	2417.74	14.214
206	J12-5	2364	4.95	2417.13	53.022

207	J12-6	2364	5.66	2417.10	52.995
208	J12-21	2373	3.54	2417.65	44.556
209	J12-22	2361	3.54	2417.60	56.486
210	J12-23	2350	3.54	2417.56	67.428
211	J12-78	2344	2.83	2417.38	73.233
212	J28-22	2635	0.00	2670.36	35.287
213	J28-7	2603	6.14	2667.75	64.615
214	J28-8	2619	7.87	2669.02	49.918
215	J28-13	2654	1.20	2671.50	17.466
216	J28-12	2650	11.82	2665.44	15.412
217	J28-11	2607	6.85	2666.61	59.492
218	J28-1	2631	3.02	2670.08	38.998
219	J28-7a	2601	0.00	2667.75	66.611
220	J28-23	2616	0.00	2669.55	53.446
221	J28-15	2633	4.04	2669.50	36.427
222	J28-5	2645	4.18	2667.95	22.908
223	J28-17	2604	5.43	2669.58	65.443
224	J28-16	2611	2.45	2667.84	56.726
225	J28-20	2651	3.87	2666.82	15.79
226	J28-10	2594	5.34	2668.24	74.094
227	J28-25	2633	0.00	2670.08	37.004
228	J28-8a	2614	0.00	2669.02	54.908
229	J28-6a	2627	0.00	2668.10	41.012
230	J28-4	2621	3.89	2668.32	47.226
231	J28-38	2590	0.00	2691.59	101.389
232	J28-6	2609	6.31	2668.10	58.976
233	J28-14	2645	3.72	2670.87	25.814
234	J28-3	2627	3.71	2669.77	42.688
235	J28-9	2606	8.01	2669.92	63.793

Appendix B6 – Results of Pipes Discharge and Velocity, Steady State Analysis, Continuous Model

No.	Link Label	Length (m)	Diameter (mm)	Material	Initial Status	Discharge (l/s)	Pressure Pipe Headloss (m)	Velocity (m/s)
1	P22-4	92.66	150	PVC	Open	-5.52	0.08	0.31
2	P22-29	206.04	150	DCI	Open	16.45	2.71	0.93
3	P22-12	606.25	150	PVC	Open	6.52	0.73	0.37
4	P22-21	227.08	150	DCI	Open	-15.1	2.54	0.85
5	P22-41	521.21	150	PVC	Open	-0.94	0.02	0.05
6	P22-8	688.85	150	DCI	Open	-2.26	0.23	0.13
7	P22-15	227.99	350	DCI	Open	84.48	0.59	0.88
8	P22-25	582.47	200	DCI	Open	11.14	0.92	0.35
9	P22-7	193.55	250	DCI	Open	26.18	0.5	0.53
10	P22-31	758.04	200	PVC	Open	19.9	1.77	0.63
11	P22-9	57.91	350	DCI	Open	-45.4	0.05	0.47
12	P22-13	405.69	150	PVC	Open	7.3	0.6	0.41
13	P22-33	500.79	200	PVC	Open	-20.38	1.22	0.65
14	P22-43	334.67	300	DCI	Open	73.49	1.41	1.04
15	P22-39	299.92	150	DCI	Open	2.03	0.08	0.11
16	P22-34	395.33	150	PVC	Open	-8.72	0.81	0.49
17	P22-42	526.69	300	DCI	Open	50.82	1.12	0.72
18	P22-40	422.15	150	DCI	Open	-15.8	5.15	0.89
19	P22-36	787.91	100	PVC	Open	-1.72	0.57	0.22
20	P22-16	736.4	450	DCI	Open	-201.93	2.8	1.27
21	P22-32	281.03	250	PVC	Open	45.77	1.03	0.93
22	P22-38	719.02	150	PVC	Open	-4.65	0.46	0.26
23	P22-17	594.66	150	PVC	Open	-12.64	2.43	0.72
24	P22-11	237.13	200	PVC	Open	-14.61	0.31	0.47
25	P22-10	422.76	150	PVC	Open	2.9	0.11	0.16
26	P22-23	36.27	150	PVC	Open	-8.89	0.08	0.5
27	P22-5	654.1	150	DCI	Open	7.3	1.91	0.41
28	P22-24	462.08	200	DCI	Open	23.16	2.82	0.74
29	P22-30	289.26	450	DCI	Open	208.1	1.16	1.31
30	P22-20	877.52	150	PVC	Open	-7.33	1.3	0.41

31	P22-18	705.92	100	PVC	Open	-0.28	0.02	0.04
32	P22-86	80.16	400	DCI	Open	105.67	0.28	0.84
33	P22-87	47.24	200	PVC	Open	32.97	0.28	1.05
34	P22-88	269.75	150	DCI	Open	13.46	2.44	0.76
35	P22-89	204.22	150	DCI	Open	6.87	0.53	0.39
36	P22-91	865.33	400	DCI	Open	92.32	2.33	0.73
37	P22-92	170.38	400	DCI	Open	102.96	0.56	0.82
38	P22-93	386.79	200	PVC	Open	-16.83	0.66	0.54
39	P22-94	197.51	500	DCI	Open	253.89	0.69	1.29
40	P22-95	851	700	DCI	Open	541.2	2.33	1.41
41	P22-96	252.07	500	DCI	Open	248.16	0.84	1.26
42	P22-97	59.44	500	DCI	Open	305	0.29	1.55
43	P22-98	18.29	500	DCI	Open	305	0.09	1.55
44	P22-99	732.43	250	DCI	Open	28.58	2.22	0.58
45	P22-100	142.34	250	DCI	Open	14.61	0.12	0.3
46	P22-101	17.37	150	PVC	Open	-10.54	0.05	0.6
47	P22-104	442.87	250	DCI	Open	-11.71	0.26	0.24
48	P22-103	811.38	450	DCI	Open	164.86	2.12	1.04
49	P22-105	207.87	450	DCI	Open	126.4	0.33	0.79
50	P22-106	647.4	350	DCI	Open	90.91	1.91	0.94
51	P24-31	340.77	150	PVC	Open	5.59	0.31	0.32
52	P24-56	560.83	200	PVC	Open	14.83	0.76	0.47
53	P24-17	356.92	250	PVC	Open	40.33	1.04	0.82
54	P24-35	209.7	200	PVC	Open	19.92	0.49	0.63
55	P24-15	572.11	350	DCI	Open	77.4	1.25	0.8
56	P24-53	214.27	200	PVC	Open	16.24	0.34	0.52
57	P24-38	356.62	250	PVC	Open	46.82	1.37	0.95
58	P24-34	516.64	250	PVC	Open	30.61	0.9	0.62
59	P24-33	352.96	200	PVC	Open	20.41	0.86	0.65
60	P24-122	541.02	150	PVC	Open	-6.49	0.64	0.37
61	P24-16	1,042.72	300	DCI	Open	57.48	2.79	0.81
62	P24-32	396.24	200	PVC	Open	13.46	0.45	0.43
63	P24-55	248.41	250	PVC	Open	36.17	0.59	0.74
64	P24-54	117.04	200	PVC	Open	25.51	0.43	0.81
65	P22-108	3,913.33	300	DCI	Open	77.83	18.34	1.1
66	EN-6	16.46	250	Steel	Open	38.94	0.05	0.79

67	EN-5	15.54	200	Steel	Open	38.94	0.15	1.24
68	EN-3	21.95	200	Steel	Open	-38.88	0.2	1.24
69	EN-4	19.51	250	Steel	Open	-38.88	0.06	0.79
70	P27-15	352.96	200	PVC	Open	14.69	0.47	0.47
71	P27-3	260.3	100	PVC	Open	-2.29	0.32	0.29
72	P27-7	372.47	200	PVC	Open	-11.92	0.34	0.38
73	P27-9	460.55	250	PVC	Open	35.23	1.04	0.72
74	P27-16	374.29	150	PVC	Open	2.57	0.08	0.15
75	P27-6	280.72	250	PVC	Open	-27.68	0.41	0.56
76	P27-8	290.17	150	PVC	Open	0.77	0.01	0.04
77	P27-11	416.66	150	PVC	Open	10.43	1.19	0.59
78	P27-5	226.16	250	PVC	Open	32.74	0.45	0.67
79	P27-4	410.57	200	PVC	Open	21.53	1.11	0.69
80	P27-1	103.02	300	DCI	Open	56.76	0.27	0.8
81	P27-33	647.4	200	PVC	Open	34.53	4.18	1.1
82	P27-13	514.2	200	PVC	Open	-16.02	0.8	0.51
83	P27-31	429.16	150	PVC	Open	-4.77	0.29	0.27
84	P27-14	460.55	200	PVC	Open	-21.38	1.22	0.68
85	RS-1	22.25	250	Steel	Open	34.53	0.06	0.7
86	RS-2	24.38	200	Steel	Open	34.53	0.18	1.1
87	P29-3	318.21	150	PVC	Open	8.12	0.57	0.46
88	P29-9	167.64	250	PVC	Open	-27.51	0.24	0.56
89	P29-2	371.25	150	PVC	Open	-3.94	0.17	0.22
90	P30-3	300.84	150	PVC	Open	6.04	0.31	0.34
91	P29-5	277.67	150	PVC	Open	-2.39	0.05	0.14
92	P26-33	22.56	250	Steel	Open	-29.57	0.04	0.6
93	P29-23	444.7	200	PVC	Open	33.17	2.67	1.06
94	P29-7	379.78	150	PVC	Open	1.26	0.02	0.07
95	P26-34	45.11	150	PVC	Open	9.63	0.11	0.55
96	P26-5	226.77	150	PVC	Open	11.54	0.78	0.65
97	P30-16	20.12	150	Steel	Open	13.18	0.1	0.75
98	P29-8	170.38	200	PVC	Open	-14.74	0.23	0.47
99	P26-13	265.79	150	PVC	Open	6.74	0.34	0.38
100	P26-4	144.17	150	PVC	Open	12.06	0.54	0.68
101	P26-10	261.52	150	PVC	Open	10.53	0.76	0.6
102	P26-28	573.94	250	DCI	Open	48.09	2.68	0.98

103	P26-6	257.56	150	PVC	Open	-5.28	0.21	0.3
104	P26-11	306.32	150	PVC	Open	3.97	0.15	0.22
105	P29-4	67.06	150	PVC	Open	1.35	0	0.08
106	P26-30	1,309.73	250	Steel	Open	59.14	8.97	1.2
107	P30-18	17.37	150	Steel	Open	13.18	0.09	0.75
108	P29-21	303.89	250	PVC	Open	29.95	0.51	0.61
109	P26-3	374.29	250	PVC	Open	36.53	0.91	0.74
110	P30-19	392.28	150	DCI	Open	13.18	2.01	0.75
111	P26-2	598.63	150	DCI	Open	9.4	2.79	0.53
112	P30-2	64.92	200	PVC	Open	17.17	0.11	0.55
113	P29-10	334.06	150	PVC	Open	-1.49	0.03	0.08
114	P26-29	24.99	250	Steel	Open	29.57	0.05	0.6
115	P29-11	162.76	150	PVC	Open	-6.36	0.19	0.36
116	P29-24	22.25	200	Steel	Open	33.17	0.15	1.06
117	P26-12	374.6	150	PVC	Open	8.79	0.78	0.5
118	P26-7	327.36	150	DCI	Open	4.41	0.38	0.25
119	P29-6	59.44	152	PVC	Open	8.58	0.11	0.47
120	P30-7	139.9	100	PVC	Open	1.9	0.12	0.24
121	P26-9	306.32	200	PVC	Open	18.74	0.64	0.6
122	P26-32	26.82	200	Steel	Open	-29.57	0.15	0.94
123	P30-4	153.01	100	PVC	Open	2.85	0.29	0.36
124	P26-31	23.16	200	Steel	Open	29.57	0.13	0.94
125	P30-1	356.01	150	PVC	Open	7.75	0.59	0.44
126	P29-22	14.63	200	Steel	Open	33.17	0.1	1.06
127	P26-14	328.57	150	PVC	Open	8.99	0.71	0.51
128	P30-8	221.59	200	PVC	Open	-21.49	0.6	0.68
129	P30-6	217.32	100	PVC	Open	3.49	0.59	0.44
130	P18-123	395.33	300	DCI	Open	72.71	1.63	1.03
131	P18-9	342.6	100	PVC	Open	0.27	0.01	0.03
132	P18-14	500.18	150	PVC	Open	-8.96	1.08	0.51
133	P18-4	689.46	250	DCI	Open	39.4	3.79	0.8
134	P18-34	354.18	150	PVC	Open	-4.6	0.22	0.26
135	P18-41	363.02	100	PVC	Open	-2.84	0.67	0.36
136	P18-52	405.69	250	PVC	Open	36.99	1	0.75
137	P18-23	396.54	150	PVC	Open	9.84	1.02	0.56
138	P18-21	451.71	200	PVC	Open	19.03	0.97	0.61

139	P18-127	681.53	150	DCI	Open	-2.33	0.24	0.13
140	P18-19	662.03	250	PVC	Open	44.82	2.34	0.91
141	P18-37	172.52	100	PVC	Open	-1.78	0.13	0.23
142	P18-125	292.91	200	DCI	Open	-9.31	0.33	0.3
143	P18-126	652.27	200	DCI	Open	-13.87	1.54	0.44
144	P18-119	84.73	250	DCI	Open	36.48	0.4	0.74
145	P18-118	234.09	200	DCI	Open	-30.91	2.43	0.98
146	P18-59	328.57	250	PVC	Open	36.72	0.8	0.75
147	P18-15	658.37	150	PVC	Open	-1.43	0.05	0.08
148	P18-56	957.07	350	DCI	Open	89.57	2.75	0.93
149	P18-49	385.57	200	DCI	Open	21.06	1.97	0.67
150	P18-13	49.99	250	PVC	Open	33.04	0.1	0.67
151	P18-6	338.94	150	DCI	Open	-11.18	2.18	0.63
152	P18-135	508.41	400	DCI	Open	6.26	0.01	0.05
153	P18-50	451.71	500	DCI	Open	251.11	1.54	1.28
154	P18-131	576.68	250	DCI	Open	-2.62	0.02	0.05
155	P18-48	593.14	200	DCI	Open	11.35	0.97	0.36
156	P18-40	382.52	500	DCI	Open	243.86	1.23	1.24
157	P18-35	331.62	450	DCI	Open	149.49	0.72	0.94
158	P18-27	146.3	100	PVC	Open	1.88	0.13	0.24
159	P18-11	80.77	150	PVC	Open	-4.62	0.05	0.26
160	P18-2	478.84	250	DCI	Open	1.88	0.01	0.04
161	P18-45	154.23	250	DCI	Open	30.01	0.51	0.61
162	P18-58	261.52	150	PVC	Open	0.75	0.01	0.04
163	P18-122	515.42	250	DCI	Open	40.16	2.94	0.82
164	P18-55	455.07	200	PVC	Open	-16.74	0.77	0.53
165	P18-31	770.84	150	PVC	Open	-6.89	1.02	0.39
166	P18-8	261.52	200	DCI	Open	2.44	0.02	0.08
167	P18-28	549.55	150	PVC	Open	3.65	0.22	0.21
168	P18-12	443.18	150	PVC	Open	10.57	1.3	0.6
169	P18-18	1,113.74	250	DCI	Open	23	2.26	0.47
170	P18-47	76.2	200	DCI	Open	31.72	0.83	1.01
171	P18-36	1,031.44	350	DCI	Open	113.5	4.59	1.18
172	P18-128	482.19	150	DCI	Open	1.3	0.06	0.07
173	P18-39	416.97	500	DCI	Open	224.84	1.16	1.15
174	P18-26	360.27	100	PVC	Open	0.01	0	0

175	P18-51	520.29	500	DCI	Open	235.02	1.57	1.2
176	P18-17	252.68	150	PVC	Open	-0.71	0.01	0.04
177	P18-42	518.46	150	PVC	Open	8.51	1.02	0.48
178	P18-20	658.37	450	DCI	Open	179.55	2.01	1.13
179	P18-124	48.77	500	DCI	Open	263.42	0.18	1.34
180	P18-129	1,075.33	400	DCI	Open	-110.31	4.03	0.88
181	P18-57	984.81	300	DI	Open	61	2.94	0.86
182	P18-29	622.4	150	PVC	Open	1.71	0.06	0.1
183	P18-130	1,154.58	200	DCI	Open	17.24	4.07	0.55
184	P18-133	1,210.06	500	DCI	Open	243.46	3.89	1.24
185	P18-134	1,151.84	400	DCI	Open	77.74	2.26	0.62
186	P15-102	15.54	1,400.00	DCI	Open	2,309.00	0.02	1.5
187	P15-101	3,044.34	1,400.00	DCI	Open	2,309.00	4.19	1.5
188	PRU1	4,909.41	800	DCI	Open	657	10.06	1.31
189	PRU1a	23.47	800	DCI	Open	657	0.05	1.31
190	PSH1	517.86	1,400.00	DCI	Open	5,108.00	3.1	3.32
191	PSH2	1,767.54	1,200.00	DCI	Open	2,554.00	6.21	2.26
192	PSH2a	18.9	1,200.00	DCI	Open	2,554.00	0.07	2.26
193	PSH3a	24.08	1,200.00	DCI	Open	-2,554.00	0.08	2.26
194	PSH3	1,727.00	1,200.00	DCI	Open	-2,554.00	6.07	2.26
195	PRU3	3,763.67	900	DCI	Open	1,973.00	33.3	3.1
196	PRU3a	39.62	1,200.00	DCI	Open	1,973.00	0.09	1.74
197	PRU2	3,530.80	1,200.00	DCI	Open	1,973.00	7.69	1.74
198	PRU2a	38.4	1,200.00	DCI	Open	1,973.00	0.08	1.74
199	P24-121	683.06	150	PVC	Open	2.79	0.17	0.16
200	P18-10	303.58	100	PVC	Open	-4.55	1.34	0.58
201	P18-10a	252.37	100	PVC	Open	3.32	0.62	0.42
202	P18-63	1,142.39	500	DCI	Open	7.86	0.01	0.04
203	P18-61	456.59	500	DCI	Open	23.49	0.03	0.12
204	P18-62	465.12	500	DCI	Open	8.47	0.01	0.04
205	P18-30	478.54	150	PVC	Open	-8.68	0.97	0.49
206	P18-22	704.39	100	PVC	Open	1.78	0.55	0.23
207	P22-26	979.02	200	DCI	Open	15.07	2.69	0.48
208	P22-119	97.84	200	PVC	Open	18.35	0.2	0.58
209	P22-1	706.22	200	DCI	Open	18.35	2.8	0.58
210	P22-3	173.43	150	DCI	Open	5	0.25	0.28

211	P22-124	90.53	200	PVC	Open	-15.07	0.13	0.48
212	P22-118(2)	68.88	350	Ductile Iron	Open	110	0.29	1.14
213	*PN1*	*6,939.08*	*1,000.00*	*DI*	*Open*	*1,153.00*	*13.59*	*1.47*
214	*PN-2*	*31.7*	*1,000.00*	*DI*	*Open*	*1,153.00*	*0.06*	*1.47*
215	PE-1	4,756.4	900	DI	Open	773	10.4	1.22
216	PE-2	2,688.95	900	DI	Open	497	2.6	0.78
217	P-372	51.51	800	DI	Closed	0	0	0
218	P14-151	135.03	400	DCI	Open	9.59	0.01	0.08
219	*P14-77*	*565.4*	*150*	*PVC*	*Open*	*-5.59*	*0.51*	*0.32*
220	*P14-78*	*1,324.66*	*150*	*PVC*	*Open*	*-4.28*	*0.73*	*0.24*
221	P14-149	1,063.14	400	DCI	Open	18.27	0.14	0.15
222	P14-144	202.39	400	DCI	Open	32.16	0.08	0.26
223	P14-143	366.06	400	DCI	Open	37.35	0.18	0.3
224	*P14-79*	*607.77*	*100*	*PVC*	*Open*	*1.51*	*0.35*	*0.19*
225	P14-142	483.72	150	DCI	Open	-3.3	0.32	0.19
226	P14-89	179.53	400	DCI	Open	37.62	0.09	0.3
227	P14-90	281.03	400	DCI	Open	39.19	0.15	0.31
228	P14-91	153.62	400	DCI	Open	42.19	0.1	0.34
229	P14-96	465.43	400	DCI	Open	45.2	0.33	0.36
230	P14-141	217.02	150	DCI	Open	-0.54	0.01	0.03
231	P14-147	599.24	150	GS	Open	11.23	3.88	0.64
232	*P14-1*	*237.74*	*150*	*DI*	*Open*	*3.07*	*0.08*	*0.17*
233	P14-148	908.3	150	GS	Open	4.42	1.05	0.25
234	P14-76	411.18	150	GS	Open	2.41	0.15	0.14
235	P14-86	449.88	400	DCI	Open	2.01	0	0.02
236	P14-126	54.56	800	DI	Open	433.31	0.05	0.86
237	P14-125	840.03	800	DCI	Open	390.71	1.12	0.78
238	P14-124	907.69	350	DCI	Open	42.6	1.12	0.44
239	P14-123	158.8	800	DCI	Open	299.65	0.13	0.6
240	*P14-119*	*402.64*	*200*	*PVC*	*Open*	*16.08*	*0.63*	*0.51*
241	P14-111	613.56	300	DCI	Open	28.49	0.76	0.4
242	P14-118	494.39	500	DCI	Open	20.24	0.03	0.1
243	*P14-135*	*809.55*	*150*	*PVC*	*Open*	*3.63*	*0.33*	*0.21*
244	P14-117	424.28	500	DCI	Open	14.63	0.01	0.07
245	P14-116	862.89	300	DCI	Open	4.81	0.04	0.07

246	P14-112	466.34	200	DCI	Open	18.08	1.8	0.58
247	P14-115	239.88	200	DCI	Open	15.64	0.71	0.5
248	P14-114	246.89	200	DCI	Open	14.29	0.62	0.46
249	*P14-133*	*549.55*	*200*	*PVC*	*Open*	*11.12*	*0.44*	*0.35*
250	P14-113	377.95	200	DCI	Open	26.52	2.96	0.84
251	P14-158	596.19	500	DCI	Open	281.08	4.26	1.43
252	P14-157	191.11	500	DCI	Open	253.3	1.13	1.29
253	P14-120	352.04	200	DCI	Open	27.31	2.91	0.87
254	P14-85	242.01	500	DCI	Open	249.98	1.39	1.27
255	*P14-145*	*157.58*	*400*	*DI*	*Open*	*244.81*	*1.52*	*1.95*
256	*P21-100*	*132.59*	*400*	*DI*	*Open*	*270*	*1.53*	*2.15*
257	*P21-101*	*18.59*	*400*	*DI*	*Open*	*270*	*0.21*	*2.15*
258	P14-84	386.49	500	DCI	Open	3.26	0	0.02
259	*P14-132*	*932.69*	*250*	*PVC*	*Open*	*24.63*	*1.09*	*0.5*
260	*P14-130*	*1,041.81*	*200*	*PVC*	*Open*	*-15.8*	*1.58*	*0.5*
261	P14-110	779.07	350	DCI	Open	91.36	3.95	0.95
262	P14-105	193.85	350	DCI	Open	78.84	0.75	0.82
263	P14-104	311.51	350	DCI	Open	75.52	1.11	0.78
264	*P14-131*	*848.56*	*150*	*PVC*	*Open*	*7.42*	*1.29*	*0.42*
265	P14-82	1,044.85	150	DCI	Open	10.34	5.81	0.59
266	P14-107	149.66	150	DCI	Open	9.21	0.67	0.52
267	P14-106	237.44	150	DCI	Open	6.67	0.59	0.38
268	P14-109	273.71	150	DCI	Open	4.09	0.27	0.23
269	P14-108	445.01	150	DCI	Open	8.07	1.56	0.46
270	P14-127	472.44	150	DCI	Open	6.39	1.08	0.36
271	P14-128	534.62	150	DCI	Open	-7.88	1.8	0.45
272	*P14-129*	*1,058.57*	*150*	*PVC*	*Open*	*5.36*	*0.88*	*0.3*
273	*P14-134*	*423.06*	*100*	*PVC*	*Open*	*0.18*	*0*	*0.02*
274	P14-103	244.75	350	DCI	Open	70.87	0.78	0.74
275	P14-102	235.31	350	DCI	Open	66.81	0.67	0.69
276	P14-101	384.66	350	DCI	Open	63.53	1	0.66
277	P14-100	583.69	350	DCI	Open	64.64	1.56	0.67
278	P14-99	431.29	400	DCI	Open	57.85	0.49	0.46
279	P14-98	250.24	400	DCI	Open	52.63	0.24	0.42
280	P14-97	309.07	400	DCI	Open	49.35	0.26	0.39
281	P14-93	418.19	150	DCI	Open	-7.18	1.18	0.41

282	P14-92	756.51	150	DCI	Open	4.9	1.06	0.28
283	P14-94	819.91	150	DCI	Open	1.4	0.11	0.08
284	*P12-38*	*25.6*	*600*	*DI*	*Open*	*245.37*	*0.03*	*0.87*
285	*P12-50*	*145.69*	*600*	*DI*	*Open*	*226.04*	*0.17*	*0.8*
286	P12-31	998.52	150	DCI	Open	6.69	2.48	0.38
287	P12-29	344.42	150	DCI	Open	3.97	0.33	0.22
288	P12-51	385.57	300	DCI	Open	37.73	0.81	0.53
289	P12-113	244.14	300	DCI	Open	43.17	0.65	0.61
290	P12-114	266.7	300	DI	Open	48.28	0.52	0.68
291	P12-30	165.81	250	DCI	Open	28.56	0.5	0.58
292	P12-27	518.77	150	DCI	Open	2.04	0.14	0.12
293	P12-28	353.87	250	DCI	Open	15.01	0.33	0.31
294	P12-26	149.05	150	DCI	Open	4.68	0.19	0.26
295	*P12-125*	*154.23*	*250*	*PVC*	*Open*	*25.43*	*0.19*	*0.52*
296	*P12-12*	*539.5*	*250*	*PVC*	*Open*	*-21.63*	*0.49*	*0.44*
297	P12-36	483.72	400	DCI	Open	-29.22	0.15	0.23
298	P12-115	704.39	150	DCI	Open	3.8	0.61	0.22
299	*P12-44*	*89.92*	*200*	*PVC*	*Open*	*6.6*	*0.03*	*0.21*
300	P12-8	865.33	200	DCI	Open	9.25	0.96	0.29
301	*P12-121*	*621.18*	*200*	*PVC*	*Open*	*7.74*	*0.25*	*0.25*
302	P12-35	286.21	350	DCI	Open	21.18	0.1	0.22
303	P12-34	187.45	350	DCI	Open	17.64	0.05	0.18
304	P12-33	227.08	350	DCI	Open	14.11	0.04	0.15
305	*P12-120*	*254.2*	*200*	*PVC*	*Open*	*10.57*	*0.18*	*0.34*
306	*P28-61*	*171.3*	*250*	*DCI*	*Open*	*0*	*0*	*0*
307	*P28-48*	*167.94*	*400*	*DCI*	*Open*	*131.04*	*0.51*	*1.04*
308	*P28-53*	*171.6*	*250*	*DCI*	*Closed*	*0*	*0*	*0*
309	*P28-57*	*270.36*	*350*	*DCI*	*Open*	*72.59*	*0.53*	*0.75*
310	*P28-54*	*325.22*	*250*	*DCI*	*Closed*	*0*	*0*	*0*
311	*P28-40*	*252.98*	*450*	*DCI*	*Open*	*-161.35*	*0.63*	*1.01*
312	*P28-9*	*435.25*	*200*	*PVC*	*Open*	*23.38*	*1.37*	*0.74*
313	*P28-11*	*220.68*	*150*	*PVC*	*Open*	*7.78*	*0.37*	*0.44*
314	*P28-56*	*211.23*	*250*	*DCI*	*Closed*	*0*	*0*	*0*
315	*P28-7*	*513.59*	*200*	*DCI*	*Open*	*8.61*	*0.5*	*0.27*
316	*P28-51*	*102.11*	*300*	*DCI*	*Open*	*58.45*	*0.28*	*0.83*
317	*P28-58*	*85.04*	*250*	*DCI*	*Open*	*0*	*0*	*0*

318	P28-12	457.5	200	PVC	Open	11.78	0.4	0.37
319	P28-44	23.47	300	DCI	Open	50.28	0.05	0.71
320	P28-63	340.46	300	DCI	Open	57.94	0.92	0.82
321	P28-62	123.75	250	DCI	Closed	0	0	0
322	P28-39	69.8	200	PVC	Open	27.81	0.3	0.89
323	P28-14	416.36	200	PVC	Open	22.01	1.17	0.7
324	P28-16	772.06	200	PVC	Open	15.85	1.18	0.5
325	P28-42	1,805.33	300	DCI	Open	100.55	13.59	1.42
326	P28-10	403.86	100	PVC	Open	0.83	0.08	0.11
327	P28-65	514.81	200	DCI	Closed	0	0	0
328	P28-3	582.47	450	DCI	Open	163.58	1.5	1.03
329	P28-45	29.57	250	DCI	Open	50.28	0.15	1.02
330	P28-59	239.57	250	DCI	Closed	0	0	0
331	P28-18	705.61	150	PVC	Open	7.21	1.02	0.41
332	P28-17	600.15	200	PVC	Open	-20.9	1.53	0.67
333	P28-66	195.99	300	DCI	Open	46.2	0.35	0.65
334	P28-64	106.07	200	DCI	Open	0	0	0
335	P28-46	31.39	300	Steel	Open	50.27	0.07	0.71
336	P28-47	28.96	250	Steel	Open	50.27	0.15	1.02
337	P28-67	513.59	250	PVC	Open	34.77	1.13	0.71
338	P28-15	620.88	100	PVC	Open	-1.49	0.35	0.19
339	P28-60	275.23	350	DCI	Open	72.59	0.53	0.75
340	P28-2	345.95	300	DCI	Open	16.4	0.15	0.23
341	P28-55	143.56	350	DCI	Open	72.59	0.28	0.75