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Addis Ababa University (Since 1950)

ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGNEERING

ASSESSMENT OF THE WATER DISTRIBUTION NETWORK OF METU TOWN WATER SUPPLY SYSTEM, ETHIOPIA

By

Benyam Bogale

A thesis Submitted to the School of Graduate Studies of Addis Ababa University for the Partial Fulfillment of the Degree of Master of Science in Civil and Environmental Engineering

(Water Supply and Environmental Engineering Stream)

Advisor

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Addis Ababa University Institute of Technology

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DECLARATION

I hereby declare that this submission is my original thesis work and it is not contains material previously published by another person nor which has been accepted for the award of any other academic degree of the University, except I have been used and where due acknowledgement has been made and cited in the reference part of this work.

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Signature -------------------------------

November, 2016

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ABSTRACT

Intermittent water distribution is the key problems of many water authorities in developing countries including Ethiopia. Hence, this research was conducted to carry out the assessment of the water distribution network of Metu town existing water supply system which is located in western Oromia region of Ethiopia. To examine the hydraulic performance of the water distribution network, water CAD modeling was adopted. Accordingly, different reviewed reports, percentage of Non-Revenue for water, and discussions with water service personnel were conducted to analyze water losses and leakage management practice in the town. As per the analyzed results; the current maximum water demand in Metu town is estimated at 4,206.93 m^3/day, while small reservoirs capacity and low pump efficiency were observed in the town water distribution networks. According to simulated results; the maximum of 203.68m and 199.49m, and minimum of 5.36m and 2.97m water pressure head were examined in the transmission and distribution main, respectively. Further, the analyzed water losses result in Metu town indicates that about 34.64% of production is Non-Revenue Water. Thereby, apparent losses cover 21.12% of total loss and 13.52 % were physical losses. Accordingly, for the case of Metu town apparent losses are more significant, however physical losses contributed considerable volume of lost. In general, rising in water demand, small capacities of existing infrastructures and large volume of water loss were leads to intermittent water distribution in Metu. Hence, most of residences were not satisfied on the town water service. Therefore, it is significant to rehabilitate and improve the water distribution system capacities and providing more attention to water losses reduction policies and strategies are vital for remedial measures.

KEY WORD: water distribution network, hydraulic water CAD modeling, water loss, leakage management, Metu town, Oromia region, Ethiopia.

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AAU	Addis Ababa University
CAPL	Current Annual Volume of Physical Losses
CSA	Central Statistics Agency
CWT	Clear Water Tank
CWPS	Clear Water Pumping Station
DCI	Ductile Cast Iron
DP	Distribution Point
EELPA	Ethiopian Electric Line and Power Authority
EFC	Environmental Finance Center
EPA	Environmental protection Agency
ETB	Ethiopian Birr
FDRE	Federal democratic Republic of Ethiopia
GI	Galvanized Iron
G.C	Gregorian Calendar
GPS	Global Position System
ILI	Infrastructure Leakage Index
IMF	International Monetary fund
ITCZ	Inter Tropical Convergence Zone
IWA	International Water Association
MAAPL	Minimum Achievable Annual Physical Losses
m.a.s.l.	Meter above sea level
MoWIE	Ministry of Water, Irrigation and Electric
NFFs	Needed Fire Flows

NRC	National Research Council
NRW	Non Revenue Water
PF	Public Fountain
PRVs	Pressure Release Valves
PVC	Polyvinyl Chloride
RC	Reinforced Concrete
RSWW	Standard for Water Works
RWPS	Raw Water Pumping Station
SI	System International
SSF	Slow Sand Filter
UARL	Unavoidable Annual Real Loss
USAID	United States Agency for International Development
WDNs	Water Distribution Networks
WDS	Water Distribution System
WUAM	Water Utility Asset Management

CHAPTER ONE

1. INTRODUCTION

1.1 Background

'All peoples, whatever their stage of development and social and economic condition, have the right to have access to drinking-water in quantities and of a quality equal to their basic needs' (WHO, 1997). Water is the precious gift of nature, the source of prosperity, most crucial for sustaining life, basic to most economic activities and its role in human survival and health is well known. So, it is not exaggerate to say that supplying and distributing of adequate water form the foundation of contemporary life (NRC, 2006).

One of the principal roles of public work is providing water in sufficient quantity to users. Water supply and distribution is a complex system and that exists to satisfy the various needs of peoples. Whereby, it consists of various components of physical assets including reservoirs, pipes, pumps, and different hydraulic controlling accessories that make up the water distribution system. It is generally desired that water should be supply continuously in the required quantities with adequate pressure and flow from sources to all customers. However, occasional disruptions due to failures of their system components and variation of demands may occur over the service life (Jalal, 2008).

Problems with access to sufficient water are most happen in the developing world, and more than one billion people were suffer without access to water for their basic needs. Thereby, the United Nations Millennium Declaration and the plan of implementation of the world; was set reducing the proportion of people having without adequate access to water by one-half for the year 2015. Hence, adequate water distribution is one of the international goals for sustainable development (Renwick, 2013).

Most water distribution system across the world was built decades ago, and many are reaching their expected life spans within 30 years (NRC, 2006). Accordingly, in developing countries; one of the commonly cited constraints to effective water provisioning is the "aging infrastructure" problem. And these were presents many technical limitations for effective and continues water distribution system to customers (Grady et al., 2014).

Intermittent piped water networks were found all over the developing world. And it is estimated that one third of urban water supplies in Africa were operated intermittently. As result of; high population growth rate, scarcity of source water, treatment plant size, reservoirs and storage tank capacity, power outages to run water pumps, high leakage problems, or some combination of these conditions were the primary causes for intermittent water distribution in the water system (Renwick, 2013).

The other major factor which affecting water utilities are the considerable difference between the amounts of water produced into the distribution system and water billed to consumers. Current statistical surveys indicated that Non-Revenue Water in developing countries is around 45 to 50% i.e. half of the total system input volume. This is largely because most of the water utilities do not have enough attention and monitoring systems within water losses and its management. Further; water theft, metering error, and lack of effective data recording and handling systems is the other problems of the water utility in developing countries. Accordingly, the water distribution system in such countries does not meet the need of water for various demands since high levels of water losses in their distribution networks (Dighade, et al., 2014).

Large quantity of water is also losses through leaking pipes, joints, valves and fittings of the distribution systems. Age of the installations, bad quality of materials used, and/or poor workmanship are the main sources of these water losses. Therefore, Constraints to water access also include limitations directly related to the aging, operation and maintenance capacity of the water services (Grady et al., 2014).

Water utilities in many developing countries are struggling to ensure that customers to be receive a reasonable supply of adequate drinking water. But, problems related with less engineering aspects, low level of technology and costs associated with water provisioning were lead to poor management and controlling of the water system including non-revenue water. Thus, the water tariff systems and revenue collection policies were not reflect the true value of water supplied, which limits the utility's cost recovery and encourages customers to undervalue the service (Farley, et al., 2008).

In general, water problem is a growing global concern and that has an impact on countries' economic prospects. Rising water stress, large supply variability, and lack of access to safe and adequate drinking water are a frequent problems in many parts of the world. Especially, developing countries face greater challenges of adequate water distribution because of their larger population growth rate, poor infrastructure, lower income levels, and less developed policy and institutional capacity (Kochhar, et al., 2015).

According to Metu town water supply service office, one of the common problems in the town water system was related with intermittent supply due to the current performance of the water distribution system. Thereby, there were inadequate amount of water supply and low coverage in the town. Therefore, this research work was prepared to assess Metu town water distribution network in terms of the hydraulic performance, water loss and leakage management practice.

1.2 Statement of problem

One of the major challenges on reduction of the performance of towns' water supply system is the demand on water increases due to the growth of population and urbanization of the town. In many Ethiopian urban areas including Metu town majority of householders consume their total water needs from the town's water supply system either directly through private connections or public taps. According to Metu town water supply service office, existing water supply system has served beyond its design period and currently there is intermittent water distribution in the town.

In many developing countries water supply system the problem of intermittent water distribution is a growing concern. One of the major indicators of intermittent water distribution is the capacities and configuration of system components. Reservoirs capacity, pump size, pipeline and pipeline network schematization has impact on quantity of water distribution in a system. Accordingly, in Metu town water distribution system it was observed that; treated water supplied has not reached the service reservoir located at higher elevation of the town.

Most of the water infrastructure in developing world including Ethiopia is in service for decades and can be a significant source of water loss through leaks. In addition to leakage, water can be lost through unauthorized consumption (water theft), data handling errors, metering inaccuracies/failure and administrative errors. Hence, the level of water loss in towns' water distribution system depends not only on aging of the infrastructure, but also the quality of material used, workmanship, and customers' awareness and attitude towards water. The other observed problem in Metu town is frequent pipe bursting in the water distribution network during which the town water utility does not have immediate response for maintenance. Further, statistical surveys indicated that approximately 39.11% of treated water in Metu is loss and unaccounted for the last eight year, thus financially it made crisis on the town water supply authority. (For this reasons, this study paper was prepared to address the current performance of Metu town existing water distribution network.)

1.3 Research Questions

- How was the distribution system assessed with modeling?
- What are the major factors for intermittent water supply experienced in Metu town water distribution network?
- How much water is lost in the system comparing with system production?
- What are the primary sources contributing to water loss in the town water system?
- How are the town water supply service office; plan, policy and strategy for leakage management practice?

1.4 Objective

1.4.1 General Objective

The general objective of this work is to assess the performance of Metu town water distribution networks and will give guidance and awareness for municipal officials of the town to a better evaluation and decision making of future water distribution system in the town.

1.4.2 Specific Objective

- To assess the hydraulic performance of water distribution network with modeling
- To assess the major factors of water loss in the distribution network,

- To assess the town water utility leakage management practice, and
- To recommend the possible improvement measures

1.5 Scope of the research

The objective of this research is to present the fundamental concept of hydraulics applied to Metu town water supply network, in order for municipal officials of the town to a better evaluation and decision making of water distribution and delivery systems. Therefore, the research work was limited to assess the water distribution network (from clear water well to distribution end point) of Metu town water supply system in western Oromia region of Ethiopia and it mainly focus and was assess to identify the hydraulic performance and the factors for intermittent supply, water loss, and leakage management strategy of the town water distribution system. This was achieved with hydraulic modeling (Water CAD software), water loss analysis, and by made of discussion with the town water utility personnel to gather relevant information in the subject area. But, due to lack of enough budgets, chemical reagents, resources/ logistics and distance of the study area from laboratory these research exclude the water quality analysis in the distribution system of the study area.

1.6 Structure of the thesis

Chapter One: The introduction part contain about the background of the research, statement of problem, general objective, specific objectives, research questions, and the scope and limitations of the research.

Chapter Two: It contains different reviewed literatures which were related to the objective of this research work.

Chapter Three: It includes explanation about description of the study area and detail descriptions of the methodology work.

Chapter Four: It contains the results and discussion part of research outputs.

Chapter Five: Is the conclusion and recommendation part of the research work.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 General

In water distribution system, the reliability of water with a constant flow rate should be available to customers throughout the design time. If water is not available in sufficient quantities it should be pumped for a short period of time and at high flow rate, to meet the various demand of customers. Accordingly, service reservoir/storage tanks usually provided in order to store water when the pumping rate is higher than the demand at low/night times. But, this can be also used in the case that the pumping rate is below the needed demand, since to equalize the pressure in the network (Hussni & Zyoud, 2003).

In developing countries; many water authorities are facing the challenges in providing adequate water supply to the rapidly growing populations'. Thereby, most of the existing water supply systems are unable to meet the various demands of water. Beside to this; infrastructural aging problem, poor management of the existing system components/assets and utilities capacity shortages were increases the level of water losses in the distribution system (Welday, 2005; Jalal, 2008).

Water utilities are facing the high level of water loss in their distribution networks. *'For many utilities, reducing loss should be the first option to pursue when addressing low service coverage levels and increased demand for piped water supply. But, expanding water distribution networks without addressing water losses will only lead to a cycle of waste and inefficiency'* (Frauendorfer & Liemberger, 2010).

However, there is no simple solution to reduce water losses in the distribution system especially in the developing world, it should be involving improvements not only regar to the water system, but also required a change in attitudes (WUAM, 2013). In addition *'understanding how leakage are currently performing and collecting relevant data, and turning it into useful information for planning and good information systems'* are essential to water loss reduction polices (Farley, et al., 2008).

In general, using a computer model; assessing the hydraulic behaviors and evaluating the performance of existing towns' water distribution network are advantageous. Therefore, *'making hydraulic simulation software, especially from hydraulic point view using engineering approach is one of the method used for discussion and decision measure on the system, either is the system within level of service based on pressure consideration or not'* (Hussni & Zyoud, 2003).

2.2 Types of water distribution system

According to (Tomas, et al., 2003), the water distribution networks can classifed as explained below;

2.2.1 Branched system

This network is also called a tree system. The water has only one possible path from the source to a customer. Thereby, these are applicable for small-capacity water suppliers, and are common in most developing countries. The advantage of these system is the most economical because of its low cost, but it has some disadvantages as presented below;

- Low reliability, affects all users especially located downstream of any breakdown in the system. So that, their water services were interrupted until the repairs are finished.
- Fluctuating in water demand, producing rather large pressure variations in the system.
- When there is a need for developing the network, new branches follow that development and new dead ends will be constructed.
- It also danger of contamination during the network without water.

2.2.2 Looped system

As the name suggests, in looped systems it serves different paths that water can follow to get from the source to a particular customer. The systems are generally more desirable than branched systems because it coupled with sufficient valves and accessories, and can provide reliability in the water distribution. In these system because of more than one path for water, the system capacity is greater and it improves the hydraulics of the distribution system. For example, consider a main break occurring near the reservoir in each system depicted in Figure 2.1 below. In the looped system, that break can be isolated and repaired with little impact on customers outside of that immediate area. While, the effet of water service interruption is more significant to branched system.

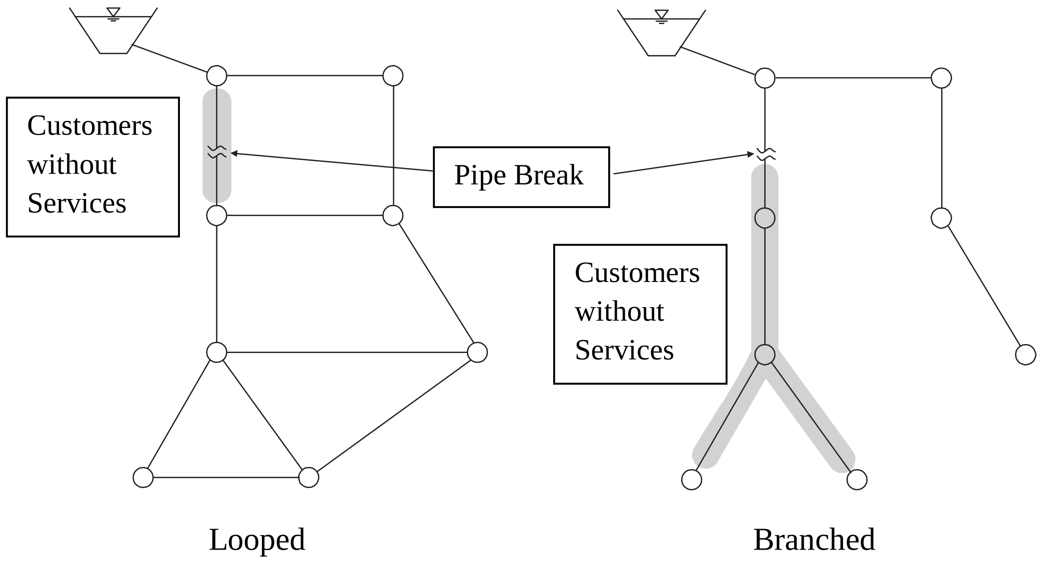


Figure 2.1: Looped and branched networks after network failure (source: Advanced water distribution modeling and management: Haestad Methods)

2.3 Components of water distribution network

2.3.1 Transmission and distribution mains

In the water distribution system, piping system is often categorized as transmission/trunk mains and distribution mains (Tomas, et al., 2003);

2.3.1.1 Transmission mains

Transmission mains were consist of components that are convey large amounts of water over great distances, typically between major facilities within the distribution system. In most water supply system, transmission main are mainly used to transport water from treatment plant to service reservoirs/ storage tanks. Whereby, individual customers are usually not served from these mains.

2.3.1.2 Distribution mains

Distribution mains are an intermediate pipeline used to delivering water from transmission main to customers. The mains are smaller in diameter than transmission mains, and typically follow the general topology and alignment of the town streets. Diffrent fittings such as elbows, tees, reducers, crosses and numerous other accessories are used in the main to connect pipes. While, other maintenance and operational appurtenances, such as fire hydrants and valves are also connected directly to the distribution mains. Further,services also called service line were laid and transmit water from the distribution mains to end customers.

2.3.2 Reservoir and storage tanks

In the watre distribution system, reservoir and storage tanks are mainly provided inorder to meet the fluctuations of water demand and to stabilize pressure within the distribution system. Similarly, these components were reserve water for emergency requirements. Accordingly, the common reservoirs established in the water suppy system are circular and/or rectangular type which build either from concrete or steel materials. And , the recommended location of such facilities are mainly in elevated area beyond the center of service area (NRC, 2006).

2.3.3 Pump Stations

Pumps are used for convey energy to the water in order to boost water at higher elevations. Most pumps used in the water supply systems are centrifugal in nature, and are installed to improve the water distribution, if gravity is insufficient to supply water at an adequate pressure. So that, to control the operational condition of pumps switch-board were provided in the station (NRC, 2006; Chambers, et al., 2004).

2.3.4 Accessory Equipments

The accessory equipment in the water distribution pipelines can be classified as fittings, valves (such as; control valves, air release valves, pressure reducing valves, etc), hydrants, drainage facility, flow meters, and etc. All these accessories has been installed at places were necessary for connecting the network, controlling and management of the system, and for maintenance purposes during failure is occure (Bhadbhade, 2009).

2.4 Factors causing loss of hydraulic integrity in water distribution network

‘In most of the developing regions, the design of water distribution systems is based on the assumption of direct supply, although most of these systems are intermittent systems which result in severe supply, insufficient pressure in the distribution system (pressure losses in several areas

in the network), inequitable distribution of the available water and very short duration of supply' (Hussni & Zyoud, 2003).

However, the purpose of hydraulic integrity in the water distribution system is to supply water at adequate/accptable pressure and flow. But, according to (Chambers, et al., 2004; NRC, 2006; Tomas, et al., 2003; Marta & Rudolf, 1987; Hickey, 2008; Dighade, et al., 2014) the most common factors for intermittent water supply and loss of hydraulic integrity in the distribution system are;

2.4.1 Low pressure

'However, there is pressure loss by the action of friction at the pipe wall and its magnitude also dependent on the water demand, properties of the fluid that is passing through the pipe, the speed at which it is moving, the internal roughness of the pipe, pipe length, gradient and diameter of the pipe. Such situations may occur where there are: properties on high ground, remote properties at the end of long lengths of pipe, demands that are greater than the design demand, pipes of inadequate capacity (too small diameter), rough pipes (e.g. corroding iron pipes or pipes with a build-up of sediment) and equipment failures such as pumps and valves. In general, poor pressures tend to be caused by inadequate capacity in a pipe or pump, high elevations, or some combination of the two' (Chambers, et al., 2004).

Therefore, one of the most hydraulic integrity is maintaining adequate water pressure inside the pipe. Hence, the water utilities should be achieve a high degree of hydraulic integrity through a combination of proper system design, operation, and maintenance along with good monitoring.

2.4.2 High pressure during low demand conditions

High pressure during low demand conditions can cause pipe bursting, leakage and large amount of water losses through the distribution networks. Therefore, when dealing with high pressures, PRVs should be used to reduce and regulate pressure in the system (Tomas, et al., 2003). Accordingly, pipes and pumps must be sized to overcome these problem and to provide acceptable pressure in the system. Although, sizing of control valves based on the desired flow conditions and pressure differential is vital (NRC, 2006).

2.4.3 Pump Capacity

A pump is device in which mechanical energy is applied and transferred to the water as total head, and these head is afunction of flow rate through the pump (Tomas, et al., 2003). While, *'the failurity, location, size and capacity of pumps in water distribution are the major impacts for low flow or negative pressurer arised in the system, and this can lead to intermittent water supply in the distribution system'* (Chambers, et al., 2004).

There are many reasons and factors why a pump is not performing well in a certain situation of water distribution system. But, as per Marta & Rudolf, 1987; the important and possible reasons to less performing of pumps were identified as below;

- When the pump is of poor design and quality,
- If it is not suitable for the given situation and does not work in its optimal range,
- If the pump is not being used properly and maintained regularly (cleaning, greasing, etc.),
- If the pump is excessively exposed to sun, rain, dust, etc,
- If it is overused and was not repaired properly after a break-down and
- If supply of spare parts is difficult.

2.4.4 Demand Increase

Rising water demand as a result of population growth and urbanization has an effcet on the availability and reliability of existing water distribution system. Therefore, *'water demands need to be assessed on the basis of considering the year and date supplying water through the distribution system. The primary objective is to make sure that the community is being serviced adequately. If there are deficiencies in meeting current or future goals because of population growth, this needs to be identified for the areas of the community where there may be inadequate flows to meet customers consumption during peak hour water demand of the day'* (Hickey, 2008).

2.4.5 Poor infrastructures

In most of the developing countries it has been observed that pipe network is very old and which is laid many years ago. With aging problem there is considerable reduction in carrying capacity of the pipelines. Although, most of the distribution pipeline were get corroded and leakage were occur, since resulting in loss of water and pressure reduction. Hence, *'All these materials suffer from degradation over time and result in leakage in the network. It is, therefore, Preventive maintenance of distribution system assures and providing conditions for adequate flow through the pipelines. Incidentally, this will prolong the effective life of the pipeline and restore its carrying capacity. Some of the main functions in the management of preventive maintenance of pipelines are assessment, detection and prevention of loss of water from pipelines through leaks, maintaining the capacity of pipelines, cleaning of pipelines and relining'* (Dighade, et al., 2014).

2.4.6 Operation and maintenance activities

'Water distribution systems are occasionally subject to emergencies or planned maintenance activities in which certain components become not workable and the system can no longer provide the minimum level of service to customers. Planned maintenance activities include supplies going off line (e.g., reservoir shutdown for inspection, cleaning, or repairs; installation of new pipe connections; pipe rehabilitation or break repairs; and transmission main valve repairs.) while, emergency situations include earthquakes, power failures, equipment failures, or transmission main failures. Therefore, all these activities can result in a reduction in system capacity and supply pressure, and changes to the flow paths of water within the distribution system' (NRC, 2006).

Therefore, lack of attention to the important aspect of operation and maintenance of water supply schemes were leads to deterioration of the useful life of the distribution systems. Further, as per Dighade, et al., 2014; some of the key issues contributing to the poor operation & maintenance have been identified as follows;

- Lack of funds, operation manuals and real time field information
- Inappropriate system design and poor workmanship,
- Overlapping responsibilities and inadequate training of personnel,
- Inadequate emphasis on preventive maintenance,

Whereby, there is a need for clear policies, legal framework and decision of responsibilities and mandates within the water supply authority.

2.5 Basic Principles of Hydraulic Modeling

In line with Jalal, 2008; the main reason for modeling a system is to assist designers, managers and planners to explore the governing laws of such systems and to accurately analyze their behavior. Hence, models are employed to resolve problems in system's design and operation.

'Model-based simulation is a method for mathematically approximating the behavior of real water distribution systems. To effectively utilize the capabilities of distribution system simulation software and interpret the results produced, the modeler must understand the mathematical principles involved' (Tomas, et al., 2003).

'In networks of interconnected hydraulic elements, every element is influenced by each of its neighbors; the entire system is interrelated in such a way that the condition of one element must be consistent with the condition of all other elements. These conditions are mainly controlled by two laws' (Tomas, et al., 2003);

2.5.1 Law of Conservation of Mass

'The principle of conservation of mass dictates that the fluid mass entering any pipe will be equal to the mass leaving the pipe (since fluid is typically neither created nor destroyed in hydraulic systems). In network modeling, all outflows are lumped at the nodes or junctions.' (Tomas, et al., 2003)

$$\sum_{\text{Pipes}} Q_i - U = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{eq. } 2.1$$

Where $\quad Q_i = \text{inflow to node in } i - \text{th pipe } \left({L^3}/{T} \right)$

$$U = Water\ used\ at\ node\ \left({L^3}/{T} \right)$$

During extended-period simulations; a term to the accumulation of water at certain nodes are considered, because water can be stored and withdrawn from storage tanks (Tomas, et al., 2003).

$$\sum_{Pipes} Q_i - U - \frac{S}{dt} = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots eq. 2.2$$

$$\text{Where} \quad \frac{dS}{dt} = \text{change in storage} \left(L^3/_T \right)$$

Therefore, the concept to conservation of mass is applied to all junction nodes and tanks in a water distribution networks.

2.5.2 Law of Conservation of Energy

According to Bernoulli's equation; *'The principle of conservation of energy dictates that the difference in energy between two points must be the same regardless of the path that is taken'* (Tomas, et al., 2003). Within a hydraulic analysis, the equation is written in terms as follows:

$$Z_1 + \frac{P_1}{\gamma} + \frac{V_1^2}{2g} + \sum h_P = Z_2 + \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + \sum h_L + \sum h_m \ldots\ldots\ldots\ldots\ldots eq. 2.3$$

Where Z = Elevation (L)

P = Pressure (M/L/T^2)

$\gamma =$ Fluid specific weight (M/L/T^2)

V = Velocity (L/T)

$g =$ gravitational acceleration constant (L/T^2)

h_P = head added at pump (L)

h_L = head loss in pipes (L)

h_m = head loss due to minor losses (L)

Therefore, in water distribution modeling the difference in energy at any two points connected in a network is equal to the energy gains from pumps and energy losses in pipes and fittings that occur in the path between them (Tomas, et al., 2003).

2.6 Water distribution network simulation

'The term simulation generally refers to the process of imitating the behavior of one system through the functions of another. It can be used to predict system responses to events under a

wide range of conditions without disrupting the actual system. Using simulations, problems can be anticipated in proposed or existing systems, and can be evaluated before time, money, and materials are invested in a real-world project' (Tomas, et al., 2003).

As per Tomas, et al., 2003; in water distribution networks the most basic type of model simulations are either steady-state or extended-period simulation.

Steady-state simulations: represent a particular view of point in time and are used to determine the operating behavior of a system under static conditions. It compute the hydraulic parameters such as flows, pressures, pump operating characteristics, and others by assuming that demands and boundary conditions were not change with respect to time. In general, this type of analysis were used to determining the short-term effect of demand conditions on the system (Tomas, et al., 2003).

Extended- period simulations: are determine the dynamic behavior of a system over a period of time, and it analyze the system on assumption that the hydraulic demands and boundary conditions were change with respect to time. Hence, *'extended period analysis used to evaluate system performance over time and allows the user to model pressures and flow rates changing, tanks filling and draining, and regulating valves opening and closing throughout the system in response to varying demand conditions and automatic control strategies formulated by the modeler. Therefore, regardless of project size, model-based simulation can provide valuable information to assist an engineer in making well-informed decisions'* (Tomas, et al., 2003).

2.7 Water CAD: Modeling Capabilities

Water CAD provides and allowing modeling practically for any distribution system aspect. Therefore, working with Water CAD used as for decision-support tool for water infrastructures and were help to assess and/or operate (Dawe, 2000; Water CAD: *USER MANUAL*);

- The hydraulic analysis at a steady-state or an extended-period simulation
- Pressure, flow and demands in the system and to see how behaves over time,
- The size of pipes, pump and computer system head curves,
- Tank, pump and valve behavior in the system,

- Leakage and water loss from the network,
- Calibration the model either manually or use the Darwin Calibrator methods
- And, generate fully customizable in graphs, charts and reports form.

2.7.1 Input data for assembling the model

In practice, pipe networks consist not only of pipes, but composed of vary fittings, services, storage tanks and reservoirs, meters, regulating valves, pumps, and electronic and mechanical controls. For modeling purposes, these system elements were organized into the following categories (Water CAD: *USER MANUAL*):

Table 2.1: Input parameters and primary purposes of water CAD tools

Element	Type	Primary modeling purpose	Input data
Reservoir	Node	Provides water to the system	Hydraulic grade line (water surface elevation)
Tank	Node	Stores excess water within the system and releases that water at times of high usage	Base Elevation, Max. Elevation, Min. Elevation, and Diameter
Junction	Node	Discharge the demand required or recharge the inflow water from/to the system	Elevation
Pipe	Link	transport water from one node to another	Elevation, Diameter, Material and Roughness coefficient
Pump	Node/ Link	provide energy to the system and raise the water pressure to overcome elevation differences and friction losses	Elevation, Pump definition (Characteristics of max. operation and design discharge and head efficiency)
Valves	Node/ Link	Controls flow or pressure through a pipe and results in a loss of energy in the system	Elevation, Diameter, Valve type,

(Source; Water CAD: *USER MANUAL*)

2.8 Water demand modeling

The first question in the design and operation of WDN is: How much water is needed?, the answer to this question is difficult because the required water is a function of various factors. While, some of the factors are completely independent and time varying. Therefore, water demand modeling is one of the most important challenges in the design of WDN, since it reflects the changes in population, climate, land use, the number of service connections and customer life style (Jalal, 2008).

2.8.1 Demand modeling approaches

In the water distribution system, there are two main approaches for water demand modeling (Jalal, 2008).

Deterministic water demand estimation: In this approach, the actual water demand for all users is estimated based on predicted water consumption over the service time. One simple approach for deterministic water demand is estimating individual needs based on type of customers and their activities and finally adding these lead to get total water demand. For example, the water demand can be estimated on the basis of per capita demand in small urban areas (Jalal, 2008).

Stochastic demand forecasting: this method mostly considers and adopt the uncertain fluctuations on demand over time and location spans. Risks and sensitivity of forecasts such as the consequence of total loss of supply and the effect of variations in rates income should be considered and included. Hence, Demand estimation based on historical consumption per user category (domestic, industrial/commercial) and expected changes (increasing or decreasing) in user category over the forecasting period is good example of stochastic demand forecasting (Jalal, 2008).

2.8.2 Variations in water demand

The per capita demand of a particular town is the average consumption of water for a year. In practice it has been seen that this demand does not remain uniform throughout the year, but it various from season to season, even hour to hour (Venkateswara, 2005).

Seasonal Variation: Water demand varies from season to season. In dry season the water demand is maximum, because the people will use more water for bathing, cooling, lawn watering and street sprinkling. While, demand will becomes minimum in rainy/wet season because less water is used in bathing and there is no lawn watering. Therefore, *'maximum day water demand is considered to meet water consumption changes with seasons and it used to size source, treatment plant and rising mains. Hence, maximum day demands can be obtain by multipling the average-day demands to the peaking factor applied to the node'* (Venkateswara, 2005).

$$Q_{max} = PF * Q_{avg} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \text{eq. } 2.4$$

Where, Q_{max} = Maximum day demand (cfs, m^3/s)

PF = Peaking factor between maximum day and average day demand

Q_{avg} = Average day demand (cfs, m^3/s)

Daily Variation: This variation mainly depends on the general behavior of people, climatic conditions and character of city as industrial, commercial or residential. More water demand is on Sundays and holidays due to more comfortable bathing, washing etc as compared to other working days**.** Accordingly, *'Average daily water demand is the sum of the domestic, non domestic and NRW which is used to estimate the maximum day & the peak hour demand'* (Venkateswara, 2005). It expressed as economic calculations over the projects lifetime.

$$Q_{avg.} = \text{Per capital water consumption}$$
$$* \text{ Total population of the town} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{eq. } 2.5$$

Where, Q_{avg} = Average day demand (cfs, m^3/s)

Hourly Variation: In most developing countries the maximum hour water demand is happen during morning and evening time over 24 hour, because in these time most people use water for bathing, washing and cooking purpose. Therefore, *'peak hour demand is the highest demand of any one hour over the maximum day. And it represents the hourly variations in water demand resulting from the behavioral patterns of the local population'* (Venkateswara, 2005).

$$Q_{hour} = PF * Q_{avg} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. \text{eq. } 2.6$$

Where, Q_{hour} = Peak hour demand (cfs, m^3/s)

PF = Peaking factor between maximum hour and average day demand

Q_{avg} = Average day demand (cfs, m^3/s)

2.8.3 Baseline demands

'The most common method of allocating baseline demands is a simple unit loading method. This method involves counting the number of customers (hectares of a given land use, number of fixture units, or number of equivalent dwelling units) that contribute to the demand at a certain node, and then multiplying that number by the unit demand (for instance, number of gallons/ liters per capita per day) for the applicable load classification' (Tomas, et al., 2003).

Therefore, average day demand were used to estimate the baseline demand and other demand in the water distribution system including unaccounted-for water. Hence, most modelers determine the water demand analysis of a given town by appling baseline demand to a variety of peaking factors and demand multipliers (Bhadbhade, 2009).

2.8.4 Demand diurnal pattern and multipliers factors

'The variations in water usage for water supply systems typically follow a 24-hour cycle. However, in reality, water demand varies over time and for extended period simulation to reflect the dynamics of the real system, these demand fluctuations must be incorporated into the model and it requires both baseline demand data and information on how demands vary over time. These demands can be determined by applying a multiplication factors or a peaking factor. Multiplication/ Peaking factors from average day to maximum day tend to range from 1.2 to 3.0, and factors from average day to peak hour are typically between 3.0 and 6.0. Of course, these values are system-specific, so it must be determined based on the demand characteristics of the system at hand' (Tomas, et al., 2003).

Therefore, When more than one demand type is served by a particular junction, the total demand for a junction at any given time is equal to the sum of each baseline demand times with its respective pattern multiplier, and it is used in most software packages to assign a different pattern to the different components of the composite demand as per below (Tomas, et al., 2003).

$$Q_{i,t} = \sum_{j} B_{i,j} P_{i,j,t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. \text{eq. } 2.7$$

Where, $Q_{i,t}$ = Total demand at junction *i* at time *t* (cfs, m^3/s)

$B_{i,j}$ = Baseline demand for demand type *j* at junction *i* (cfs, m^3/s)

$P_{i,j,t}$ = Pattern multiplier for demand type *j* at junction *i* at time *t*.

2.9 Model calibration and validation

'Model calibration is the process of fine-tuning a model until it simulates field conditions for a specified time horizon to an established degree of accuracy'. Fine-tuning includes making minor adjustments to the input data to achieve the desired output data' (Gregory, 2002). Therefore, model will not be hundred percent correct and to be calibrating it must be accurately simulate the observed data. So that, calibration is a major portion of modeling process and proper calibration were achieved through accurate field data. Further, according to Tomas, et al. 2003; hydraulic model calibration is the necessary process of modeling and it is calibrated inorder to have better confidence, understanding and identifing errors made during the model-building process.

2.9.1 Pressure calibration

Collecting pressures data throughout the water distribution system used to indicate the level of service. Pressure readings are done using pressure gauge commonly taken at pump stations, storage tanks, reservoirs, fire hydrants, home faucets, air release and other types of valves. However, different factors can contribute to deviation between model simulation and actual field data. Therefore, *'calibration can be accomplished by adjusting only internal pipe roughness values or estimates of nodal demands until an agreement between observed and computed pressures and flows is obtained. The basis for this claim is that unlike pipe lengths, diameters, and tank levels, which are directly measured, pipe roughness values and nodal demands are typically estimated, and thus have room for adjustment'* (Tomas, et al., 2003).

2.9.2 Acceptable levels of calibration

Acocrding to (Tomas, et al., 2003), *'regardless of which approach to calibration is adopted a realistic model should achieve some level of performance criteria. Accordingly, outlines the criteria for pressure through extended-period simulations has been established'.*

2.9.2.1 Pressure criteria

1) 85% of field test measurements should be within ± 0.5 m or ± 5 % of the maximum head loss across the system, whichever is greater.
2) 95% of field test measurements should be within ± 0.75 m or ± 7.5 % of the maximum head loss across the system, whichever is greater.
3) 100% of field test measurements should be within ± 2 m or ± 15 % of the maximum head loss across the system, whichever is greater.

2.10 Pump Capacity Test

Pump is a device that adds energy to the system in the form of increasing hydraulic grade to water. In water distribution systems, the most frequently type of pump is the centrifugal pump. Accordingly, the performance of these centrifugal pumps are a function of flow rate, and is described by the following four parameters listed as below (Tomas, et al., 2003);

- Head: Total dynamic head added by pump in units of length,
- Efficiency: Overall pump efficiency (wire-to-water efficiency) in units of percent,
- Brake horsepower: Power needed to turn pump (in power units) and
- Net positive suction head (NPSH): Head above vacuum (in units of length) required to prevent cavitation.

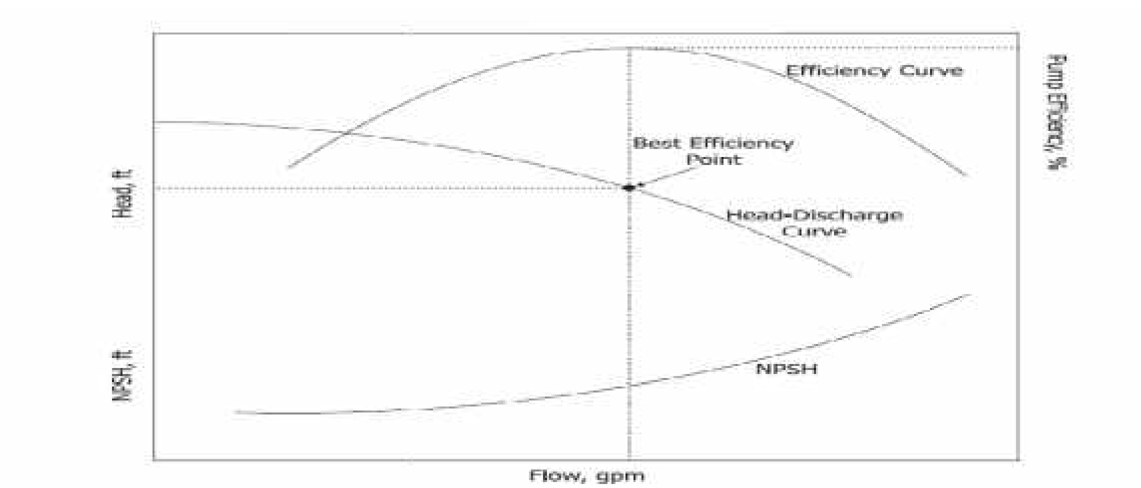


Figure 2.2: Pump efficiency curve (source: Advanced water distribution modeling and management: Haestad Methods)

'Typically, only the head characteristic curve is needed for modeling; however, some models determine energy usage at pump stations as well as flow and head. To determine energy usage, the model must convert the water power produced by the pump into electric power used by the pump. This conversion is done using the efficiency relationships summarized below' (Tomas, et al., 2003).

$$e_p = (\text{Water Power}_{out}) / (\text{Pump Power}_{in}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\text{eq. }2.8$$

Where, e_p= pump efficiency (%)

Pump power refers to the brake horsepower on the pump shaft, or the amount of power delivered to the pump from the motor. While, water power is the amount of power delivered to the water from the pump and it computed using the following relationship (Tomas, et al., 2003);

$$WP = C_f Q h_p C \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\text{eq. }2.9$$

Where, WP = Water power, Watts,

Q = flow rate, l/s

Hp = head added at pump, m,

C = Specific weight of water, 9810 N/m^3 and

C_f = Units conversion factor, 0.001 for SI

2.11 Water loss in distribution network

Water losses occur in all water distribution networks, even new one and it is only the volume that varies. Thereby, the volume of this losses reflects the capacity of water authorities to manage their distribution networks (Dighade, et al., 2014). In general, *'water losses consist of real and apparent losses. And to most water utilities, the level of Non-Revenue Water (NRW) is a key performance indicator of efficiency. Utility managers should use the water balance to calculate each component and determine where water losses are occurring. By quantifying NRW from the water balance concept, volumes of lost water into system can be calculate and they will then prioritise and implement the required policy changes and operational practices which lead to the proper understood and take the required actions'* (Farley, et al., 2008). Therefore, the water balance can guides water loss estimation in the distribution system while also indicating the level of accuracy of the Non- Revenue Water calculation.

Table 2.2: Water balance showing NRW components; IWA water loss task force

System Input Volume	Authorised Consumption	Billed Authorised Consumption	Billed Metered Consumption	Revenue Water
			Billed Unmeterd Consumption	
		Unbilled Authorised Consumption	Unbilled Metered Consumption	Non-Revenue Water
			Unbilled Unmetered Consumption	
	Water losses	Apparent Losses	Unauthorised Consumption	
			Customer Meter Inaccurracies and Data Handlling Error	
		Physical/Real Loss	Leakage on Mains (Transission and Distribution)	
			Leakage and Overflow from Utility Storage Tank	
			Leakage on Serice Connection up to the Custemmer Meter	

(Source: Farley, et al., 2008)

2.11.1 Non- Revenue Water (NRW)

According to the above water balance classification, Non-revenue water (NRW) is the total amount of water losses in the system from the water treatment plant outlet meter to the customers meter and it consistes of real loss and apparent losses. Thus, it is described as the diffrence of total amount of water production and authorised consumption figure.

$$\text{NRW} = \text{System Input Volume} - \text{Billed Authorised Consumption} \ldots\ldots\ldots\ldots\ldots\ldots \text{eq } 2.10$$

Unaccounted-for-water also expressed as a percentage and, has generally evaluated as the amount of water produced minus the metered customer use divided by the amount of water produced and multiplied by 100 (EPA, 2010).

$$\text{Unaccounted for water} = \frac{(\text{Water produced} - \text{Metered water used})}{\text{Water produced}} * 100 \ldots\ldots \text{eq } 2.11$$

2.11.2 Physical / Real Loss

'Physical losses, sometimes called 'real losses', are the annual volumes lost through all types of leaks, bursts, and overflows on mains, service reservoirs and service connections up to the point of customer metering. So, utility managers must be verify the physical loss assessment of towns water distribution system' (Farley, et al., 2008).

2.11.2.1 Leakage from transmission and distribution mains

Leakages occurring from transmission and distribution mains are usually large in volume. Thus, considerable volume of water is lost through bursts, leaking pipes, joints, valves and fittings of distribution system components. This causes are usually as result of age of the installations, bad quality of materials used, and poor workmanship. Although this factors were lead to reduction of pressure in the distribution network and intermittent in water supply (Dighade, et al., 2014).

2.11.2.2 Leakages from reservoirs and storage tanks

Leakage and overflows from reservoirs and storage tanks are easily quantified. By observing overflows, utility experts can estimate the duration and flow rate of the events. While, most overflows occur at night when demands are low, therefore it is essential to undertake regularly night observations. *'Observations can be undertaken either physically or by installing a data logger which record reservoir levels automatically at preset intervals. Also, leakage from tanks is calculated using a drop test were the utility closes all inflow and outflow valves, measures the rate of water level drop, and then calculates the volume of water lost'* (Farley, et al., 2008).

2.11.2.3 Leakage on service connections up to the customer's meter

This leakage is more difficult to identify and it covers the greatest volume of physical losses. So that, utility experts can calculate the approximate volume of leakage in service connections by deducting the mains leakage and storage tank leakage from the total volume of physical losses (Farley, et al., 2008).

2.11.3 Commercial/ Apparent Loss

Commercial loss is also refer to as apparent losses, and it consist of unauthorised consumption, all types of metering inaccuracies and data handling errors. It also include water that is consumed but not paid by the users (Farley, et al., 2008).

In the developing countries, metering inaccuracies (mainly under recorded problem) and illegal users of water within the distribution system is the common problem of water losses. Whereby, they contribute large coverage to apparent losses, so the level of these losses were one of the significant concern in developing country water distribution systems (Dighade, et al., 2014).

Therefore,'*Apparent losses can amount to a large volume of water than physical losses and often have a greater value, since reducing apparent losses increases revenue, whereas physical losses reduce production costs. For any profitable utility, the water tariff will be higher than the variable production cost and sometimes up to four times higher. Thus, even a small volume of apparent loss will have a large financial impact'* (Farley, et al., 2008).

2.11.4 The Infrastructure Leakage Index (ILI)

2.11.4.1 Performance indicator for physical loss

As per Farley, et al., 2008; The Infrastructure Leakage Index (ILI) is an excellent indicator of physical losses. Thus, the International Water Association (IWA) developed the index, and the American Water Works Association (AWWA) and Water Loss Control Committee (WLCC) were recommend this indicator. Therefore, ILI described as the ratio of Current Annual Volume of Physical Losses (CAPL) to Unavoidable Annual Real Loss (UARL).

$$\mathrm{ILI} = {}^{\mathrm{CAPL}}/_{\mathrm{UARL}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{eq. } 2.12$$

Where, the ILI has no units and thus facilitates comparisons between utilities and countries that use different measurement units. Acoording to IWA, Unavoidable Annual Real Loss (UARL) is also called the Minimum Achievable Annual Physical Losses (MAAPL); and its formula have been converted to a format using pre-defined pressure for a practical use as follow (Farley, et al., 2008).

$$\text{UARL (litres/day)} = \left(18 * L_m + 0.8 * N_c + 25 * L_p\right) * P \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{eq. } 2.13$$

Where Lm = mains length (km);

Nc = number of service connections;

Lp = total length of private pipe, property boundary to customer meter (km); and

P = average pressure (m)

'The ratio of the CAPL to UARL, or the ILI, is a measure of how well the utility implements the there infrastructure management functions. Although a well-managed system can have an ILI of 1.0 (CAPL = UARL), the utility may not necessarily aim for this target, since the ILI is a purely technical performance indicator and does not take economic considerations into account' (Farley, et al., 2008).

In general, the concept of Infrastructure Leakage Index is identifying how well a distribution network is managed to control physical losses. Therefore, according to Farley, et al., 2008; the ILI target matrix shows the expected level of physical losses of countries at differing levels of network pressure. Hence, the water utility experts can use the matrix to guide further network development and improvement.

Table 2.3: Physical loss target matrix; World Bank Institute

Technical performance category	Rank	ILI	Physical Losses (Liters/connection/day) (When the system is pressured) at an average pressure of:				
			10m	20m	30m	40m	50m

Developing Countries	A	1-4	<50	<100	<150	<200	<250
	B	4-8	50-100	100-200	150-300	200-400	250-500
	C	8-16	100-200	200-400	300-600	400-800	500-1000
	D	>16	>200	>400	>600	>800	>1000

(Source: Farley, et al., 2008)

- Category- A (Good): Further loss reduction may be uneconomic and careful analysis needed to identify cost-effective improvements.
- Category- B (Potential for marked improvements): Consider pressure management, better active leakage control, and better maintenance.
- Category- C (Poor): Tolerable only if water is plentiful and cheap, and even then intensify NRW reduction efforts.
- Category- D (Bad): The utility is using resources inefficiently and NRW reduction programmes are imperative.

2.12 Non-Revenue water management and controlling methods

Non-Revenue water control program should be flexible and modified to the specific needs and characteristics of town's water supply system. Accordingly, there are three major components to an effective water loss controlling program (EPA, 2010):

Water Audit is an assessment of the distribution, metering, and accounting operations of the water utility and uses accounting principles to determine how much water is being lost and where. This method used to compare and evaluate with consideration of all issues and concerns the public water system faces. Typical steps in water audit include;

- *Determining flows into and out of the distribution system based on estimates or metering,*
- *Calculating the standard performance indicator values and assessing water loss standing by comparing these values with ranges of values from audits from other water utilities,*
- *Assessing where water losses appear to be occurring based on available metering and estimates,*
- *Analyzing data gaps (e.g., determining if more information is necessary to make*

comparisons and an informed decision),

- *Considering options and making economic benefit comparisons of potential actions, and*
- *Selecting the appropriate interventions.*

Intervention is a process puts the options selected into action. While, more than one action may be selected and it should be based on budget constraints, public benefit, and priority of other scheduled capital improvements. Therefore, intervention can include:

- *Metering assessment, testing, or a metering replacement program,*
- *Detecting and locating leaks,*
- *Repairing or replacing pipe,*
- *Operation and maintenance programs and changes,*
- *Administrative processes or policy changes.*

Evaluation is part of the method consists of identifing the success of the audit and intervention process. The evaluation should answer questions such as:

- *How often should we repeat the Audit, Intervention, and Evaluation process?*
- *Is there another performance indicator we should consider?*
- *How did we compare to the last Audit, Intervention, and Evaluation process?*
- *How can we improve performance?*

2.13 Challenges of Non-Revenue Water

Addressing NRW is the responsibility of managers across the water utility, including finance and administration, production, distribution, customer service, and other departments. But, most of developing countries have the problem of infrastructure and establishing operational procedures to begin tackling NRW. Hence, water utilities face greater challenges including (Farley, et al., 2008):

- *Outdated infrastructure*
- *Poor operations and maintenance policy, including ineffective record-keeping systems*
- *Inadequate technical skills and technology*
- *Greater financial constraints, including unsuitable tariff structure and/or revenue collection policy*

- *Political, cultural, and social influences*
- *A higher incidence of commercial losses, particularly illegal connections*
- *Withdrawing water supply and*
- *Environmental pollution*

2.14 Causes of water loss

Leakage is usually the major source of water loss in developing countries, but this is not always the case in developing or most of developed countries, where illegal connections, customer meter reading inaccuracy, unauthorized consumption and, data handling and accounting errors are often more significant and the reasons of total water losses in the water distribution system (Farley, et al., 2008).

2.15 Leakage management in water distribution network

2.15.1 General

All water supply networks are made of assets, these are the physical components of the system and it includes; pipe, reservoirs, pumps, valves, hydrants, and other components that make up the system (EFC, 2006). Good asset management involves a combination of technical, financial and engineering practices while achieving the least cost and risk over the life cycle, and meeting service standards for customers (WUAM, 2013).

In general, urban water distribution netowrks are one the most valuable parts of the public infrastructure. So that, water utilities should be entrusted with the responsibility of managing and expanding them for current and future generations (Alegre & Coelho, 2013).

2.15.2 Infrastructure Asset Management

'Infrastructure asset management is one of a key topic towards compliance with the performance requirements in water supply and distribution networks. Systems that fully adopt infrastructure asset management principal can achieve many of benefits' (Alegre & Coelho, 2013). Therefore, the water organizations need to put plans, policies, and strategies for sustainable management of the systems, and they should be respond to the need for;

- Promoting adequate levels of service and strengthening long-term service reliability

- Improving the sustainable use of water and energy
- Managing service risk, taking into account users' needs and risk acceptance
- Extending service life of existing assets instead of building new, when feasible
- Upholding and phasing in climate change adaptations
- Improving investment and operational efficiency in the organization and
- Justifying investment priorities in a clear, straightforward and accountable manner.

2.15.3 Leakage Controlling Strategy

Many of developing country water utilities face the challenge of controlling their unacceptably high levels of Non-Revenue Water. Accordingly, large volume of this total water loss lead to increasing the cost of delivered water, and money for investment and productivity (WUAM, 2013). Therefore, to reduce these losses the water utility should be considere;

- Identifing the life span of assets,
- Setting maintenance plan and strategy inorder to reduce physical failures,
- Financing for the timely replacement and maintenance of existing assets,
- Expand distribution networks to manage with demand growth, and
- Raise their service levels 24 hours a day and 7 days a week, to meet the required outlook

In general, *'to minimize leakage, customer service-level targets are set through consultation and maintenance strategy. Further, the targets are reviewed occasionally or imposed through regulation'* (WUAM, 2013).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Description of the Study Area

Metu town is the capital of Ilu-Abba-Bora Zone of Oromia National Regional State which located between 8°17' N latitude and 35°35' E longitude at average elevation range of 1547 and 1783 m.a.s.l. with a total area of 1,632 ha along Addis Ababa – Jimma – Gambella road at a distance of 600 km west from capital city of Ethiopia. Metu is situated on the left bank side of Sor River.

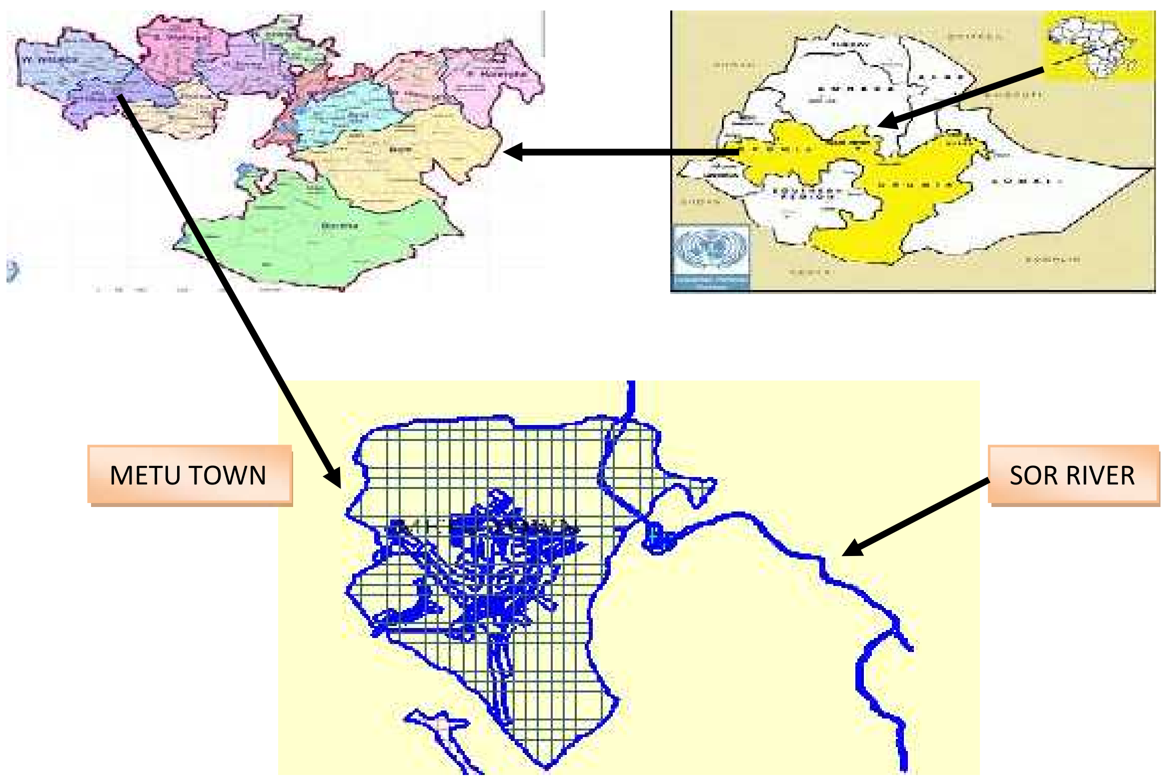


Figure 3.1: Location of Metu Town

According to the Ethiopian Central Statistical Agency (CSA), the last census population data of Metu town was 33,224 for the year 2007 G.C. The climate of the study area comes under the influence of the Inter-Tropical Convergence Zone (ITCZ) and the seasonal rainfall distribution results from the annual migration of the ITCZ. Two rainy seasons has been experienced, the main rainy season often extends from May through end of October and the small rainy season from March to end of April, the rest of the months are generally dry. The area receives an annual rainfall of 1,344mm to 2,200mm during May to September. The period from June to September is characterized by heavy cloud cover and fog. The mean daily temperature also varies between 25.50°C and 32.0°C. According to Ethiopian weather classification, Metu town is grouped in Weynadega climatic zone.

3.2 Socio-economic activity of the town

3.2.1 Economic activities

Metu is one of economically important town in the region, and the newly constructed gravel road which connects Gore and Tepi towns has created an additional opportunities for the people to move back and onward. As the town is a terminal station for Jimma, Tepi and Gambella towns having better hotel facilities compared to other towns in the area. Coffee is the main foreign currency earning cash crop, and it covers large area in and around the town. While, various categories of manufacturing and trade services at varying scales are the main sources of livelihood of the residents of the town. These operations mainly consist of activities like hotel services, fuel stations, garages, coffee hulling and pulling, woodworks, metal works, grain mills, shop keeping, grain and chat retailing, sales of charcoal and fire woods, and many unclassified other trades. In the town there is also the newly establishments of peasant training center and the orphanage of Menschen fiir Menschen (MfM). While, the state owned timber producing plant is not too far from Metu town, and cereal and grain growing areas like Darimu and Alge rural towns are connected by all weather and dry weather roads to Metu.

3.2.2 Education and health condition

According to Metu town education and health office; in the town there are 13 regular schools (1 to 8 grades), two regular schools (9 to 12 grades), two TVET, one NGO-owned college, one state owned university and four private colleges. While, with regard to health concern one hospital, one health station, six health posts, nine pharmacies and 13 clinics are found in the town.

3.3 Existing Water Supply System Description

As per information obtained from Metu town water service office, the design report was prepared by ARMA Engineering and existing water supply has been designed by German Water Engineering and constructed by Berta Construction Company some 30 years ago. Currently, householders collect their total water needs from this water supply system and using directly through private connections and public taps.

3.3.1 Potential source water

Metu area is characterized by high rainfall regime, due to this there are streams with adequate flow in the area that can be utilized as a source of water supply for the town. The potential surface water source used for Metu town water supply system is Sor River.

Sor River is a perennial river, located east of Metu town. The hydrological data shows that mean monthly flow of Sor River at Metu gauging station varies from 1.08 Mm^3 to 335.7 Mm^3. The lowest mean flow usually occurs in February while the highest flow occurs in September. Currently, existing water supply of the town was used this surface water by diverting 14.44 l/s or annually about 455,381 m^3 of water through the river side intake.

3.3.2 Components of water supply system

The source water was collected through the river side intake into a wet well via 250mm DCI inlet pipe. From the wet-well the raw water is pumped to a roughing filter which used as preliminary treatment unit. The water after passing through the roughing filter leads to slow sand filter unit. Treated water from under drainage system of slow sand filter was drained into clear water storage tank. From the clear water tank after disinfection with chlorine, the water is pumped simultaneously into the distribution network and service reservoir. In general the system consists of river side intake with raw water pumping station, roughing filter, slow sand filtration unit, chlorination system, clear water wet-well, clear water pumping unit, RC service/balancing reservoir and distribution pipe network.

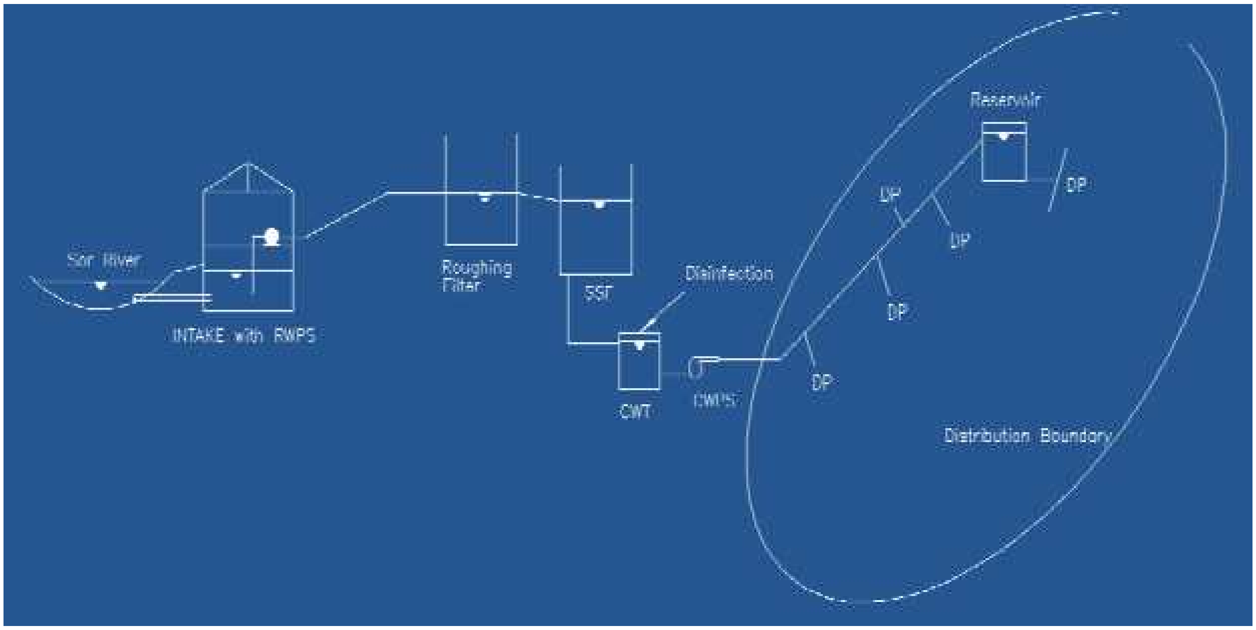


Figure 3.2: Layout of Metu town water treatment and distribution system

3.3.3 Water supply coverage

3.3.3.1 Mode of services

According to the town water service office reports, there are four major modes of services for domestic water consumers of Metu town. These are; house connections (HC), yard connections (YCP) private, yard connections (YCS) shared, and public fountains (PF). But, those populations not served from any of these modes of services are categorized as traditional source users (TSU).

3.3.3.2 Population distribution by mode of services

The percentage of population served by each mode of service is varying with time. This variation is caused because of the changes in living standards, improvement of the service level, changes in building standards and capacity of the water supply service to expand. According to the CSA 2007 census shown in table 3.1 below, the overall domestic water supply coverage of Metu town was indicate 71%. Of this only about 2.2% of the population were house tap connection users. The greater number of the populations was served their water need from both shared yard taps and public fountains found in different villages of the town are covers 30.3% and 25%, respectively. The remained 13.5% of the population were obtained water from their bounded privet yard connections. While, remain 29% of the population was got water for their day to day activates from the unprotected surface water (river and streams), and rain water harvesting technique which come during the rainy seasons.

Table 3.1: Summarized Metu town domestic water supply coverage

Mode of Services	Metu Town		
	Coverage (%)	Service Connections	Served Population
HC	2.2	192	731
YTP	13.5	1,180	4,486
YTS	30.3	591	10,066
PF	25	18	8,306
Total	71	1,981	23,589

(Source: CSA, 2007 statistical census document and the town water service office)

3.4 MATERIALS

3.4.1 Source of data

The source of data was involved both primary and secondary data. For the study, the primary data were obtained from pressure reading, elevation surveying and by made of discussion with water utility staff members to obtain additional relevant information on the subject matter. While, secondary data were collected from different literature reviews, design report, the town water supply service office existing documents and annual reported papers.

3.4.2 Equipments Used

GPS instrument was used to collect the required elevation data during pressure reading. Pressure readings were done using pressure gauge which is commonly taken in the selected points of distribution system.

3.4.3 Hydraulic Model: Water CAD

Model is something that represents things in the real world. Computer model uses mathematical equations to explain and predict physical events. Modeling of water distribution systems can allow determining system pressure and flowing rate under a variety of different conditions without having to go out and physically monitor the system (Dawe, 2000).

Water CAD is a state-of-the-art software tool and, primarily uses in the modeling and analysis of hydraulic and water quality modeling application of water distribution systems. But, the methodology is applicable to any fluid system with different characteristics, such as: steady or gradually-varying turbulent flow (Water CAD: *USER MANUAL*).

3.4.4 Additional software

ArcGIS, was used to display the overlapped shape file of the distribution network on the topographic map of the town. While, Microsoft Excel sheet were used to organize elevation data, to calculate a repeated work of nodal base water demand requirement of distribution network simulation and for manual pressure validation work.

3.5 METHODS

3.5.1 Preliminary data collection

Data collection is the most significant part in research work. In order to accomplish this work, the data were gathered with regard to the necessary input parameters of model simulation, water losses and leakage management trend in the system. The data collection techniques were done by conducted a field visit to Metu town on March 28, 2016. Data were obtained from design report of existing town water supply system, town water service office, and field observation. The summarized collected data were presented as below;

3.5.1.1 Clear water pumping station

In the clear water pumping station there were two surface horizontal centrifugal types of pumps (one operational and the other standby) with a design capacities of 14.4 l/s discharge and 236 m head. These pumps were sucked water from the clear water reservoir which is adjacent to the pump station and pumping water to the distribution line and service reservoir at the same time. Each of these installed pumps has a maximum discharge and head capacities of 28 l/s and 300 m respectively. The pumps have a 75 kW of brake horsepower on each pump shaft (pump power). According to Metu town water service office, the pumps currently operating in the system were installed before 13 years ago and performed without replacing by the new one.

3.5.1.2 Rising main and distribution pipeline network

The transmission and distribution main line consists of branching system with a total sum length of 20,920 m, and supplying water through public fountain and yard connections by pumping and gravity means. The rising main transmit clear water simultaneously into the distribution network and service reservoir. It has a DCI pipe of DN 200 mm and PN 32, and has a length of 3,340 m.

As observed from the drawn distribution layout; there was one flushing device (wash out valve), one air release, and one pressure reducing device was installed in transmission line at chain-age of 365.20 m to connect a low pressure area of the town. Currently, the PRV was damaged.

The treated water is also further connected by distribution main line which serves the population with a total length of about 17,580 m by gravity means. As per information obtained from the town water service office; the existing distribution pipe line was GI and PVC pipe type with DN 80 mm to DN 150 mm. Previously laid GI pipe of DN 50 mm was replaced by PVC pipe with DN 80 mm, and all the newly expansion line are PVC pipe with DN 80 mm. In general, the pipe categories in Metu water distribution system were DCI, GI and rigid PVC ranges from DN 80 to DN 200 of PN 10 and PN 16. While, detail description was presented as appendix-B.

Table 3.2: Summarized quantity of pipe material in distribution system

Pipe type	Length (m)	Coverage in system (%)
DCI	3,340	15.96
GI	8,930	42.69
Rigid PVC	8,650	41.35
Total	20,920	

(Source: Metu town water supply service office)

3.5.1.3 Reservoirs

There are two circular RC type reservoirs with the capacity of (400 m^3) and internal diameter of 11.70 m were used in the town water distribution system, which used as clear water tank (point of disinfection) and service reservoir. Water is pumped simultaneously into the distribution network and service reservoir, thus the part of the town that is located above the treatment plant is served from the service reservoir and the pumping line. But, the part of the town that is located below the treatment plant site is served from the clear water reservoir found at treatment plant.

3.5.1.4 Power supply units

There is power supply service in the town. The water utility were served power from Sor hydroelectric power plant and used with its own transformer which is provided by EELPA. The water distribution system was operated for 24 hours of its design period. But, there is no standby generator for distribution system during power failure is occurring.

3.5.2 Elevation data

Setting elevation is one of the significant requirements to simulate the hydraulic characteristics of water in distribution system. Most of elevation data was obtained from the town water service office which was prepared as the design report of Metu town water supply system (existing document). But, elevation data for expansion area in the town were served in the field using surveying instrument, global position system (GPS). In appendix-C, all the assigned node elevation data were listed with coordination system.

Table 3.3: Elevation data for clear water pumping and service reservoir site

Description	**Coordinates**		
	X	**Y**	**Z (Elevation, masl)**
Clear Water Reservoir	786,105.78	919,111.87	1,549.99
Clear Water Pump	786,092.79	919,098.26	1,549.00
Existing Service Reservoir	784,402.90	916,630.00	1,755.99

(Source: Metu design report)

3.5.3 Base water demand data

To estimate the current water demand of each node in the distribution network, it was necessary following the steps below;

Step one: Assigning the total population of the town

Population is the important data to assess water demand in the distribution network. Facts show that there are different population forecasting methods which are used for estimating the current or future population of a given town, but the results of the methods are vary from one to the other due to considering parameters of each method.

To predict the population of a town, it is necessary knowing factors affecting the population distribution, size and growth rate. In Ethiopia, the major factors that influences on the changes in population figure are births, death and migration. All these factors are influenced by family planning practice, war, natural disasters, development of the towns and the socio-economic activities in and around the towns. Therefore, for this study; based on the historical figures, assumptions considered (available of data) and to be precise, the CSA population estimation method was selected from the different population projection methods. Finally, the population figure of the town was assessed in (2015 G.C).

Table 3.4: Population growth rate, Oromia regional state

Year (G.C)	2005-2010	2010-2015	2015-2020	2020-2025	2025-2030	2030-2035	2035-2040
Growth rate (%)	4.55	4.33	4.15	3.93	3.68	3.68	3.27

(Source: Oromia water, mineral and energy bureau)

Step two: Identification of number of houses around each supply node

For this study, Metu town topographic map was obtained and bought from Ethiopian Mapping Authority, with the scale of 1:50,000 and twenty meter contour interval. In ArcGIS this topographic map was displayed and the town distribution network map which was drawn in

Water CAD was exported in to ArcGIS shape file and overlapped it in the topographic map of the town as shown as appendix-A. Therefore, the number of houses nearby each node were physically counted from the overlapped map and assigned to every node in the network by considering the actual condition of the residents in the town.

Step three: Assigning number of peoples in each supply node

The current average number of person in each house (person per housing unit) was obtained from the revised design report of the town population projection and taken 3.80 of the average number. The total number of houses in the town was identified by dividing the total population to the average number of person in the town, and it was estimated at 12,186. Therefore, in the opened Microsoft Excel sheet, all the 335 nodal junctions in the system and the number of houses assigned for each node were entered respectively. Then, in the third column the number of assigned houses in each node was converted in to the number of people, by multiplying the average number of person in each house of the town.

$$\begin{aligned}&\text{number of people for a supply node}\\&\qquad = \text{number of house assigned by that node}\\&\qquad * \text{average number of people in each house} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \text{eq. 3.1}\end{aligned}$$

Step four: Assigning average day water demand of Metu town

For assessing the average water demand of the town, deterministic water demand estimation method was used. Hence, the per capital water consumption of the town was calculated using the annual water consumption recorded data and projected total population figure during (2015). Therefore using equation below it was assessed.

$$\begin{aligned}&\text{Per capital consumption } (l/c\ /\ d)\\&= \text{Annual consumption } \left(m^3 * 1000\ {}^{l}/_{m^3}\right)/\text{Total population } * 365 \dots \dots \text{eq. 3.2}\end{aligned}$$

Therefore, the average water demand of the town was calculated by multiplying the per capital demand with the estimated number of population as follow.

$$Q_{avg.} = Per\ capital\ water\ consumption$$
$$* Total\ population\ of\ the\ town \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots eq. 3.3$$

Step five: Assigning base water demand in each supply node

Once the average day water demand of the system was determined, to calculate base water demand for the particular supply node the following equation was used (Bhadbhade, 2009):

$$\text{Base water demand for a supply node}$$
$$= \frac{\text{Population served by that node}}{\text{Total population of the town}}$$
$$* \text{ average day water consumption of the town} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{eq. } 3.4$$

In appendix-C, all the assigned house number, number of people and base water demand of each supply node were listed.

3.5.4 Demand multiplier factors

For modeling, peak hour demand scenario was adopted. Demand for each supply node was performed by taken demand multiplier factors of 24 hour flow duration and computed with assessed base demand. Therefore, for this study by considering the peak flow time, minimum flow condition and the actual condition of population served from the system; the demand multiplier factors were adopted data obtained from the regional water, energy and mineral bureau. Therefore, the proposed peak factor and patterns for demand multiplier factors were listed in table 3.5 below and presented in appendix-D.

Table 3.5: Proposed hourly peak factor

Population	Peak hour factor
0 – 50,000	2
50,001 – 100,000	1.8
101,000 & above	1.6

(Source: FDRE, MoWR)

3.5.5 Roughness coefficients for pipeline

The Hazen-Williams equation was developed for the action of friction at the pipe wall, because its formula uses a pipe carrying capacity factor. Higher C-factors represent smoother pipes (with higher carrying capacities) and lower C-factors describe rougher pipes (Tomas, et al., 2003). The value of roughness coefficient, C-factor is depending on pipe materials and its age; this effect can be shown in table 3.6 and 3.7 below (Tomas, et al., 2003).

According to Metu town water service office, DCI and GI pipe laid in the water distribution network was served without replacement work for the last 30 years. But, the recent PVC plastic pipe laid in the system was not served more than 10 years.

Table 3.6: Roughness coefficient, C- factor for different pipe material, continued

Type of Pipe	C-factor Values for Discrete Pipe Diameters					
	1.0 in. (2.5 cm)	3.0 in. (7.6 cm)	6.0 in. (15.2 cm)	12 in. (30 cm)	24 in. (61 cm)	48 in. (122 cm)
Coated asbestos cement - clean		147	149	150	152	
Uncoated asbestos cement - clean		142	145	147	150	
Spun cement-lined and spun bitumen-lined - clean		147	149	150	152	153
Smooth pipe (including lead, brass, copper, polyethylene, and PVC) - clean	140	147	149	150	152	153
PVC wavy - clean	134	142	145	147	150	150
Concrete - Scobey						
Class 1 - Cs = 0.27; clean		69	79	84	90	95
Class 2 - Cs = 0.31; clean		95	102	106	110	113
Class 3 - Cs = 0.345; clean		109	116	121	125	127
Class 4 - Cs = 0.37; clean		121	125	130	132	134
Best - Cs = 0.40; clean		129	133	138	140	141
Tate relined pipes - clean		109	116	121	125	127
Prestressed concrete pipes - clean				147	150	150

Lamont (1981)

(Source: Tomas, et al., 2003)

Table 3.7: Roughness coefficient, C-factor for different pipe material

	C-factor Values for Discrete Pipe Diameters					
Type of Pipe	1.0 in. (2.5 cm)	3.0 in. (7.6 cm)	6.0 in. (15.2 cm)	12 in. (30 cm)	24 in. (61 cm)	48 in. (122 cm)
Uncoated cast iron - smooth and new		121	125	130	132	134
Coated cast iron - smooth and new		129	133	138	140	141
30 years old						
Trend 1 - slight attack		100	106	112	117	120
Trend 2 - moderate attack		83	90	97	102	107
Trend 3 - appreciable attack		59	70	78	83	89
Trend 4 - severe attack		41	50	58	66	73
60 years old						
Trend 1 - slight attack		90	97	102	107	112
Trend 2 - moderate attack		69	79	85	92	96
Trend 3 - appreciable attack		49	58	66	72	78
Trend 4 - severe attack		30	39	48	56	62
100 years old						
Trend 1 - slight attack		81	89	95	100	104
Trend 2 - moderate attack		61	70	78	83	89
Trend 3 - appreciable attack		40	49	57	64	71
Trend 4 - severe attack		21	30	39	46	54
Miscellaneous						
Newly scraped mains		109	116	121	125	127
Newly brushed mains		97	104	108	112	115
Coated spun iron - smooth and new		137	142	145	148	148
Old - take as coated cast iron of same age						
Galvanized iron - smooth and new	120	129	133			
Wrought iron - smooth and new	129	137	142			
Coated steel - smooth and new	129	137	142	145	148	148
Uncoated steel - smooth and new	134	142	145	147	150	150

(Source: Tomas, et al., 2003)

3.5.6 Network Simulation

To built and simulate the hydraulic model, water CAD stand-alone, graphical editor water distribution modeling software was used. The water distribution network map was obtained from the town water service office, which was prepared as blue print drawn map report of distribution network and it was drawn in water CAD drawing pane with physical observation.

The network simulation was taken extended periods by consideration of hourly demand variation pattern over 24 hour flow duration analysis work.

For this study, the network operational set-up was done by system international; SI unit and the project liquid were taken water at 20°c. The other model input were taken and carried out as mentioned below;

- Coordinate ………………….. X-Y
- Setting……………………….. Pressure
- Tank level……………………. Elevation
- Drawing Scale………………... Scaled
- Annotation Multiplier………... Adjusted for report visibility

3.5.7 Model calibration and validation

The computed parameters of a model and actual field observation are not always has the same value. Therefore, before discussion about the simulated model results, the entire model data quality must be analyzed by calibration and validation technique. Calibration is a process of adjusting the model input data until its results become closely approximate to the measured field data. Whereby, it used to obtain approach, realistic and acceptable results. Therefore, in this study the model data quality analysis was done by comparing and calibrating the computed pressure data with the observed one.

The method of pressure readings was done during May 24, 2016 using pressure gauge commonly taken both at high and low pressure zone of the selected points in distribution network; such as clear water pump stations, service reservoir, public fountains and different end user taps (like; customers, institution and commercial tap points). These observed pressure data was taken a total of twenty (20) samples for both peak demand and low demand (night flow) time analysis. All sampling points were selected after the computed model was simulated and knowing the pressure variation area (pressure zone) in the town water distribution network.

According to (Tomas, et al., 2003), the calibration process was performed by adjusting sensitive parameters related with flow;like pipe roughness coefficient and water demand until it was become with in the acceptable limit of 85% of field test measurements (it should be within ± 0.5

m or ± 5 % of the maximum head loss across the system, whichever is greater) and then finally it was validated manually using the correlation coefficient (R^2) method using microsoft Excel sheet.

3.5.8 Pump efficiency description

The pump efficency which operate currently in the system was calculated manually after validating the model. For each computing time (a total of 24 hour) value of the water power produced by the pump and which converted in to electric power form (watt) were collected from the model outputs presented in (Appendix-G). Therefore, to calculate these pump efficiency; the maximum value of 34.14 kW water power was obtained from the computed model result and used as the value of water power deliverd from the pump.

While, the value of pump power (the brake horsepower of the pump) in the system was obtained from the pump shaft during field observation (March 28, 2016). And based on the observed pump data, the brake horsepower on the pump shaft is 75 kW. Therefore, using these data and equation below the current pump efficiency for Metu water supply system was calculated.

$$e_p = {(\text{Water Power}_{\text{out}})}\Big/{(\text{Pump Power}_{\text{in}})}$$

Where e_p= pump efficiency (%) ……………………(Source: Tomas, et al., 2003)

3.5.9 Water loss assessment

Unlike the water consumption, the water production of Metu town was only recorded at the town level. Hence, the water loss analysis in Metu was assessed at the town level based on the percentage of Non-Revenue Water which obtained from the total production and actual consumption figure.

As per data obtained from the town water service office, the last eight year (June, 2008 to June, 2015 G.C) water production and consumption (billed water volume) in the system was identified. Using this data and equation below; the total Non-Revenue Water (NRW) in the system was calculated for each recorded year.

$$\text{NRW} = \text{System Input Volume} - \text{Billed Authorised Consumption}$$

During field visit, it was also observed that the utility do not have any recorded data related with avreage leak flow, number of reported bursts and average leak duration; due to these physical loss in the main was assesed base on the available data, and it was adopted by considering the minimum achievable annual physical losses (unavoidable annual real loss) in the system (Farley, et al., 2008).

$$\text{UARL (litres/day)} = \left(18 * L_m + 0.8 * N_c + 25 * L_p\right) * P$$

Where, Lm = mains length (km); Nc = number of service connections; Lp = total length of private pipe, property boundary to customer meter (km); and P = average pressure (m)

As per data collected from town water service office, and during the year 2015 the town water system covers;

- Total mains length of the system = 20.92 Km,
- Number of service connections (registered) = 3,109 in number,
- The water utility was layed an average length of 0.018 Km private pipe from distribution line to customer boundary. Therefore, for this work total length of private pipe was taken by multipling number of service connections and average length of private pipe, and it was used 55.96 Km.
- Average pressue was taken from the actual observed pressure value of 24 hour duration, and the average value of 38.43 m was adopted.

While, the total water loss was identified as per number of connection and pipe length at the town level.

3.5.10 Assessment of leakage management practice

The water distribution leakage management practices of the town water service office were assessed based on the management, technical and financial; plan, policy and strategies. Hence, field visits were made to identify the leakage in the system and its managing processes. During field observation, discussions were conducted with town water supply service personnel to obtain information on the common failure of system, financing mechanisms, and the maintenance culture and cost drivers of maintenance. While, cost related data was collected by reviewing the annual reports and financial statements of the utility. Finally, the collected data were analyzed and presented in the next chapter.

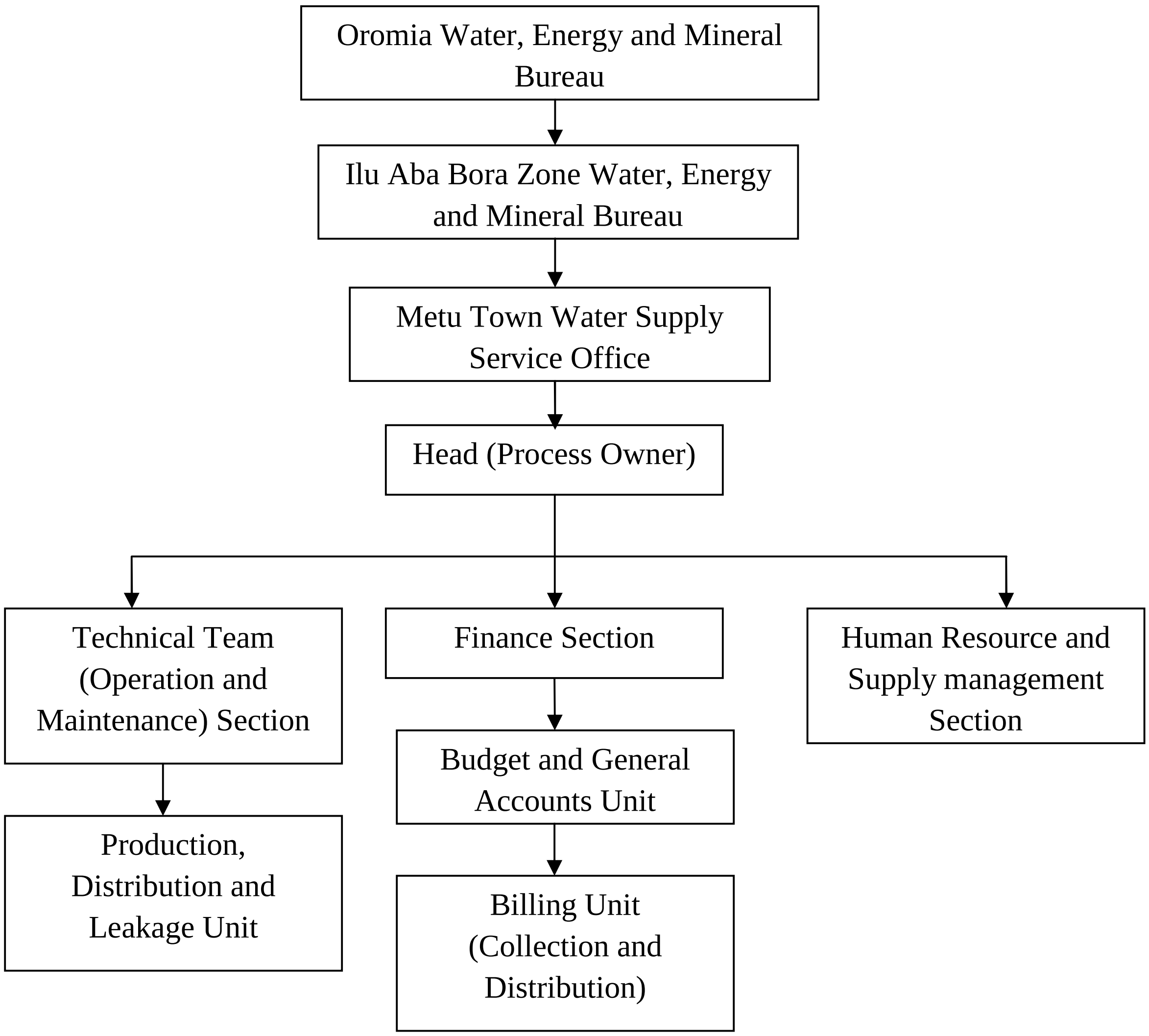


Figure 3.3: Metu town water supply service office organizational structure (source: Metu town water supply service office)

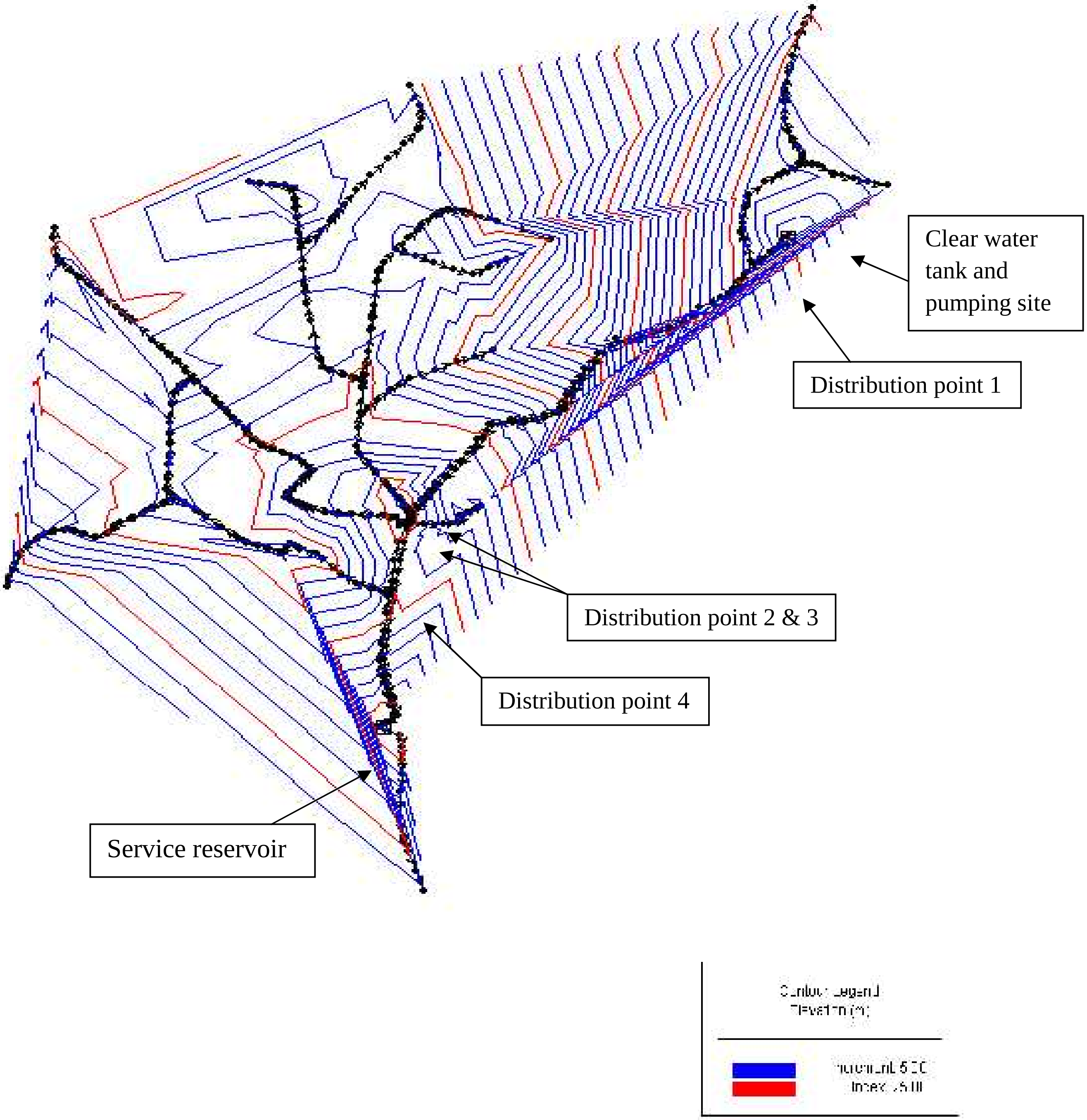


Figure 3.4: Metu Town Water Distribution Networks

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1 Estimated water demand

Estimating the expected water demand of the town were used for assessing and sizing system components such as pumping station, reservoirs, and transmission and distribution pipe line.

4.1.1 Population forecasting

The water demand of a particular town is proportionally related with the population to be served. The population of Metu town from Ethiopian CSA report, which is carried out in year 2007, was indicated 33,224 and it was used as base population for current estimation. According to CSA, the regional level annual growth rate for urban population (2015) was allocated as 4.15%.

Using the above CSA (2007) census data as a base, and applying exponential population forecasting method, the current (2015) estimated population figure for Metu town was presented in table 4.1 below.

$$P_n = P_o * e^{r*n}$$

Where: P_n = Estimated population figure

P_o = Base population figure

r = Growth rate and,

n = Number of year

Table 4.1: Metu town projected population figure (2010-2035)

Description	Unit	2007	2010	2015	2020	2025	2030	2035
Growth rate-Urban	%		4.33	4.15	3.93	3.68	3.68	3.27
Population-Urban	No	33,224	37,833	46,306	55,378	64,436	77,454	83,003

(Source: CSA, 2007 national statistical census document, Oromia region, Metu)

Therefore, regard to the above table 4.1; the estimated total population figure of Metu town was 46,306 during (2015).

4.1.2 Per capital water consumption

The per-capita water consumption for various demand categories varies depending on the size of the town and the level of development. In Metu, because of the growth of the socio-economic activity in both governmental and private sectors, there was the high water demand in the town. Using the annual water consumption and population figure in (2015), the average per capital consumption of the town was identified as below.

$$\text{Per capital consumption (l/c / d)} = 289{,}071 * 1000 / 46{,}306 * 365 = 17.10$$

But, according to existing town water supply design report; the average per capital water demand of the town at the end of the design period (2003 G.C) was estimated and adopted as 40 l/c/d. With the comparison of this figure the above estimated per capital consumption value (17.10 l/c/d) was unrealistic and unacceptable. Hence, it was not adopted for this assessment work.

Therefore, further reviewing work was necessary to fix the recent per capital water consumption of the town. And as per the revised design report of Metu town water supply system, obtained from the regional water, mineral and energy bureau; the current (2015) average per capital water consumption for Metu town were estimated and adopted as **79 l/c/d** for various activities of demand category.

4.1.3 Average water demand

There are several mathematical methods of estimating the water demands of a given town; including extrapolating historical trends and correlating demand with the socio-economic variables of the town. But, the most common means of forecasting future water demand is estimating current per-capital water consumption, and multiply this by the projected population figure. Therefore, during 2015 the average water demand for Metu town was calculated as;

$$Q_{avg.} = 46{,}306 * 79 \text{ l/c/d} = 3{,}658{,}174 \text{ l/d}$$

$$Q_{avg.} = 42.34 \text{ l/s or } 3{,}658.2 \text{ m}^3\text{/d.}$$

4.2 Water distribution network analysis

In the modern water supply system, clear water shall be delivered to the service reservoirs directly through the transmission main and which is completely isolated from the distribution system. But, existing Metu town water supply system which was constructed before 30 years ago and as it was the old system; water is pumped simultaneously into the distribution network and service reservoir. So, the impact of this network configuration and the capacity of distribution system components were described as below.

4.2.1 Existing reservoirs capacity

The capacities of reservoirs in the water supply system were determined using different methods. The most appropriate and economical approach of determining storage volume of reservoir is the 24 hours supply demand simulation mass curves. In order to develop such type of curves, it requires reliable recorded historical data of hourly water demand figures of the town. But, in the absence of such type of data, to determine the size of reservoirs, it was adopted the commonly practiced in many water supply systems and based on the urban water supply design criteria of the ministry of water resources; it was used for sizing the reservoir volume as one third of the maximum daily demand. Therefore, as per the design criteria of the FDRE; MoWIE, the maximum day factor usually varies between 1.0 and 1.3. Hence, a maximum day factor of 1.15 was adopted for assessing the maximum day water demand and reservoirs capacity for Metu town and applied it corresponding to the total average day demand of a particular year (2015).

Maximum day demand = 1.15 * average day demand

$$= 1.15 * 3{,}658.20 = 4{,}206.93\ m^3/d$$

Accordingly, the current (2015) required reservoirs volume capacity for water demand of Metu town was estimated as;

Reservoir capacity = maximum day demand *1/3

$$= 4{,}206.93*1/3 = 1{,}402.31 m^3$$

Hence, from the above finding to satisfy the current water demands of Metu town; the clear water reservoir was sized as a 1500 m^3 volume capacity of standard reservoir. But, in the existing water supply system of Metu, both storage tanks which serve as clear water tank and service reservoir had a capacity of only 400 m^3. This indicate, the existing reservoirs capacities were very small in size comparing with the current water demand of the town, and it was one of the major factors of the day to day intermittent water distribution in the town. Therefore, in order to provide as a wet well for the pumps of a continues supply of clear water, for Metu town the existing 400 m^3 reservoirs can be incorporated to the system and an additional 1100 m^3 capacity new reservoir should be constructed to deliver adequate water in the distribution network. Hence, as shown in figure 4.1; the reservoirs were found in good condition and able to serve for extra years.

Figure 4.1: Existing service reservoir (source: field observation, March 2016)

4.2.2 Pump capacity

One of the main components of water distribution systems is the pump stations. Pumps were deliver energy to the hydraulic system in order to overcome elevation difference and head losses due to pipe friction and fittings.

Pump head curve is one of the necessary input parameters for water distribution modeling and according to Tomas, et al., 2003, is an energy equation which used for solving pipe network problems. Hence , the developed pump head curve during model simulation work were presented as figure 4.2 below.

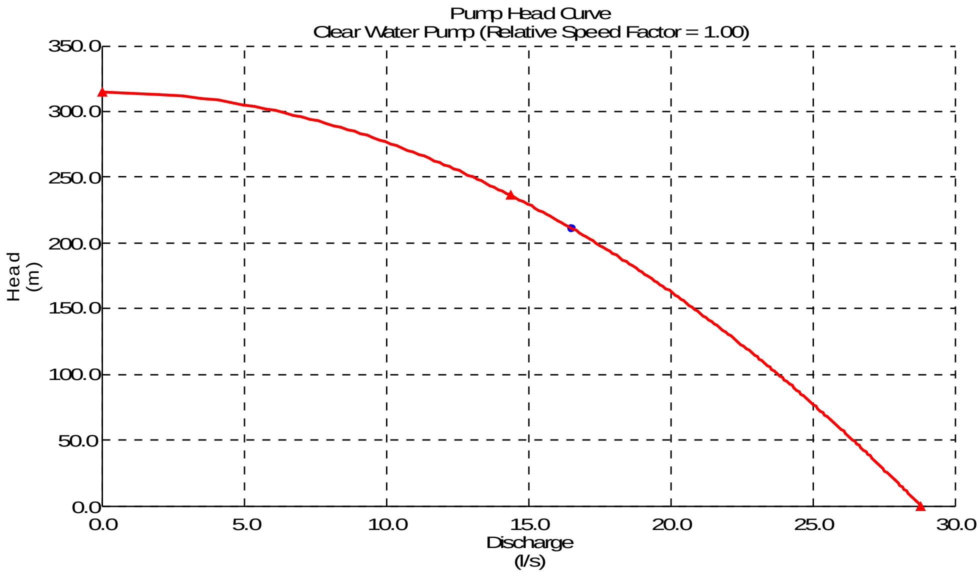


Figure 4.2: Clear water pump head curve

For this study, pump efficiency were conducted in order to determine the pumps capacity in the town water distribution system. According to field observed data and model simulated result which presented in (appendix- G); the pump brake horse power and maximum water power were collected as 75 kW and 34.14 kW, respectively. Therefore, using these finding the efficiency were assessed manually and discussed as below;

Pump Efficiency = Water Power $_{\text{out, maximum}}$ / Pump Power $_{\text{in}}$

Maximum Pump Efficiency = 34.14 kW/ 75kW = 0.4552 = 45.52%

According to the pump characteristic comply with (ISO 9906:2012); most pumps which present and perform in a good condition have an efficiency of 60-80%. While, in Metu a frequent failure and damaged of pumps due to long service time, the challenges of supplying spare parts and improper repaired after failure; made the pumps perform below the required efficiency. Therefore, the above 45.52% of the pump efficiency was shown that currently those pumps were operating in poor performance and delivering water intermittently.

As per the computed water CAD model outputs (Appendix-G) and information obtained from Metu town water service office; those pumps performing in the system were operating an average of effective 16 hours in a day. With this the pumps maximum capacity of delivering water to the distribution system was discussed as:

= maximum Pump design capacity * effective pump operation time

= 28 l/s*16 hr/day= 1,612,800 l/d or 1,612.80 m^3/d of maximum water were deliver to the system. But from the above finding the current maximum water demand of the town is 4,206.93 m^3/d, and this indicates that the pumps capacity were not meet the current water demands of Metu town.

4.2.3 Transmission main line

It is discussed that the transmission main was not isolated from the distribution network and it gives water to distribution line before entering to service reservoir. Figure 4.3 below shows that, the main cover a total of 3.34km and with the length of this interval, the elevation difference between clear water tank and service reservoir is 206.99m.

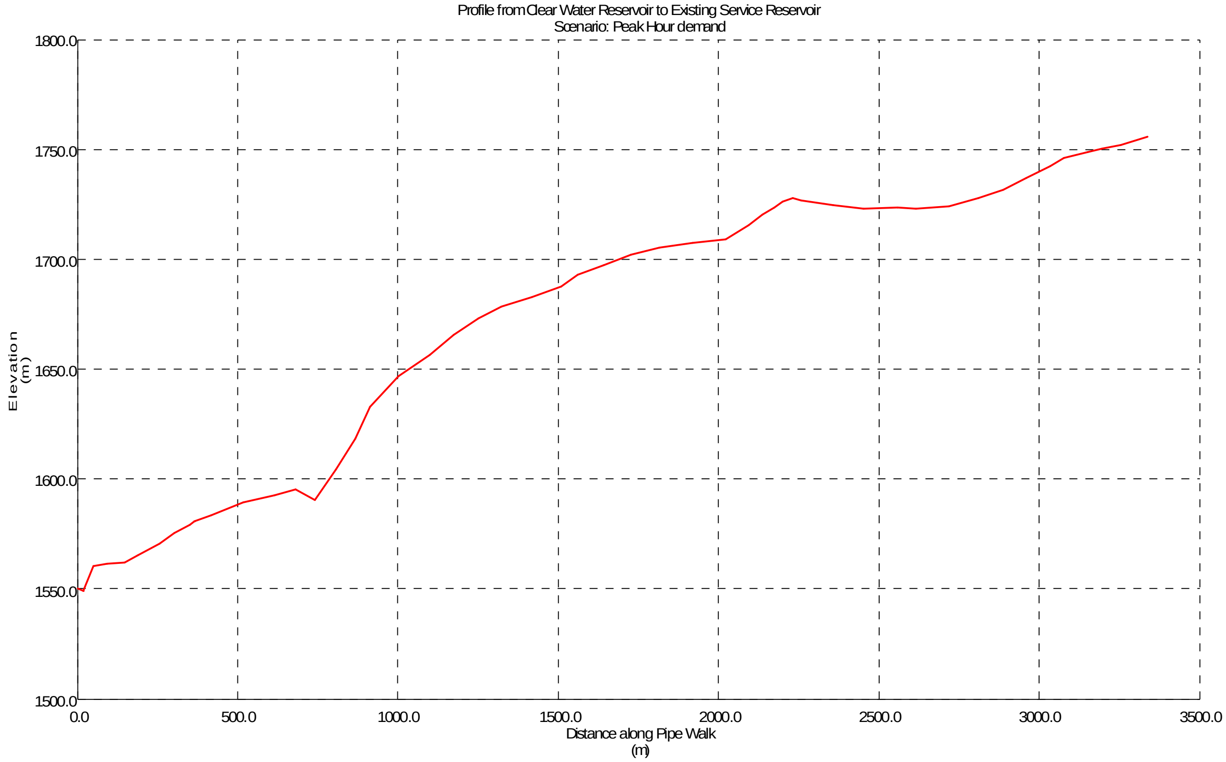


Figure 4.3: Elevation profile for transmission (pressure) main line

Most of residences found at center of town, around treatment plant and downstream of treatment plant received water directly from the distribution line before water is reaching to service reservoir. But, as shown in figure 4.4 when length of the pumped water increased, the water pressure in the main decreases. This was shown; the transmission main for Metu water system were a function of the topographic condition of the town.

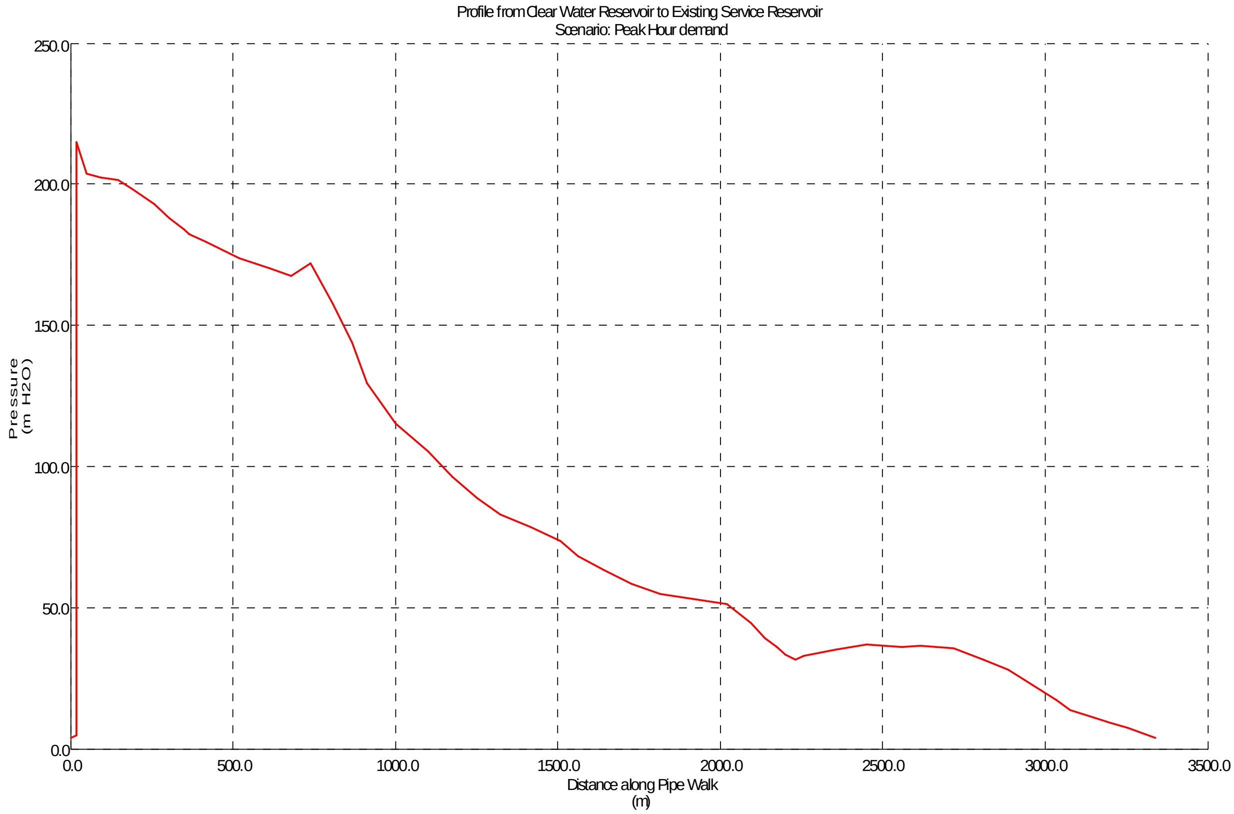


Figure 4.4: Pressure profile for transmission (pressure) main line

As per model analysis, maximum water pressure in the transmission main was 203.68m head at pumping station, and this water head was delivered using small pipe diameter (DN 200mm). Accordingly, the minimum water pressure was recorded as 5.36m head around service reservoir. From these results it was discussed that; small sizes of pipe in the main were lead for a frequent pipe bursting and leakage. While, the minimum value of water pressure indicating that there is intermittent/no water is supplied to the service reservoir. Therefore, most of the residences found around and downstream of the service reservoir were not served water from the system.

4.2.4 Distribution main line

Regards the topography of Metu town, the locations of nodes in the water distribution line is in close proximity to each other. The maximum and minimum water pressure in the distribution system was 199.85m and 2.97m head around treatment plant and service reservoir, respectively.

According to the design criteria of the FDRE; MoWIE, the maximum and minimum water pressure in the distribution system is 80m and 15m, respectively. Beside these comparisons; the current Metu town existing water distribution network was operating out of the recommended limitation. This is because of; water is delivered to the distribution main simultaneously by pumping and gravity means (old system), and the system were served beyond its design life.

4.2.4.1 Pressure variation in the distribution system

Variation of water pressure in the distribution system is mainly because of hourly fluctuation of water demand. As shown in figure 4.5 and figure 4.6 below; the water pressures in Metu water distribution system were a function of this factor. Variation of elevation difference in most part of the town has also an impact for the rising and reduction of water pressure in the network. Therefore, during peak demand time most part of the network was disconnected from the system and wide residential area of the town were not getting water (figure 4.5). While, most of the residences were get and collect water at night flow during low demand time (figures 4.6). However, residences found around treatment plant area, downstream of treatment plant and lower part of the town; were get water continuously (without any intermittent) unless otherwise the system is break at the pumping station.

4.2.4.2 Negative pressure

Situations that give rise to negative pressures should always be avoided. Hence, pressure in the distribution system is one of the factors for intermittent water supply. For this study, all negative pressure presented in appendixes indicated; the system was disconnected during peak demand time and water was not reaching to customers. Whereby, these was mainly as a result of; there is demand concentration (greater demand than the design demand), inadequate pipe capacity (small diameter), and availability of residences on higher ground of the town.

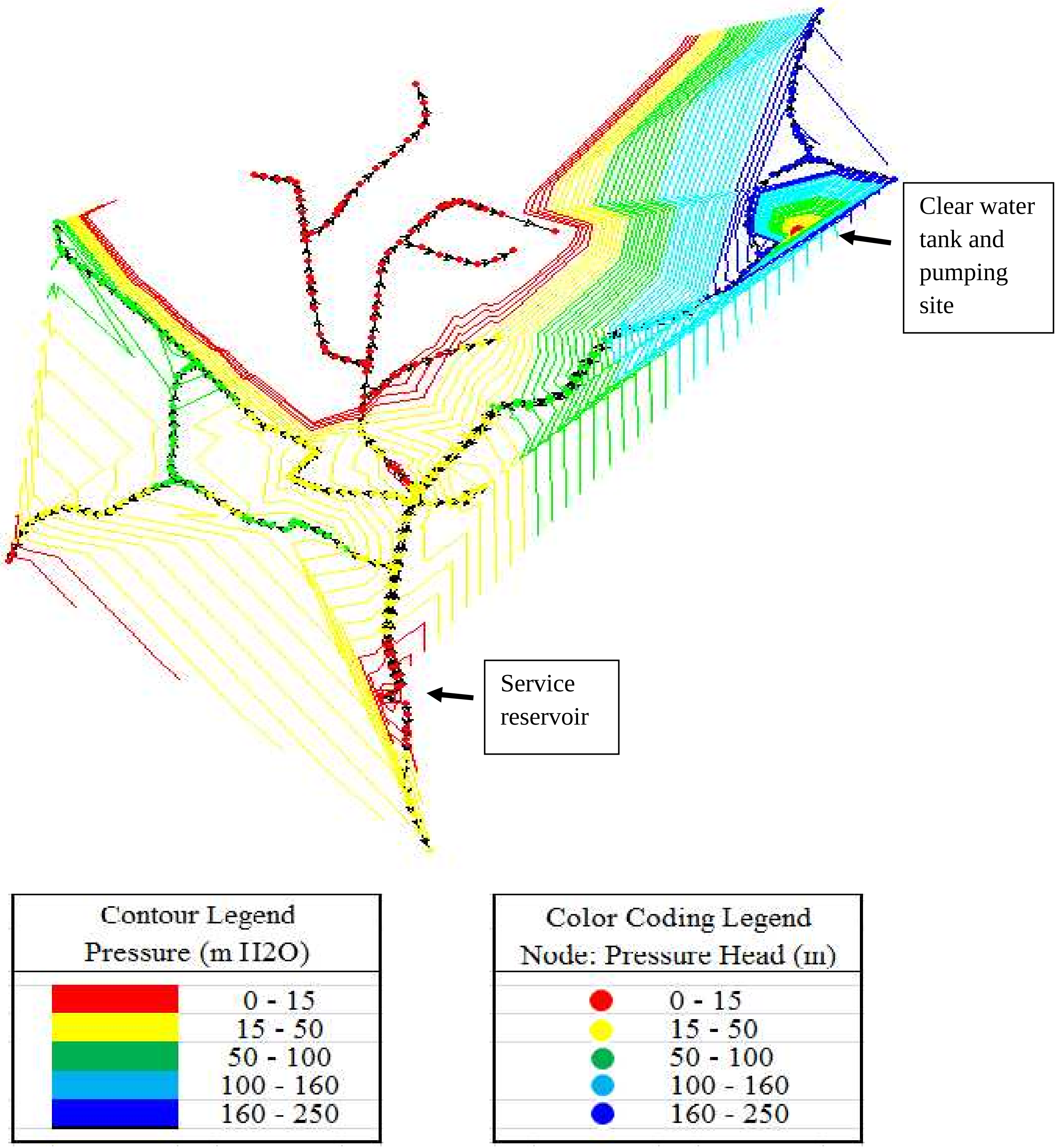


Figure 4.5: Water distribution network during peak demand time

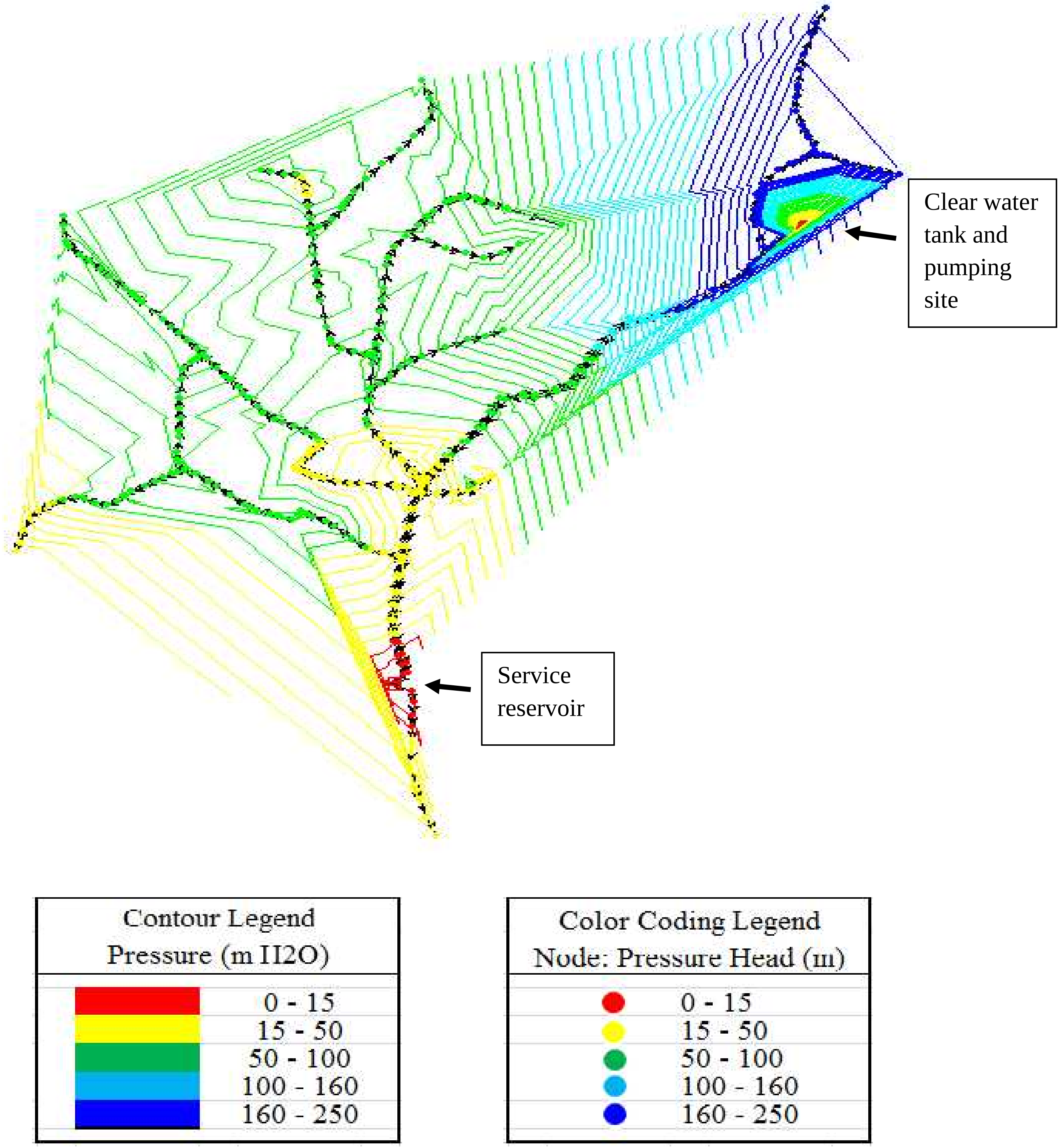


Figure 4.6: Water distribution network during night flow/low demand time

4.2.5 Hydraulic model calibration and validation

In the modern time, water utilities have able to analyze the status of their existing water supply system using hydraulic models. But, for assuring the entered water distribution model inputs data accuracy; the computed model results have been compared with the actual observed field conditions of study area.

As shown in figure 4.7 and 4.8 below; during the comparison of measured pressure value with the simulated one, gaps were recorded up to 14m head and it was out of the pressure standard and limitations suggested by Tomas, et al., 2003. Therefore, the computed pressure value of both scenarios, during peak demand time and low demand time (night flow) were calibrated until the result was approach to the observed pressure value.

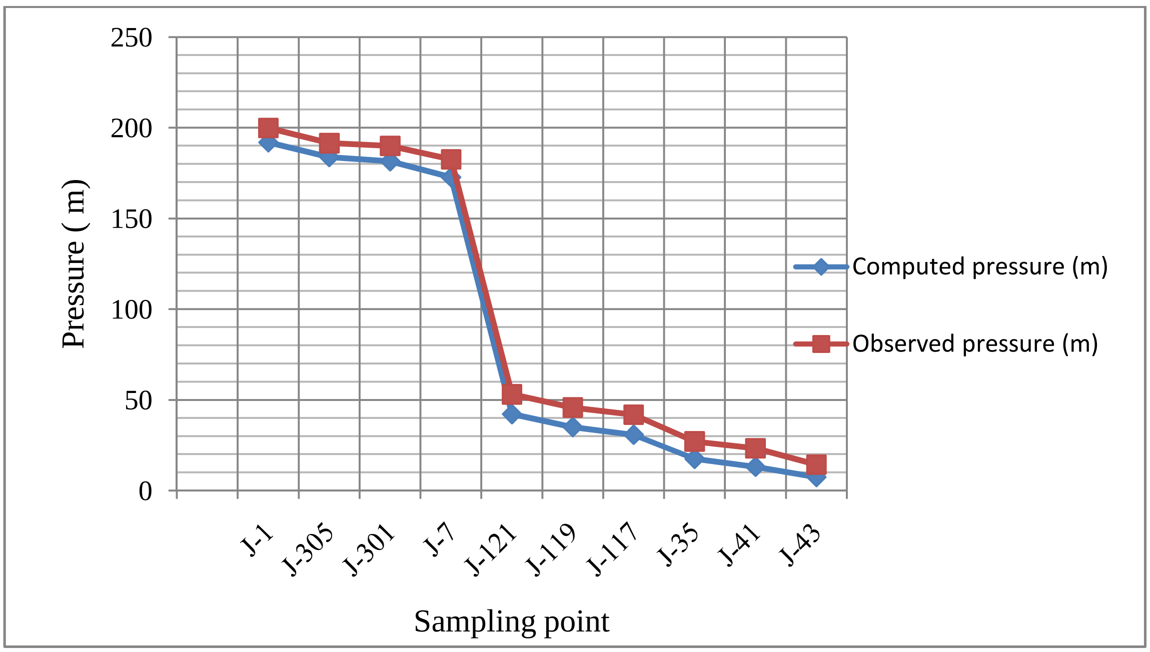


Figure 4.7: Graphical representation of the computed and observed pressure value during peak demand time

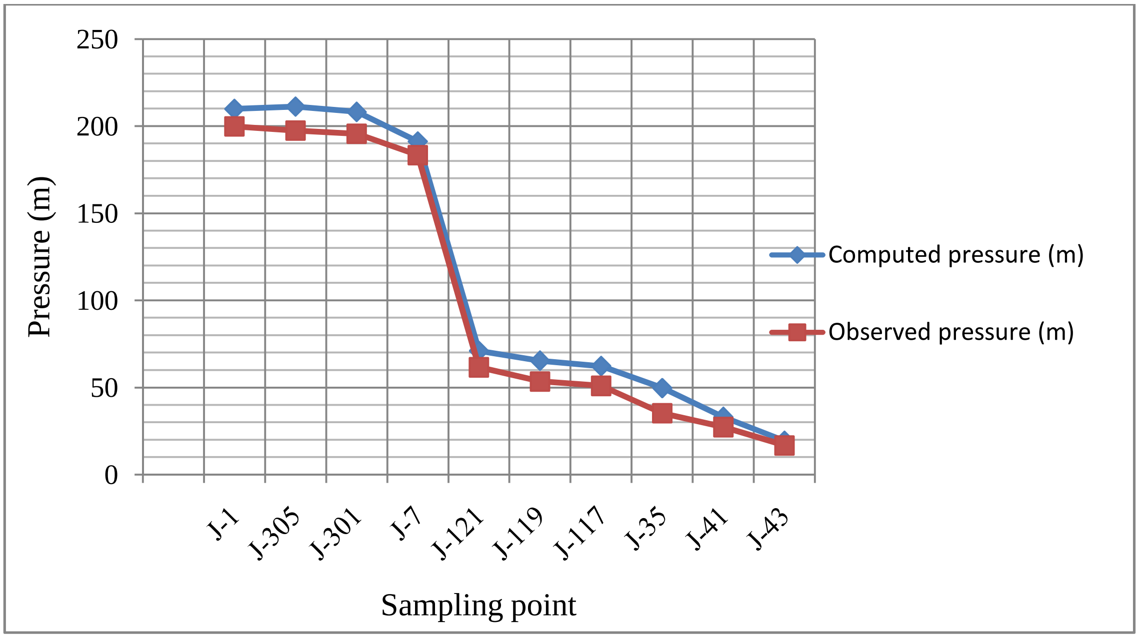


Figure 4.8: Graphical representation of the computed and observed pressure value during night flow (low demand time)

As per pressure criteria 85% of the computed model results should become within ±0.5m head of the observed field conditions. Hence to assure the acceptable level of calibration, the two most commonly used model inputs parameters; pipe roughness coefficients and junction demand data were adjusted.

Therefore, during model calibration; C-factor was used 150 for PVC, 120 for GI and average value of 109 for DCI pipe. While, as per discussion with the water utility manager, in Metu the maximum hour water demand is happen during morning and evening time, when most people use water for bathing, washing and cooking purpose. Accordingly, demand adjustment was undertaken by adopting multiplier factors in reasonable way (a maximum and minimum of 2 and 0.3, respectively) and demand concentration also adjusted based on actual condition of the town. With regard to these, time series representations of the calibrated pressure head difference were presented as appendix-E and appendix-F.

Model validation

The model validation work was taken manually using the correlation coefficient equation (R^2) method and it were described and represent graphically in figures 4.9 and 4.10 as shown below.

$$R^2 = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2\sum(y-\bar{y})^2}}$$

Where: R^2 = correlation coefficient, X and Y are the observed and computed pressure values, and $\overline{X}$ and $\overline{Y}$ are mean value of observed and computed pressure, respectively.

As shown in figure 4.9 and 4.10; it explain the results of correlation value (R^2) for both peak and low demand time was represent as 99.8% and 99.7%, respectively. Thereby, the calibrated pressure value was validated within the recommended standard.

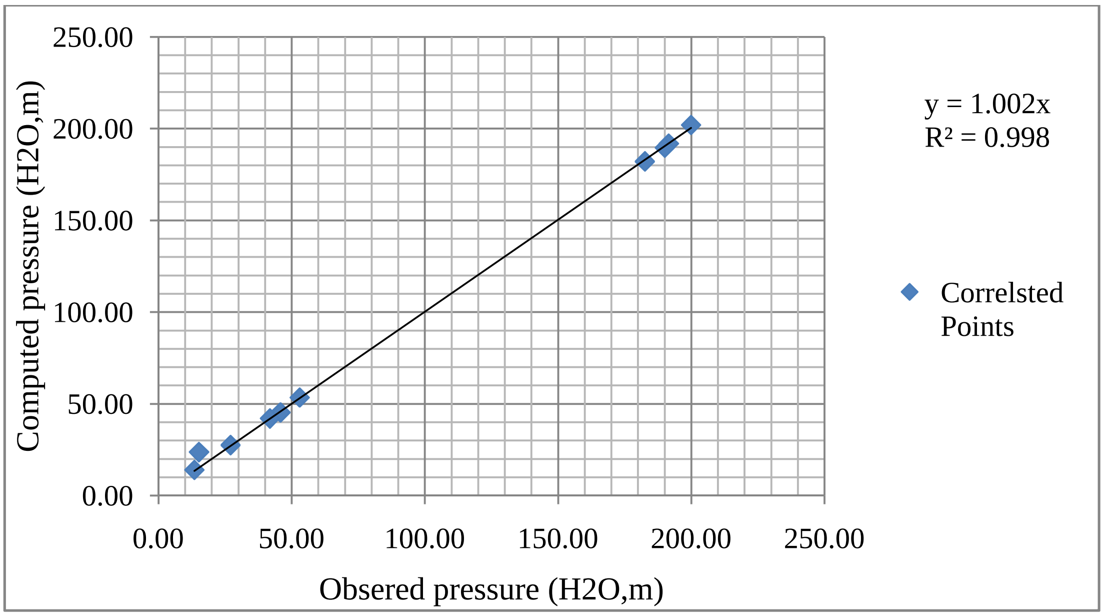


Figure 4.9: Correlated plot during pressure calibration for peak demand time

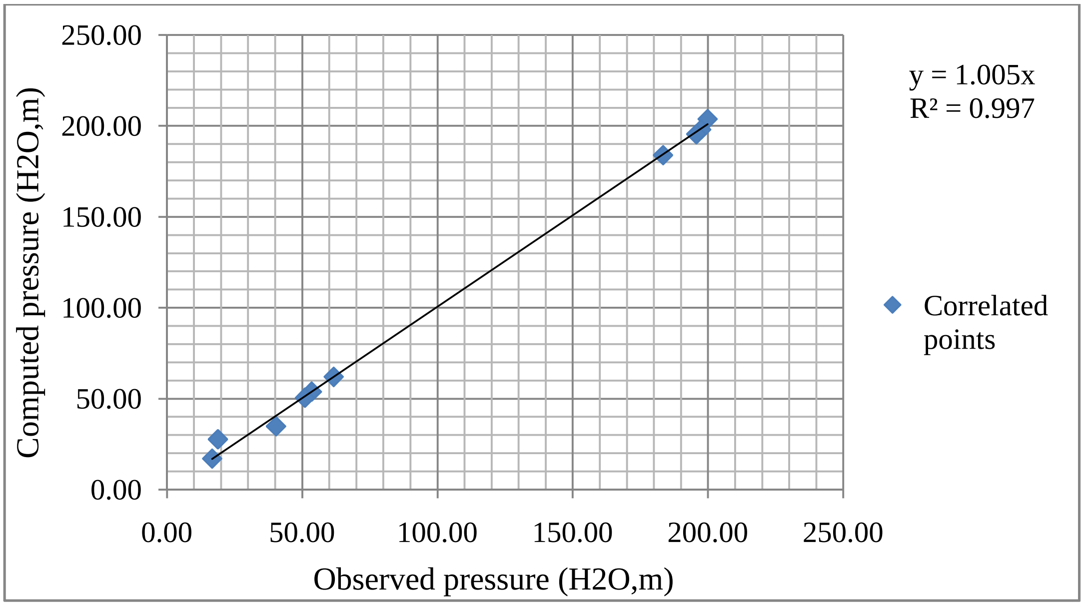


Figure 4.10: Correlated plot during pressure calibration for low demand time (night flow)

4.3 Water loss Analysis

One of the major challenges of water utilities is high volume of water loss in their distribution networks. If a large quantity of supplied water is lost; it is difficult to meet the required quantity to demands, and correspondingly made challenges to keep the water tariffs in the system at a reasonable level. Whereby, water loss for Metu town was assessed and discussed as below;

4.3.1 Percentage of water loss

Non-Revenue Water includes water losses in the water distribution system, illegal connections, and improper metering and recording. The amount is expressed as percentage of the total produced water from the water supply system. The percentage usually varies and depending on the age of the pipes and complexity of the system. According to the town water service office; during 2015, total Non-Revenue Water in Metu town was estimated as 34.64%.

$$\text{Total percentage of water loss } (\%) = \frac{\text{Unbilled volume}}{\text{System production}} * 100$$

Table 4.2: Percentage of Non-Revenue Water

Year (G.C)	Production (m^3/year)	Consumption (m^3/year)	NRW	
			(m^3)	(%)
2008	433,120	233,380	199,740	46.12
2009	436,937	251,317	185,620	42.48
2010	437,824	263,326	174,498	39.86
2011	440,472	269,218	171,254	38.88
2012	441,068	273,791	167,277	37.93
2013	441,804	278,406	163,398	36.98
2014	442,149	283,062	159,087	35.98
2015	442,258	289,071	153,187	34.64

(Source: Metu town water supply service office, existing document)

But, as shown in table 4.2 above; due to the constant production/supply of water to the system, and accordingly the increases of water consumption in the town were the reason for reduction of total volume of NRW in recent years.

4.3.2 Category of water loss

From the above table 4.3, the total Non-Revenue Water during 2015 was recorded as 153,187 m^3. These amount of water loss were categorized as physical/real and apparent loss. Unavoidable annual real loss (UARL) or the minimum achievable annual physical losses was adopted as the total physical loss in the system, and it was analyzed as;

$$\text{UARL (litres/day)} = \left(18 * L_m + 0.8 * N_c + 25 * L_p\right) * P$$

Where, Lm = mains length (km); Nc = number of service connections; Lp = total length of private pipe, property boundary to customer meter (km); and P = average pressure (m)

UARL (litres/day) = (18*20.92+0.8*3109+25*55.96)*38.43 = 163,802.03 litres/day or UARL=59,787.74 m^3/year

Total apparent losses in the system were determined from the town water balance as;

Apparent loss = Total NRW – UARL = (153,187 – 59,787.74) m^3/year = 93,399.26 m^3/year

From the above discriptions, apparent loss was large in volume, and it covers 21.12% of total volume of water losses in Metu town water distribution system. While, physical losses were also contribute a considerable volume of loss in the system and it covers 13.52% of total NRW.

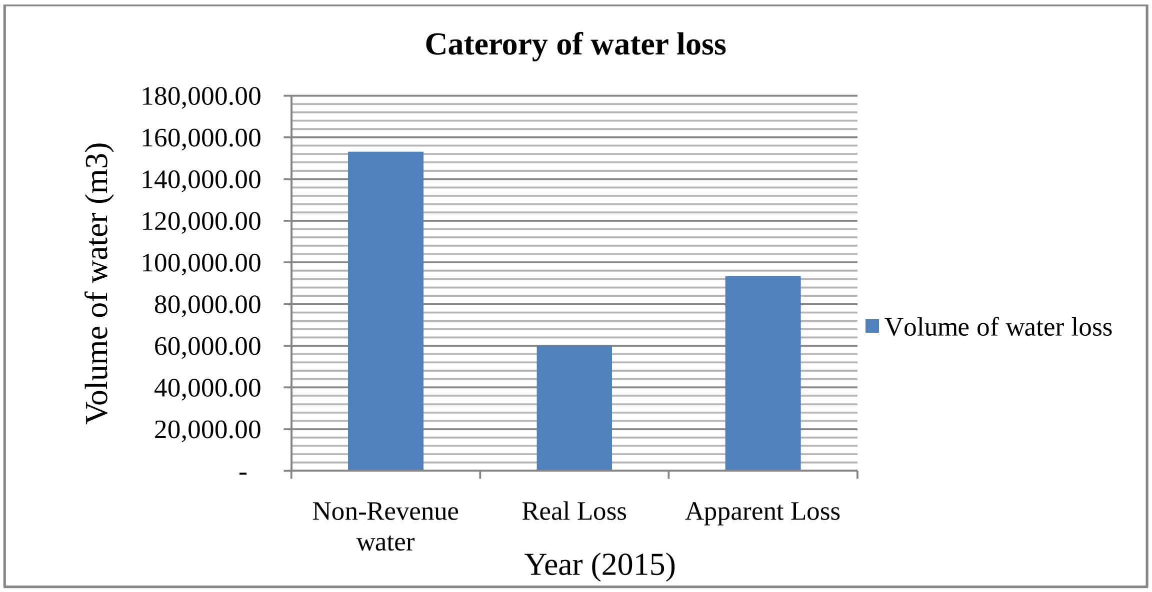


Figure 4.11: Category of water loss, during end of June, 2015 (G.C)

4.3.3 Water loss as per number of service connection

One of the appropriate indicators of water loss in the distribution system is describing it as per number of service connection (liters per service connection per day, l/c/d), and it gives more precise figure than NRW as a percentage of inputs volume. Based on the obtained data; the total number of service connections in Metu town was 3109 and taken this, the volume of water loss as per connection were analyzed from the total unbilled volume.

loss per connection = (Unbilled volume *1000 l/m^3)/ (total number of connection*365 day)

loss per connection = (153,187 m^3/year *1000 l/m^3)/ (3109*365 day) = 134.99 liters/c/day .

According to (Farley, et al., 2008), performance indicator of physical loss target matrix; Metu town water loss per connection were found in good condition, which is < 150 l/c/day of loss when the system is pressured in distribution system with average pressure of 30m. However, leakage related with connection contributed as the sources of physical loss in Metu town water distribution system.

4.3.4 Water loss as per pipe length

The other good indicator of water loss in the distribution network is determining loss as per pipe length (liters per kilometer of pipe line per day, l/km/d). According to the town water utility, the total length of water distribution line including both main and privet pipe line (from property boundary to customer's meter) were estimated about 76.88 km. Therefore using this, the estimated amount of water loss; as per kilometer of the pipe length of the town was calculated as 5,459.03 liters/km/day or 5.46 m^3/km/day.

loss per pipe length = (Unbilled volume*1000 l/m^3)/(total pipe length in the town *365 day)

loss per pipe length = (153,187 m^3/year *1000 l/m^3)/(76.88*365 day) = 5,459.03 liters/km/day

As per revised literature, *'the average condition of water loss as per pipe length is 10,000-18,000 liter/km/day, and bad condition of system is >18,000 liter/km/day.'* Therefore, this figure shown that if distribution line is expanded, water loss also increases in the pipe network.

4.3.5 Major factors contributing to water loss in Metu town

There are several reasons for the high level of water loss in the water distribution networks. Beside to these, the major sources of water loss experienced throughout Metu water distribution system were as a result of;

4.3.5.1 Age and size of pipe

It has been observed that small size and aged pipes were laid in Metu town water distribution network, and as shown in table 4.4 below nearly 32% of the pipe were served without any replacement for the last 30 years. Whereby, these pipe materials suffered its quality due to long service time, water carrying capacity and environmental conditions. Therefore, age and pipe size are the main factors for frequent pipe bursting and real losses in the town water distribution network. Accordingly, the water utility were lost 5.46 m^3/l/day of water from the system, and these mainly were occur in the transmission main, and distribution line served around treatment plant and in center of the town.

Table 4.3: Pipe length by age and size category

Description	Age category	Diameter (mm)	Length (m)	Length (%)
Ductile Cast Iron	30 year and more	200	3,340	15.96
Galvanized Iron	30 years and more	150-200	1,440	6.88
	20-30	80-150	1,750	8.37
	10-20	80-150	5,740	27.44
Polyvinyl Chloride	10 year and less	80	8,650	41.35
Total			20,920	100

(Source: Metu town water service office)

4.3.5.2 Metering inaccuracies

The type and brand of water meter has an effect in the accuracy of customer water metering. From the total of 4,917 a single-jet type (class B, dry dial) customer water meters; 2817 DN 15mm, 1968 DN 20mm, 106 DN 25mm, 24 DN 32mm and 2 DN 90mm were installed in Metu town water service system. As per the town water service office; 60% of these water meter were manufactured in China, while remain 40% was manufactured in Poland. According to the regional water, mineral and energy bureau; the organization was taken meter testing flow rate of 200 l/c/day for all customer water meters as a testing bench. Accordingly, as shown in table 4.4 below; Water losses as result of metering inaccuracies were analyzed using the comparison of this testing bench figure and the average water meter reading value of customer meter obtaining from the authorized revenue water in 2015.

Table 4.4: Water loss as result of metering inaccuracies

Description	Number of meter	Total revenue water, 2015 (authorized)	Average meter reading (per connection)	Meter testing flow rate	Difference	Total water loss
	A	B	C = B/A	D	E = D-C	F = E*A
All customer water meter in Metu	4,917	289,071 m^3/year or, 791,975.34 liters/day	0.161 m^3/c/day or, 161.10 l/c/day	200 l/c/day	38.90 l/c/day	191,271.30 l/day or, **69,814 m^3/year**

As shown in the above table 4.4, the water utility was lost an estimated of 69,814 m^3 water in 2015. Therefore, this figure shown that; under registration is the main technical problems of customer water meter, and it was found as the main source of apparent loss in Metu town water supply system.

4.3.5.3 Data handling errors

Data handling error in the meter reading and billing process were contributed for apparent losses. Customer meter reading practice; especially unbilled metered trends were the common problem of Metu town water service office. Whereby, recording of under/over estimated figure lead the water utility to improper collection of revenue, and at the end of the month the authority were lost money. Accordingly, as per the authority 2015 annual report; the town water authority has lost 2,357 m^3/year of water due to poor data handling process.

4.3.5.4 Illegal connections

As a developing town; there are a significant number of illegal users of water within Metu town water distribution network, and were contribute to the reduction in service level to authorized consumers. The town water utility were not known the actual figure of residences that do not pay water tariffs but received water from the distribution system. But as per the feedback from the water utility; construction sectors, different enterprises and hotels in the town are mainly contributing in large number. Due to limitation of data, water losses as result of illegal connections were analyzed from the water balance. And, the town water service office was lost an expected of 21,228.26 m^3/year of water illegally (unauthorized consumption). Therefore, illegally connected users have alos contributed large volume of water loss in Metu town.

4.3.5.5 Poor maintenance practices

Many water utilities have less attention for water loss as a result of their poor maintenance capacities. In Metu water service it was observed that; there are no enough budget, proper instrument, accessories, and strong policies for suitable leakage management. But, these have a considerable impact for physical losses in the town water distribution system.

4.4 Leakage management practice

Good leakage management practice is one of the ways of reducing water loss in the distribution system. The leakage management trends of Metu town water supply service office were assessed and described as;

4.4.1 Water utility organization

A strong management and organizational setup is the main reason for good leakage management practice in the water supply services and to the satisfaction of the customers. According to Metu town water service office, the total numbers of staff members including supporting sections are 40 in number. Of these six are professionals from technique section (one electrician, one electromechanical, two plumbers and one operator). Based on the policy and guidelines of the regional administration, the town water supply service manager can organize, directs and administers the overall activities of the water service unit. While, regard to the leakage management view, the operation and maintenance section of the utility is the most important section in the water supply service and the head of this section shall be accountable to the manager of the water service office. The main activities of this section are direct, coordinate and control the water supply operations and maintenances work including production, distribution, leakage and laboratory units.

4.4.2 Operation and maintenance practice

As per the collected information and field observation, the operation and maintenance culture of Metu town water distribution system were presented as below:

- **Operation system:**
  - It includes the operation of the intake, treatment units, pumping stations and the associated transmission mains
  - There is no operators dwelling and permanent operators who control the above assets in the treatment plant site
  - Mostly the operation system was controlled by the utility guards (non-skilled man power) who protects the intake and treatment plant site
  - Recently there is no controlling and operating mechanisms at service reservoir due to empty of water in the tank
  - There is the practice of recording treated water production and consumption figures by the utility experts.

- **Maintenance culture:**
  - The overall maintenances of system components were not checked by schedule and it was maintained during failure or damage is occurring.
  - Valves and all accessories installed in the main were not properly used and maintained regularly (greasing and cleaning). Such as, the PRV in the distribution network was not functional all the operation time, and it made challenges to limit pressure in the network.
  - No functional controlling check valves within the network. Accordingly, when failure is happened; the utility were maintaining the system by switching off the pumps operating at pumping station. Whereby, the technique group forced to stay until the water pressure was reduced in the system.
  - Maintaining, removing and replacing of both customers service line and bulk flow meters were done when the utility was reported or requested by the customers during failure is appear.
  - The other collected information was due to limitation of budget; when failure is occur at customer's service line, the customers forced to supply all the necessary accessories. Accordingly, until the required accessories is purchased and replaced a considerable quantity of water is lost.

4.4.3 Financial analysis

The main financial source of Metu town water service office is the government budget and regional contribution. Accordingly, the financial plan and polices in the town water service system was assessed as below;

4.4.3.1 Water tariff policies

One of the leakage management strategies in the water utilities is the water tariff carried out in the system. The major objective of water tariff is to make financial sustainability and cost recovery, with the consideration of low-income groups. Accordingly, the water tariff structure for Metu town water system was reviewed and applied based on the regional water, mineral and energy bureau recommended value, and the expected capital benefit of the water utility.

As per the town water service office, the tariff structure is adopted as flat and graded rate. Table 4.6 below shown that; public fountain users are charged flat rate i.e. the same rate for all consumption. While, house and yard connection users are charged progressive rate polices i.e. the tariff rate increases with the consumption volume of water.

Table 4.5: Water tariff policies

Block	**Consumption range (m^3/month)**	**Tariff (ETB)/m^3**
1	< 5	4.60
2	6-10	5.50
3	11-30	6.60
4	>30	7.90
PF	All Consumption	4.00

(Source: Metu town water supply service office, existing document)

From the above table 4.6; taken the average unit price of 5.72 birr and financially, the water utility were collect 1, 653,486.12 birr from authorized revenu water. But, the authority was lost an estimated of 876, 229.64 birr as result of total water loss. Therefore, from this figure it was discussed that; the general leakage management trends of Metu town water service system were in poor status, and the utility was given less attention for water loss.

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The existing water distribution system of Metu town was established for an estimated population of 10,000. But, as compared with the current population figure of 46,306, it was served beyond the design life and low coverage in the town.

For various demand categories, the current average per capital water consumption of Metu town was found as 79 l/c/d. besides comparing the maximum water demand of the town (4,206.93 m^3/day), in contrast the size of existing infrastructural components such as clear water reservoir, pumping station and distribution pipes were found small in capacities, and leads to supplying water intermittently. Thereby, water pressure in the distribution network observed that were not performing within the proposed maximum and minimum design criteria set by FDRE, MoWIE. Accordingly, the water distribution network were faced a frequent pipe bursts and failures during low demand time and exposed to large volume of water loss especially in high pressure zone areas, while during high demand time mostly residences found in dense population and higher level of the town were not received and/served continuous water from the system.

Although with low water distribution in the town, water loss was analyzed from recorded annual production and consumption figure. Whereby, during 2015 the town water balance indicated that 34.64% of treated water was lost as a total Non-Revenue Water. Thus, 13.52% of total losses were within the distribution network and accounted as physical loss, while 21.12% is lost as a result of apparent loss. Further water loss was examined based on the infrastructure leakage index method, and however there is physical losses and contribute considerable volume of water losses in the distribution system. While, apparent losses are more significant and the major sources of water losses in Metu. In general, aging and size of pipe material, metering inaccuracies (under registration), illegal connections, systematic data handling errors and poor maintenance practices were found as the major sources of water losses in Metu water distribution networks.

Gaps related with financial limitations, lack of professionals' experts, and less attention towards water loss management are the major problems of Metu town water utility. Whereby, the overall maintenance and leakage controlling practices of the authority were found in poor performance.

In general, it was concluded that the current water distribution network of Metu town was in poor performance and were not conducted adequate water to the various demand categories of the town.

5.2 Recommendations

Based on the analyzed findings the following recommendations were mentioned to Metu town existing water supply system:

- As the current water demand in the town is much greater of the daily water production of the system, so it is necessary revising the design and rehabilitates the water distribution system by improving the size of reservoirs capacity and replacing the new pumps with the required hydraulic performance.
- Pipe rehabilitation decision should be involved. For the case of Metu, by considering that most of existing pipe is still an asset for the utility, it is most advisable and recommended installation of a parallel main line with larger diameter than replacement of the old line. While, cleaning and removing deposits from the old pipeline walls should be also advised to improve flow through the pipeline and restoring lost carrying capacity in the mains.
- It was recommended that transmission main should be totally isolated from distribution main, and water should be distributed from the service reservoir by gravity mean.
- To control and protect the pump sets against high pressure conditions and broken pipe situations, the pump station should be provided with new switchboards.
- To control and minimize risks related with variation of pressure, water hammer and back water flow; it was advised installing the necessary valves and accessories in the water distribution system.
- During water loss analysis, it was observed that large amount of water were lost as result of meter under registration. So, it is much advised that; those customer meters were performed in poor status and served for a long period should be replaced by good brand meters. Further, the town water authority should be regularly examined and tested all customer metering accuracies in accordance with the manufacturer's recommendations.
- Illegal connection and data handling problem is the other challenges of the water utility. So that, the water authority should be provides customer awareness programs and should be encouraged to report illegal connections, and regulations should be in place to penalize the water thieves. While, town water utility should be improved their data handling system supporting with computerized recording technology.

- It was also advised to conducting a complete customer survey within each district meter areas, whereby utility representatives visit every property in the district meter area whether or not customers are recorded in the billing system.
- In addition to this, the water authority should be pay enough attention and put forward dimensions on water loss management strategies through the processes with involving engineering approaches and international experiences.

REFERENCES

Alegre, H. & Coelho, S.T. (2013). *Infrastructure Asset Management of Urban Water Systems.* National Civil Engineering Laboratory, Lisbon, Portugal.

Bhadbhade, N.M. (2009). *Performance evaluation of a drinking water distribution system*: using hydraulic simulation software for the city of Oilton, Oklahoma.

Chambers, K., Creasey, J. & Forbes, L. (2004). *Design and Operation of Water Distribution Net works: Managing water quality in piped distribution system.* Published by International Water Association, London, United Kingdom.

Dawe, P. (2000). *Workshop on Hydraulic Network Modeling with Water CAD.*Published.

Dighade, R.R., kadu, M.S. & Pande, A.M. (2014). *Challenges in water loss management of water distribution system in developing countries.* International Journal of Innovative Research in Science, Engineering and Technology, 3 (6), 13838 - 13846

Environmental Finance Center (EFC). (Eds.). (2006). *Asset Management: A guide for water and waste water.* New Mexico Environmental Finance Center Publishing.

Environmental Protection Agency (EPA). (2010). *Control and mitigation of drinking water loss in distribution system.* USA.

Farley, M., Wyeth, G., Ghazali, Z.B., Istandar, A. & Singh, S. (2008). A guide to understanding water loss: the managers' non-revenue water hand book. Published by USAID.

Federal Democratic Republic of Ethiopia, Ministry of Water Resources (FDRE, MoWR). (2009). *Detail design and tender document preparation of Negele area long range water supply project,* unpublished.

Frauendorfer, R. & Liemberger, R. (2010). *The issue and challenges of reducing non-revenue water.* Published by Asian Development Bank.

Gottipati, P.V. & Nanduri, U.V. (2014). *Equity in water supply in intermittent water distribution networks.* Water and Environmental Journal, 28, 509-515.

Grady, C.A., Weng, S.C. & Blatchlet, E.R. (2014). *Global potable water: Current status, critical problems and future perspectives.* Springer international publishing, Switzerland.

Gregory, H.J. (2002). *Water Distribution Model Calibration: for the Design of the Ortley Beach and Seaside Heights, NJ Water System.* For Partial Fulfillment of Computer Models in Environmental and Natural Resources Engineering, Purdue University.

Hickey, H.E. (2008). *Water Supply System and Evaluation methods. Volume II:* Water Supply Evaluation Methods.

Hussni, S. & Zyoud, A.R. (2003). *Hydraulic performance of Palestinian water distribution systems: Jenin water supply networks as a case study*. Thesis submitted to An-Najah National University, Nablus, Palestine.

International Organization for Standardization (ISO). (2012). *Rotodynamic pumps: Hydraulic performance acceptable test.* ISO 9906:2012, published in Switzerland.

Jalal, M.M. (2008). *Performance measurement of water distribution systems: A critical and constructive appraisal of the state of the art*. Thesis Submitted to the Requirement for the Degree of Master of Civil Engineering, University of Toronto, Canada.

Kochhar, K., Pattillo, C., Sun, Y. & et al. (2015). *Issues in managing water challenges and policy instruments.* Published by IMF.

Marta, G.G. & Rudolf G. (1987). *Water supply volume II. Small projects training manual*. Published by Sudan council of churches, Khartoum.

National Research Council (NRC). (2006). *Drinking water distribution systems: Assessing and reducing risks.* The national academics press, Washington, D.C.

Oromia Water, Energy and Mineral Bureau (2011): *Design Review of Metu Town Water Supply System*, unpublished.

Recommended Standard for Water Works (RSWW). (2012). *Policies for the Review and Approval of Plans and Specifications for Public Water Supplies.* Published by: Health Research Inc. & Health Education Services Division. New York, U.S.A.

Renwick, D.V. (2013). *The effects of an intermittent piped water network and storage practices on household water quality in Tamale, Ghana.* For Partial Fulfillment of the Degree of Master in Civil and Environmental Engineering, Massachusetts Institute of Technology.

Ruffell, P. & Light, C. (2012). *Water Supply Asset Management Plan.*

Tomas, M.W., Donald, V.C., Dragan, A.S., Walter, G., Stephen, B. & Edmundo, K. (2003). (1stEd.) *Advanced water distribution modeling and management*: Haestad Press, USA Published.

Venkateswara, P. (2005). *Water Supply Engineering*. Printed and Published by: The Telugu Academic, Hyderabad on behalf of State Institute of Vocational Education Government of Andhra Pradesh, Hyderabad.

Water CAD Stand-Alone. *Water Distribution Modeling Software. USER MANUAL:* Unpublished http://www.haestad.com

Water Utility Asset Management (WUAM). (2013). *A guide for development practitioners.* Published by Asian Development Bank.

Welday, B.D. (2005). *Water supply coverage and water loss in distribution systems, the case of Addis Ababa.* Thesis submitted to the International Institute for Geo-information Science and Earth Observation, Enscede, The Netherland.

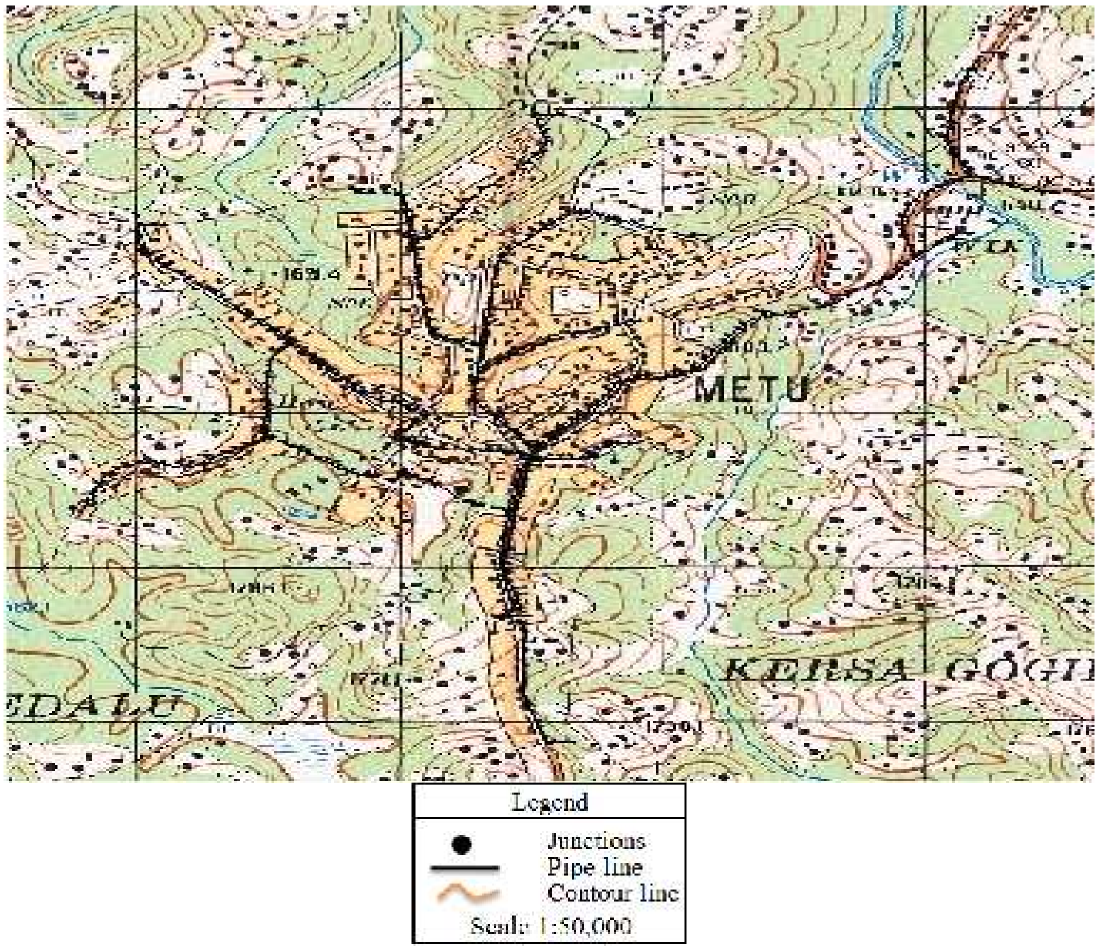
Whittle, A.J., Allen, M. & Iqbal, M. (2013). *Sensor network for monitoring and control of water distribution systems.* The 6th international conference on structural health monitoring of intelligent infrastructure, Hong kong.

World Health Organization (WHO). (1997). *Guidelines for drinking water quality: surveillance and control of community supplies*, *Second edition.* Vol.3. Switzerland, Geneva: Published.

APPENDIX

Appendix A

Map shown the overlapped distribution pipeline on contour map of the town



Appendix B

Metu town water distribution network coverage

Description	Connected junctions	Connected pipe	Pipe type	Pipe length (km)	Pipe age (year)	Remark
Treated water transmission main line	J-1 to J-47	P-1 to P-50	DCI	3.34	>=30	Existing line
Service reservoir - road to Gore town	J-48 to J-59	P-51 to P-62	PVC	0.94	<=10	Expansion line

Service reservoir - big square in the town	J-60 to J-77	P-63 to P-80	GI	1.44	>=30	Existing line
Big square - 4 kilo square - road to Abdibori children's camp	J-77 to J-94	P-81 to P-97	GI	1.00	10-20	Existing line
	J-94 to J-113	P-98 to P-116	PVC	1.35	<=10	Expansion line
Big square - town market	J-114 to J-121	P-117 to P-124	GI	0.50	20-30	Existing line
	J-121 to J-130	P-125 to P-133	GI	0.80	10-20	
Transmission main - St. Michael church	J-131 to J-140	P-134 to P-143	GI	0.47	10-20	Existing line
Big square - 4 kilo square - TTC collage	J-141 to J-153	P-144 to P-156	GI	0.30	20-30	Existing line
	J-153 to J-169	P-157 to P-172	GI	0.70	10-20	
	J-169 to J-196	P-173 to P-199	PVC	1.71	<=10	Expansion line
Big square - hospital village	J-197 to J-213	P-200 to P-216	GI	0.55	20-30	Existing line
	J-213 to J-231	P-217 to P-235	GI	1.20	10-20	
Hospital village - Adha Shifa village	J-232 to J-251	P-236 to P-255	PVC	0.93	<=10	Expansion line
4 kilo square - Beg tera Village	J-252 to J-260	P-256 to P-264	GI	0.77	10-20	Existing line
4 kilo square - Abdibori children's camp branched - St. Medhihanialem church Village	J-261 to J-273	P-265 to P-277	GI	0.40	20-30	Existing line
	J-273 to J-280	P-278 to P-284	GI	0.80	10-20	
	J-280 to J-296	P-285 to P-300	PVC	1.18	<=10	Expansion line
Transmission main - road to Noppa town (around and downstream of treatment plant)	J-297 to J-321	P-301 to P-325	PVC	1.46	<=10	Expansion line, P- 310 and P-311 are GI
Sor river brige - road to Bedele town	J-322 to J-329	P-326 to P-333	PVC	0.49	<=10	Expansion line
4 kilo square - Abdibori children's camp branched - town hall area	J-330 to J-335	P-334 to P-339	PVC	0.59	<=10	Existing line
Total length				20.92		

Additional information; P-340 and P-341 are GI pipes which deliver water from transmission main to distribution main at J-32 (big square area) and J-38 (around road to St. Michael church), respectively.

(Source: Metu town water service office, during data collection. March, 2016)

Appendix C

Assigned Base Water Demand to Each Supply Node

Description	Number of houses	Number of population	Base demand (l/s)	Coordinates (meter)		
				X	Y	Z (elevation)
J-1	5.00	19.00	0.02	786,071.66	919,074.41	1,560.18
J-2	6.00	22.80	0.02	786,038.67	919,047.15	1,561.51
J-3	8.00	30.40	0.03	786,001.03	919,007.90	1,562.25
J-4	8.00	30.40	0.03	785,968.52	918,982.97	1,565.09
J-5	0.00	0.00	0.00	785,927.92	918,927.98	1,570.52
J-6	0.00	0.00	0.00	785,897.67	918,893.57	1,575.20
J-7	11.00	41.80	0.04	785,877.09	918,850.82	1,579.40
J-8	0.00	0.00	0.00	785,827.00	918,808.19	1,583.65
J-9	0.00	0.00	0.00	785,736.29	918,761.21	1,589.28
J-10	0.00	0.00	0.00	785,674.77	918,688.12	1,592.69
J-11	0.00	0.00	0.00	785,616.06	918,657.34	1,595.04
J-12	0.00	0.00	0.00	785,559.32	918,637.53	1,590.43
J-13	0.00	0.00	0.00	785,499.32	918,608.16	1,604.63
J-14	0.00	0.00	0.00	785,440.36	918,598.35	1,618.34
J-15	0.00	0.00	0.00	785,394.69	918,587.58	1,632.67
J-16	0.00	0.00	0.00	785,332.41	918,524.96	1,646.92
J-17	0.00	0.00	0.00	785,275.27	918,445.33	1,656.58
J-18	0.00	0.00	0.00	785,236.08	918,381.58	1,665.32
J-19	0.00	0.00	0.00	785,199.10	918,314.38	1,672.91
J-20	0.00	0.00	0.00	785,167.65	918,249.21	1,678.51
J-21	0.00	0.00	0.00	785,086.52	918,204.37	1,682.67
J-22	0.00	0.00	0.00	784,999.24	918,175.22	1,687.47
J-23	0.00	0.00	0.00	784,946.92	918,182.38	1,692.85
J-24	0.00	0.00	0.00	784,868.64	918,166.79	1,697.27

J-25	0.00	0.00	0.00	784,825.36	918,092.02	1,702.12
J-26	0.00	0.00	0.00	784,781.11	918,016.70	1,705.44
J-27	0.00	0.00	0.00	784,710.67	917,939.74	1,707.32
J-28	0.00	0.00	0.00	784,643.19	917,863.55	1,708.79
J-29	0.00	0.00	0.00	784,598.80	917,806.26	1,715.36
J-30	0.00	0.00	0.00	784,574.48	917,770.40	1,720.45
J-31	0.00	0.00	0.00	784,548.55	917,742.36	1,723.73
J-32	30.00	114.00	0.10	784,536.27	917,722.01	1,726.29
J-33	30.00	114.00	0.10	784,521.08	917,694.38	1,727.93
J-34	40.00	152.00	0.14	784,512.76	917,668.70	1,726.92
J-35	40.00	152.00	0.14	784,488.76	917,571.39	1,724.58
J-36	45.00	171.00	0.16	784,474.73	917,478.19	1,722.82
J-37	47.00	178.60	0.16	784,456.60	917,371.85	1,723.51
J-38	47.00	178.60	0.16	784,443.82	917,288.96	1,723.23
J-39	44.00	167.20	0.15	784,434.71	917,213.86	1,723.82
J-40	41.00	155.80	0.14	784,423.41	917,123.16	1,727.81
J-41	41.00	155.80	0.14	784,414.39	917,046.83	1,731.73
J-42	40.00	152.00	0.14	784,407.05	916,974.56	1,736.80
J-43	40.00	152.00	0.14	784,415.82	916,901.80	1,742.36
J-44	39.00	148.20	0.14	784,424.47	916,857.11	1,746.07
J-45	39.00	148.20	0.14	784,441.67	916,787.20	1,748.82
J-46	36.00	136.80	0.13	784,452.45	916,740.37	1,750.47
J-47	33.00	125.40	0.11	784,466.16	916,687.09	1,752.06
J-48	21.00	79.80	0.07	784,372.45	916,630.45	1,754.99
J-49	21.00	79.80	0.07	784,476.92	916,585.67	1,751.73
J-50	20.00	76.00	0.07	784,485.44	916,527.51	1,751.07
J-51	20.00	76.00	0.07	784,479.93	916,458.81	1,750.38
J-52	18.00	68.40	0.06	784,482.43	916,397.63	1,744.97
J-53	17.00	64.60	0.06	784,477.92	916,306.37	1,734.38
J-54	16.00	60.80	0.06	784,472.91	916,168.97	1,727.32
J-55	13.00	49.40	0.05	784,489.77	916,074.74	1,728.19
J-56	13.00	49.40	0.05	784,494.47	916,053.14	1,724.24
J-57	12.00	45.60	0.04	784,509.51	916,000.99	1,723.69
J-58	12.00	45.60	0.04	784,541.60	915,903.71	1,727.43
J-59	12.00	45.60	0.04	784,577.71	915,805.93	1,730.68
J-60	38.00	144.40	0.13	784,450.84	916,683.96	1,752.06
J-61	40.00	152.00	0.14	784,436.30	916,734.60	1,750.47
J-62	41.00	155.80	0.14	784,424.27	916,784.25	1,748.82

J-63	43.00	163.40	0.15	784,408.22	916,852.44	1,746.07
J-64	44.00	167.20	0.15	784,399.19	916,898.08	1,742.36
J-65	46.00	174.80	0.16	784,389.67	916,973.29	1,736.80
J-66	48.00	182.40	0.17	784,398.69	917,053.52	1,731.73
J-67	44.00	167.20	0.15	784,404.71	917,123.73	1,727.81
J-68	42.00	159.60	0.15	784,416.24	917,213.49	1,723.82
J-69	44.00	167.20	0.15	784,427.27	917,293.22	1,723.23
J-70	40.00	152.00	0.14	784,432.48	917,318.75	1,723.00
J-71	42.00	159.60	0.15	784,441.82	917,369.94	1,723.51
J-72	47.00	178.60	0.16	784,451.84	917,476.74	1,722.82
J-73	49.00	186.20	0.17	784,469.90	917,571.02	1,724.58
J-74	44.00	167.20	0.15	784,496.26	917,652.91	1,726.81
J-75	46.00	174.80	0.16	784,501.99	917,670.30	1,726.92
J-76	39.00	148.20	0.14	784,517.53	917,716.44	1,726.29
J-77	43.00	163.40	0.15	784,522.74	917,726.79	1,727.01
J-78	47.00	178.60	0.16	784,501.57	917,739.43	1,729.13
J-79	59.00	224.20	0.20	784,495.01	917,751.84	1,730.44
J-80	53.00	201.40	0.18	784,475.98	917,784.47	1,731.98
J-81	50.00	190.00	0.17	784,444.68	917,830.91	1,730.42
J-82	52.00	197.60	0.18	784,426.67	917,852.72	1,729.47
J-83	54.00	205.20	0.19	784,376.31	917,917.49	1,719.81
J-84	55.00	209.00	0.19	784,344.22	917,959.90	1,714.39
J-85	53.00	201.40	0.18	784,298.72	918,024.06	1,708.03
J-86	50.00	190.00	0.17	784,290.68	918,059.18	1,706.03
J-87	49.00	186.20	0.17	784,298.77	918,157.43	1,703.67
J-88	46.00	174.80	0.16	784,305.25	918,224.78	1,703.26
J-89	34.00	129.20	0.12	784,314.59	918,354.30	1,704.03
J-90	33.00	125.40	0.11	784,318.61	918,393.93	1,703.75
J-91	35.00	133.00	0.12	784,321.36	918,412.38	1,703.50
J-92	37.00	140.60	0.13	784,331.01	918,469.14	1,702.16
J-93	39.00	148.20	0.14	784,340.49	918,536.91	1,697.05
J-94	39.00	148.20	0.14	784,350.39	918,642.05	1,691.63
J-95	38.00	144.40	0.13	784,357.08	918,701.68	1,691.39
J-96	36.00	136.80	0.13	784,362.60	918,767.74	1,690.36
J-97	35.00	133.00	0.12	784,375.55	918,891.46	1,689.53
J-98	37.00	140.60	0.13	784,381.37	918,936.48	1,689.18
J-99	40.00	152.00	0.14	784,406.22	918,991.00	1,687.89
J-100	43.00	163.40	0.15	784,455.41	919,052.73	1,690.40

J-101	51.00	193.80	0.18	784,508.00	919,110.55	1,691.87
J-102	49.00	186.20	0.17	784,549.66	919,155.94	1,691.33
J-103	46.00	174.80	0.16	784,570.09	919,178.83	1,689.22
J-104	44.00	167.20	0.15	784,620.50	919,230.80	1,686.18
J-105	47.00	178.60	0.16	784,636.42	919,244.79	1,685.13
J-106	48.00	182.40	0.17	784,651.22	919,252.91	1,684.40
J-107	47.00	178.60	0.16	784,677.06	919,261.21	1,682.51
J-108	41.00	155.80	0.14	784,705.56	919,263.86	1,680.48
J-109	44.00	167.20	0.15	784,743.44	919,254.57	1,677.52
J-110	36.00	136.80	0.13	784,773.21	919,242.13	1,674.66
J-111	32.00	121.60	0.11	784,816.21	919,224.26	1,669.08
J-112	32.00	121.60	0.11	784,881.90	919,198.55	1,669.15
J-113	22.00	83.60	0.08	785,107.85	919,105.80	1,674.08
J-114	55.00	209.00	0.19	784,534.08	917,748.53	1,723.73
J-115	59.00	224.20	0.20	784,565.67	917,781.62	1,720.45
J-116	55.00	209.00	0.19	784,591.75	917,815.72	1,715.36
J-117	57.00	216.60	0.20	784,623.34	917,866.37	1,708.79
J-118	54.00	205.20	0.19	784,691.03	917,943.59	1,707.32
J-119	56.00	212.80	0.19	784,757.73	918,018.81	1,705.44
J-120	57.00	216.60	0.20	784,802.86	918,097.03	1,702.12
J-121	57.00	216.60	0.20	784,846.48	918,173.25	1,697.27
J-122	57.00	216.60	0.20	784,944.26	918,199.33	1,692.85
J-123	55.00	209.00	0.19	784,997.92	918,191.81	1,687.47
J-124	55.00	209.00	0.19	785,081.66	918,220.39	1,682.67
J-125	55.00	209.00	0.19	785,146.85	918,254.99	1,678.51
J-126	55.00	209.00	0.19	785,174.93	918,323.18	1,672.91
J-127	50.00	190.00	0.17	785,212.04	918,382.86	1,665.32
J-128	50.00	190.00	0.17	785,254.16	918,452.56	1,656.58
J-129	50.00	190.00	0.17	785,312.83	918,532.79	1,646.92
J-130	50.00	190.00	0.17	785,386.37	918,603.49	1,631.67
J-131	31.00	117.80	0.11	784,521.97	917,665.73	1,727.02
J-132	30.00	114.00	0.10	784,578.90	917,659.62	1,720.98
J-133	34.00	129.20	0.12	784,661.42	917,664.40	1,712.08
J-134	34.00	129.20	0.12	784,714.45	917,669.52	1,710.77
J-135	37.00	140.60	0.13	784,743.75	917,680.84	1,711.89
J-136	38.00	144.40	0.13	784,729.73	917,689.99	1,710.64
J-137	35.00	133.00	0.12	784,722.64	917,701.88	1,702.28
J-138	34.00	129.20	0.12	784,762.27	917,722.69	1,710.85

J-139	39.00	148.20	0.14	784,790.26	917,735.50	1,711.30
J-140	41.00	155.80	0.14	784,813.92	917,751.30	1,710.65
J-141	54.00	205.20	0.19	784,476.64	917,657.70	1,726.99
J-142	52.00	197.60	0.18	784,473.96	917,672.88	1,727.48
J-143	52.00	197.60	0.18	784,460.09	917,693.50	1,727.98
J-144	51.00	193.80	0.18	784,432.54	917,698.55	1,726.25
J-145	51.00	193.80	0.18	784,409.91	917,701.11	1,724.16
J-146	51.00	193.80	0.18	784,349.03	917,705.91	1,719.17
J-147	52.00	197.60	0.18	784,273.77	917,713.15	1,716.13
J-148	52.00	197.60	0.18	784,222.61	917,715.91	1,715.79
J-149	51.00	193.80	0.18	784,169.24	917,721.90	1,715.00
J-150	50.00	190.00	0.17	784,109.28	917,739.91	1,713.55
J-151	50.00	190.00	0.17	784,087.23	917,749.56	1,712.92
J-152	50.00	190.00	0.17	784,064.84	917,758.60	1,711.52
J-153	52.00	197.60	0.18	784,036.29	917,773.83	1,711.40
J-154	50.00	190.00	0.17	784,013.24	917,785.22	1,711.02
J-155	54.00	205.20	0.19	783,991.22	917,796.42	1,710.42
J-156	42.00	159.60	0.15	784,003.34	917,818.32	1,711.05
J-157	50.00	190.00	0.17	784,021.33	917,839.33	1,711.28
J-158	53.00	201.40	0.18	784,044.62	917,863.85	1,711.80
J-159	51.00	193.80	0.18	784,067.25	917,888.39	1,712.20
J-160	53.00	201.40	0.18	784,078.41	917,902.03	1,712.19
J-161	54.00	205.20	0.19	784,099.74	917,922.60	1,711.31
J-162	57.00	216.60	0.20	784,105.16	917,927.59	1,711.39
J-163	51.00	193.80	0.18	784,090.51	917,949.46	1,709.09
J-164	56.00	212.80	0.19	874,067.89	917,970.92	1,706.79
J-165	52.00	197.60	0.18	784,039.63	917,992.30	1,704.87
J-166	55.00	209.00	0.19	783,988.51	918,022.77	1,701.86
J-167	52.00	197.60	0.18	783,938.26	918,043.47	1,701.42
J-168	51.00	193.80	0.18	783,900.80	918,060.65	1,702.05
J-169	51.00	193.80	0.18	783,856.97	918,094.39	1,702.11
J-170	50.00	190.00	0.17	783,839.19	918,119.54	1,700.76
J-171	50.00	190.00	0.17	783,794.25	918,174.76	1,696.50
J-172	50.00	190.00	0.17	783,773.41	918,202.21	1,694.03
J-173	50.00	190.00	0.17	783,751.07	918,231.20	1,691.40
J-174	49.00	186.20	0.17	783,717.84	918,272.00	1,689.09
J-175	49.00	186.20	0.17	783,700.31	918,290.63	1,687.62
J-176	51.00	193.80	0.18	783,665.40	918,332.58	1,685.84

J-177	52.00	197.60	0.18	783,620.96	918,387.09	1,683.41
J-178	52.00	197.60	0.18	783,603.30	918,407.85	1,681.95
J-179	51.00	193.80	0.18	783,578.82	918,437.92	1,683.14
J-180	53.00	201.40	0.18	783,538.29	918,485.15	1,683.56
J-181	55.00	209.00	0.19	783,506.49	918,524.32	1,684.03
J-182	54.00	205.20	0.19	783,475.47	918,554.46	1,683.64
J-183	50.00	190.00	0.17	783,435.95	918,598.68	1,681.16
J-184	53.00	201.40	0.18	783,349.30	918,691.60	1,673.89
J-185	51.00	193.80	0.18	783,330.16	918,712.36	1,673.06
J-186	52.00	197.60	0.18	783,311.78	918,731.70	1,673.15
J-187	52.00	197.60	0.18	783,280.64	918,764.45	1,674.17
J-188	46.00	174.80	0.16	783,214.27	918,832.22	1,679.41
J-189	45.00	171.00	0.16	783,176.99	918,870.59	1,682.62
J-190	43.00	163.40	0.15	783,131.64	918,913.38	1,684.94
J-191	41.00	155.80	0.14	783,090.94	918,946.55	1,684.53
J-192	39.00	148.20	0.14	783,049.02	918,988.85	1,681.50
J-193	35.00	133.00	0.12	783,040.28	919,002.30	1,680.07
J-194	30.00	114.00	0.10	783,029.90	919,023.97	1,678.17
J-195	29.00	110.20	0.10	783,019.07	919,108.48	1,672.28
J-196	29.00	110.20	0.10	783,020.69	919,160.75	1,671.38
J-197	46.00	174.80	0.16	874,419.56	917,322.05	1,723.00
J-198	46.00	174.80	0.16	784,363.96	917,337.88	1,719.02
J-199	45.00	171.00	0.16	784,311.98	917,355.03	1,712.35
J-200	45.00	171.00	0.16	784,291.74	917,365.41	1,708.08
J-201	45.00	171.00	0.16	784,225.85	917,415.11	1,700.18
J-202	46.00	174.80	0.16	784,151.57	917,485.56	1,694.80
J-203	45.00	171.00	0.16	784,124.94	917,509.08	1,695.26
J-204	46.00	174.80	0.16	784,062.29	917,534.39	1,694.89
J-205	46.00	174.80	0.16	784,036.67	917,552.00	1,694.85
J-206	47.00	178.60	0.16	784,015.02	917,561.38	1,693.71
J-207	47.00	178.60	0.16	784,003.91	917,541.98	1,693.56
J-208	45.00	171.00	0.16	783,977.14	917,515.03	1,694.35
J-209	45.00	171.00	0.16	783,923.66	917,537.91	1,694.50
J-210	46.00	174.80	0.16	783,885.37	917,550.27	1,693.52
J-211	46.00	174.80	0.16	783,833.54	917,566.21	1,692.57
J-212	46.00	174.80	0.16	783,802.26	917,584.07	1,696.46
J-213	46.00	174.80	0.16	783,779.42	917,601.32	1,698.32
J-214	46.00	174.80	0.16	783,725.50	917,647.43	1,699.86

J-215	46.00	174.80	0.16	783,662.19	917,698.65	1,697.79
J-216	48.00	182.40	0.17	783,629.78	917,722.64	1,694.37
J-217	48.00	182.40	0.17	783,575.56	917,762.96	1,688.89
J-218	48.00	182.40	0.17	783,526.87	917,788.64	1,687.58
J-219	48.00	182.40	0.17	783,504.43	917,819.57	1,692.12
J-220	47.00	178.60	0.16	783,494.23	917,840.76	1,693.94
J-221	47.00	178.60	0.16	783,496.83	917,885.81	1,692.89
J-222	46.00	174.80	0.16	783,502.72	917,962.03	1,687.30
J-223	51.00	193.80	0.18	783,507.14	917,998.47	1,689.77
J-224	51.00	193.80	0.18	783,509.11	918,068.46	1,692.20
J-225	53.00	201.40	0.18	783,507.45	918,117.71	1,691.92
J-226	50.00	190.00	0.17	783,506.23	918,175.81	1,690.56
J-227	49.00	186.20	0.17	783,514.51	918,270.04	1,685.29
J-228	41.00	155.80	0.14	783,524.64	918,330.42	1,680.71
J-229	35.00	133.00	0.12	783,551.76	918,364.65	1,678.53
J-230	34.00	129.20	0.12	783,570.53	918,379.94	1,676.86
J-231	32.00	121.60	0.11	783,591.33	918,397.06	1,681.95
J-232	47.00	178.60	0.16	783,498.30	917,776.07	1,689.80
J-233	44.00	167.20	0.15	783,482.19	917,769.01	1,691.71
J-234	40.00	152.00	0.14	783,437.71	917,745.95	1,694.89
J-235	40.00	152.00	0.14	783,404.15	917,725.07	1,696.80
J-236	41.00	155.80	0.14	783,359.49	917,698.40	1,698.63
J-237	44.00	167.20	0.15	783,301.40	917,669.59	1,698.20
J-238	42.00	159.60	0.15	783,277.07	917,649.75	1,698.69
J-239	43.00	163.40	0.15	783,247.67	917,619.00	1,699.83
J-240	45.00	171.00	0.16	783,201.38	917,594.70	1,702.41
J-241	44.00	167.20	0.15	783,151.85	917,608.13	1,703.75
J-242	44.00	167.20	0.15	783,104.85	917,630.35	1,704.08
J-243	41.00	155.80	0.14	783,071.97	917,637.94	1,704.39
J-244	41.00	155.80	0.14	783,025.28	917,627.66	1,706.07
J-245	43.00	163.40	0.15	782,977.24	917,607.63	1,709.03
J-246	41.00	155.80	0.14	782,959.65	917,595.67	1,710.76
J-247	40.00	152.00	0.14	782,913.68	917,561.03	1,718.07
J-248	40.00	152.00	0.14	782,881.66	917,523.78	1,724.40
J-249	39.00	148.20	0.14	782,856.44	917,464.48	1,729.21
J-250	37.00	140.60	0.13	782,834.14	917,391.51	1,733.19
J-251	37.00	140.60	0.13	782,820.97	917,346.09	1,738.36
J-252	36.00	136.80	0.13	784,345.09	918,251.17	1,700.11

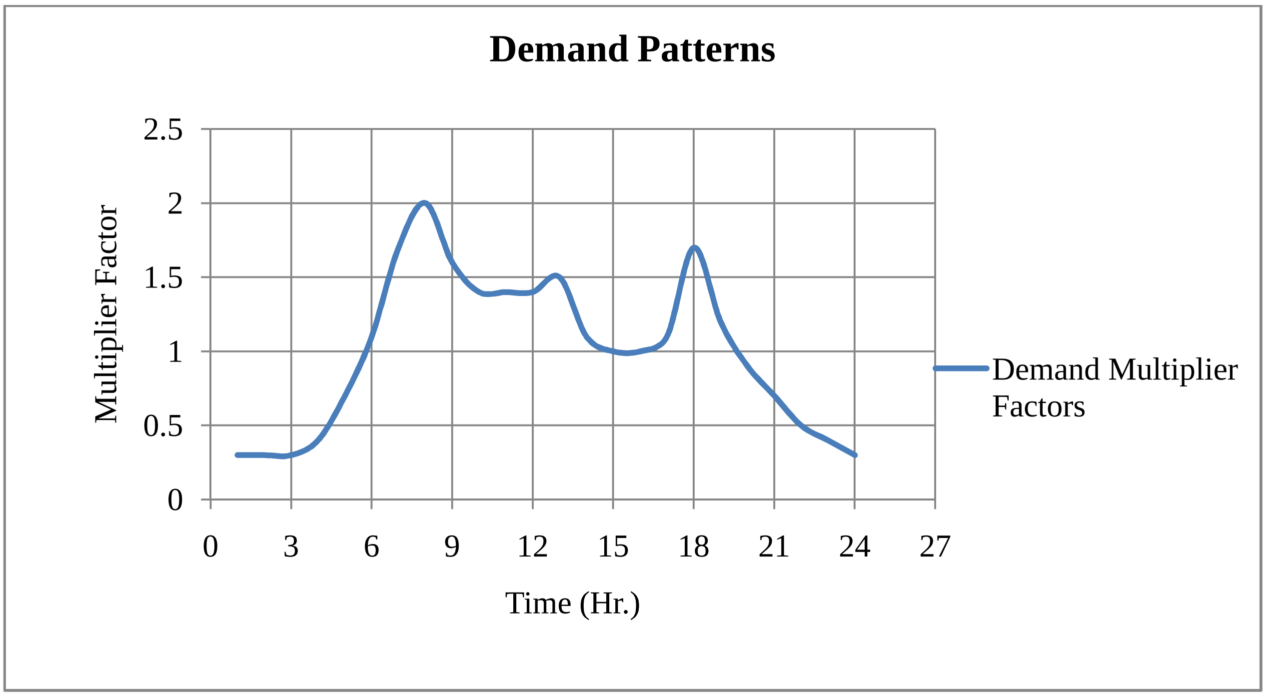
J-253	34.00	129.20	0.12	784,384.56	918,293.42	1,697.42
J-254	31.00	117.80	0.11	784,430.78	918,344.32	1,694.27
J-255	35.00	133.00	0.12	784,472.01	918,374.66	1,690.32
J-256	39.00	148.20	0.14	784,519.38	918,401.56	1,687.53
J-257	39.00	148.20	0.14	784,625.45	918,449.01	1,679.78
J-258	35.00	133.00	0.12	784,715.26	918,487.45	1,673.93
J-259	33.00	125.40	0.11	784,789.97	918,510.18	1,669.22
J-260	35.00	133.00	0.12	784,866.24	918,543.13	1,664.10
J-261	46.00	174.80	0.16	784,294.55	918,404.44	1,702.47
J-262	49.00	186.20	0.17	784,240.80	918,421.83	1,697.31
J-263	45.00	171.00	0.16	784,184.56	918,443.21	1,693.87
J-264	44.00	167.20	0.15	784,147.74	918,461.89	1,692.17
J-265	46.00	174.80	0.16	784,138.36	918,494.57	1,690.90
J-266	49.00	186.20	0.17	784,122.75	918,554.98	1,689.93
J-267	46.00	174.80	0.16	784,097.34	918,695.94	1,694.02
J-268	45.00	171.00	0.16	784,086.30	918,777.97	1,693.73
J-269	42.00	159.60	0.15	784,078.11	918,836.20	1,690.60
J-270	44.00	167.20	0.15	784,076.68	918,869.33	1,686.78
J-271	43.00	163.40	0.15	784,068.17	918,952.29	1,682.03
J-272	42.00	159.60	0.15	784,059.56	919,059.98	1,678.99
J-273	41.00	155.80	0.14	784,057.63	919,090.79	1,679.24
J-274	40.00	152.00	0.14	784,091.60	919,094.95	1,678.67
J-275	43.00	163.40	0.15	784,144.46	919,142.64	1,678.97
J-276	45.00	171.00	0.16	784,184.88	919,198.51	1,682.48
J-277	42.00	159.60	0.15	784,200.40	919,226.24	1,684.09
J-278	43.00	163.40	0.15	784,217.31	919,252.80	1,684.78
J-279	44.00	167.20	0.15	784,239.94	919,288.30	1,684.47
J-280	44.00	167.20	0.15	784,288.63	919,361.41	1,683.56
J-281	44.00	167.20	0.15	784,352.33	919,438.44	1,682.58
J-282	43.00	163.40	0.15	784,427.13	919,518.26	1,680.98
J-283	43.00	163.40	0.15	784,491.76	919,593.78	1,683.90
J-284	42.00	159.60	0.15	784,548.01	919,662.46	1,682.29
J-285	42.00	159.60	0.15	784,563.88	919,723.25	1,681.46
J-286	41.00	155.80	0.14	784,556.35	919,788.86	1,682.16
J-287	40.00	152.00	0.14	784,518.46	919,888.61	1,678.26
J-288	40.00	152.00	0.14	784,052.07	919,140.75	1,681.65
J-289	39.00	148.20	0.14	784,044.40	919,211.38	1,688.70
J-290	39.00	148.20	0.14	784,037.21	919,272.79	1,694.07

J-291	38.00	144.40	0.13	784,032.47	919,311.95	1,694.87
J-292	35.00	133.00	0.12	784,021.20	919,363.07	1,693.14
J-293	34.00	129.20	0.12	783,993.61	919,383.64	1,691.25
J-294	32.00	121.60	0.11	783,949.32	919,385.53	1,691.29
J-295	31.00	117.80	0.11	783,892.02	919,395.53	1,691.46
J-296	30.00	114.00	0.10	783,842.48	919,404.86	1,690.27
J-297	22.00	83.60	0.08	785,953.68	918,993.62	1,566.39
J-298	21.00	79.80	0.07	785,921.80	919,103.62	1,572.85
J-299	21.00	79.80	0.07	785,907.53	919,140.21	1,571.39
J-300	23.00	87.40	0.08	785,913.45	919,187.60	1,570.48
J-301	24.00	91.20	0.08	785,921.60	919,270.10	1,568.07
J-302	24.00	91.20	0.08	785,945.68	919,333.42	1,567.22
J-303	24.00	91.20	0.08	786,011.83	919,405.02	1,566.83
J-304	23.00	87.40	0.08	786,067.96	919,438.29	1,565.90
J-305	22.00	83.60	0.08	786,092.21	919,451.67	1,565.49
J-306	21.00	79.80	0.07	786,121.86	919,471.38	1,564.87
J-307	21.00	79.80	0.07	786,151.85	919,494.67	1,563.94
J-308	11.00	41.80	0.04	786,163.61	919,510.88	1,564.12
J-309	13.00	49.40	0.05	786,166.11	919,538.95	1,564.02
J-310	10.00	38.00	0.03	786,142.90	919,583.48	1,565.07
J-311	12.00	45.60	0.04	786,127.03	919,612.30	1,564.88
J-312	13.00	49.40	0.05	786,110.22	919,650.65	1,563.58
J-313	11.00	41.80	0.04	786,090.13	919,724.96	1,564.04
J-314	12.00	45.60	0.04	786,089.90	919,802.85	1,566.54
J-315	10.00	38.00	0.03	786,095.77	919,848.27	1,564.98
J-316	14.00	53.20	0.05	786,094.84	919,868.10	1,565.46
J-317	12.00	45.60	0.04	786,106.30	919,950.35	1,570.08
J-318	11.00	41.80	0.04	786,121.81	920,035.51	1,572.13
J-319	11.00	41.80	0.04	786,154.59	920,143.21	1,574.04
J-320	10.00	38.00	0.03	786,175.23	920,196.34	1,575.53
J-321	10.00	38.00	0.03	786,211.15	920,283.00	1,576.04
J-322	18.00	68.40	0.06	786,178.76	919,493.18	1,563.77
J-323	18.00	68.40	0.06	786,208.54	919,492.52	1,564.02
J-324	16.00	60.80	0.06	786,231.43	919,485.33	1,564.41
J-325	17.00	64.60	0.06	786,289.34	919,450.08	1,564.56
J-326	13.00	49.40	0.05	786,330.20	919,433.72	1,563.94
J-327	10.00	38.00	0.03	786,383.85	919,417.55	1,564.48
J-328	9.00	34.20	0.03	786,439.64	919,405.23	1,564.45

J-329	7.00	26.60	0.02	786,523.16	919,385.18	1,568.21
J-330	35.00	133.00	0.12	784,542.76	919,019.92	1,689.92
J-331	33.00	125.40	0.11	784,618.87	918,985.10	1,688.67
J-332	32.00	121.60	0.11	784,701.91	918,956.26	1,689.13
J-333	30.00	114.00	0.10	784,781.32	918,932.54	1,688.13
J-334	30.00	114.00	0.10	784,851.36	918,960.42	1,689.91
J-335	29.00	110.20	0.10	784,929.28	919,008.11	1,690.46
Total	**12,186.00**	**46,306.80**	**42.34**			

Appendix D

Patterns for hourly demand multiplier factors



(Source: Oromia Water, Mineral and Energy Bureau)

Appendix E

Time series representation of pressure value; for peak demand time

Item	Sample taken point	Location			Measured time	Computed pressure (m)	Observed pressure (m)	Errors (m)
		X (m)	Y (m)	Z (m)				
1	J-1	786,071.66	919,074.41	1,560.18	2:00	201.90	199.85	2.05
2	J-305	786,092.21	919,451.67	1,565.49	2:30	191.79	191.50	0.29
3	J-301	785,921.60	919,270.10	1,568.07	2:45	189.51	190.00	-0.49
4	J-7	785,877.09	918,850.82	1,579.40	3:15	182.09	182.55	-0.46
5	J-121	784,846.48	918,173.25	1,697.27	4:00	53.41	53.00	0.41
6	J-119	784,757.73	918,018.81	1,705.44	4:15	45.29	45.75	-0.46
7	J-117	784,623.34	917,866.37	1,708.79	4:30	42.00	41.80	0.20
8	J-35	784,488.76	917,571.39	1,724.58	5:00	27.50	27.05	0.45
9	J-41	784,414.39	917,046.83	1,731.73	5:30	23.68	15.20	8.48
10	J-43	784,415.82	916,901.80	1,742.36	5:45	13.99	13.50	0.49
R^2=0.9980								

Appendix F

Time series representation of pressure value; for low demand time/night flow

Item	Sample taken point	Location			Measured time	Computed pressure (m)	Observed pressure (m)	Errors (m)
		X (m)	Y (m)	Z (m)				
1	J-1	786,071.66	919,074.41	1,560.18	2:00	203.68	199.85	3.83
2	J-305	786,092.21	919,451.67	1,565.49	2:30	197.96	197.50	0.46
3	J-301	785,921.60	919,270.10	1,568.07	2:45	195.41	195.70	-0.29

4	J-7	785,877.09	918,850.82	1,579.40	3:15	183.84	183.40	0.44
5	J-121	784,846.48	918,173.25	1,697.27	4:00	62.04	61.60	0.44
6	J-119	784,757.73	918,018.81	1,705.44	4:15	53.89	53.50	0.39
7	J-117	784,623.34	917,866.37	1,708.79	4:30	50.55	51.00	-0.45
8	J-35	784,488.76	917,571.39	1,724.58	5:00	34.88	40.30	-5.42
9	J-41	784,414.39	917,046.83	1,731.73	5:30	27.75	18.80	8.95
10	J-43	784,415.82	916,901.80	1,742.36	5:45	17.15	16.70	0.45
R^2=0.9970								

Appendix G

Pump result: Calculated water power (kW)

Time (Hr.)	Calculated Water Power (kW)
0:00:00	34.14
1:00:00	34.14
2:00:00	34.14
3:00:00	34.14
4:00:00	0.00
5:00:00	0.00
6:00:00	29.30
7:00:00	16.68
8:00:00	21.60
9:00:00	0.00
10:00:00	0.00
11:00:00	29.12
12:00:00	16.50
13:00:00	21.24
14:00:00	33.50
15:00:00	0.00
16:00:00	0.00
17:00:00	29.10

18:00:00	16.64
19:00:00	21.41
20:00:00	33.28
21:00:00	0.00
22:00:00	0.00
23:00:00	29.13
24:00:00	16.50

Appendix H

Junctions (nodal) pressure result; for peak demand time

Label	Demand (Calculated) (l/s)	Calculated Hydraulic Grade (m)	Pressure (m H2O)
J-1	0.02	1,761.38	201.90
J-2	0.02	1,761.28	199.37
J-3	0.03	1,761.15	198.51
J-4	0.03	1,761.06	195.58
J-5	0	1,760.93	190.03
J-6	0	1,760.84	185.27
J-7	0.04	1,760.76	182.09
J-8	0	1,760.63	176.63
J-9	0	1,760.44	170.82
J-10	0	1,760.26	167.23
J-11	0	1,760.14	164.77
J-12	0	1,760.03	169.26
J-13	0	1,759.91	154.97
J-14	0	1,759.79	141.17
J-15	0	1,759.71	126.78
J-16	0	1,759.54	112.40
J-17	0	1,750.20	93.44
J-18	0	1,750.08	84.59
J-19	0	1,749.95	76.88
J-20	0	1,749.83	71.17
J-21	0	1,749.67	66.87
J-22	0	1,749.52	61.93

J-23	0	1,749.43	56.47
J-24	0	1,749.30	51.93
J-25	0	1,749.16	46.94
J-26	0	1,749.01	43.48
J-27	0	1,748.83	41.43
J-28	0	1,748.66	39.80
J-29	0	1,748.54	33.12
J-30	0	1,748.47	27.97
J-31	0	1,748.41	24.63
J-32	0.18	1,748.37	22.04
J-33	0.18	1,748.58	21.60
J-34	0.25	1,748.76	24.80
J-35	0.25	1,749.55	27.50
J-36	0.29	1,750.30	27.43
J-37	0.29	1,751.18	27.62
J-38	0.29	1,751.65	28.36
J-39	0.27	1,752.54	28.66
J-40	0.25	1,753.34	25.48
J-41	0.25	1,754.02	23.68
J-42	0.25	1,754.68	17.84
J-43	0.25	1,755.34	13.99
J-44	0.25	1,755.76	9.68
J-45	0.25	1,756.44	7.60
J-46	0.23	1,756.90	6.42
J-47	0.20	1,757.43	5.36
J-48	0.13	1,757.97	2.97
J-49	0.13	1,757.88	6.14
J-50	0.13	1,757.85	6.76
J-51	0.13	1,757.81	7.42
J-52	0.11	1,757.79	12.80
J-53	0.11	1,757.77	23.34
J-54	0.11	1,757.74	30.36
J-55	0.09	1,757.73	29.48
J-56	0.09	1,757.73	33.42
J-57	0.07	1,757.73	33.97
J-58	0.07	1,757.73	30.24
J-59	0.07	1,757.73	26.99
J-60	0.23	1,757.12	5.05

J-61	0.25	1,756.64	6.16
J-62	0.25	1,756.19	7.36
J-63	0.27	1,755.58	9.49
J-64	0.27	1,755.18	12.79
J-65	0.29	1,754.53	17.69
J-66	0.31	1,753.84	22.07
J-67	0.27	1,753.26	25.40
J-68	0.27	1,752.51	28.63
J-69	0.27	1,751.85	28.57
J-70	0.25	1,751.64	28.59
J-71	0.27	1,751.01	27.95
J-72	0.29	1,749.73	26.85
J-73	0.31	1,748.60	23.97
J-74	0.27	1,747.62	20.77
J-75	0.29	1,747.61	20.65
J-76	0.25	1,747.58	21.25
J-77	0.27	1,747.58	20.52
J-78	0.29	1,746.64	17.48
J-79	0.36	1,746.12	15.65
J-80	0.32	1,744.73	12.73
J-81	0.31	1,742.69	12.25
J-82	0.32	1,741.68	12.19
J-83	0.34	1,738.78	18.93
J-84	0.34	1,736.91	22.48
J-85	0.32	1,734.21	26.13
J-86	0.31	1,732.99	26.90
J-87	0.31	1,709.20	5.52
J-88	0.29	1,693.06	-10.18
J-89	0.22	1,665.01	-38.94
J-90	0.20	1,656.46	-47.19
J-91	0.22	1,656.32	-47.09
J-92	0.23	1,655.90	-46.17
J-93	0.25	1,655.43	-41.54
J-94	0.25	1,654.76	-36.80
J-95	0.23	1,654.40	-36.91
J-96	0.23	1,654.04	-36.24
J-97	0.22	1,653.41	-36.04
J-98	0.23	1,653.20	-35.91

J-99	0.25	1,652.94	-34.88
J-100	0.27	1,652.63	-37.70
J-101	0.32	1,652.47	-39.32
J-102	0.31	1,652.37	-38.88
J-103	0.29	1,652.32	-36.82
J-104	0.27	1,652.24	-33.87
J-105	0.29	1,652.18	-32.88
J-106	0.31	1,652.15	-32.18
J-107	0.29	1,652.11	-30.34
J-108	0.25	1,652.08	-28.35
J-109	0.27	1,652.05	-25.42
J-110	0.23	1,652.04	-22.58
J-111	0.20	1,652.03	-17.02
J-112	0.20	1,652.02	-17.10
J-113	0.14	1,652.02	-22.02
J-114	0.34	1,747.56	27.78
J-115	0.36	1,747.53	32.02
J-116	0.34	1,747.50	38.07
J-117	0.36	1,747.47	42.00
J-118	0.34	1,747.42	43.02
J-119	0.34	1,747.38	45.29
J-120	0.36	1,747.35	48.14
J-121	0.36	1,747.33	53.41
J-122	0.36	1,747.16	54.21
J-123	0.34	1,747.10	59.51
J-124	0.34	1,747.01	64.21
J-125	0.34	1,746.96	68.31
J-126	0.34	1,746.92	73.86
J-127	0.31	1,746.86	81.37
J-128	0.31	1,746.81	90.05
J-129	0.31	1,746.78	99.66
J-130	0.31	1,746.78	114.88
J-131	0.20	1,748.74	21.67
J-132	0.18	1,748.60	27.56
J-133	0.22	1,748.44	36.29
J-134	0.22	1,748.35	37.51
J-135	0.23	1,748.32	36.36
J-136	0.23	1,748.30	37.59

J-137	0.22	1,748.29	45.92
J-138	0.22	1,748.28	37.35
J-139	0.25	1,748.27	36.90
J-140	0.25	1,748.27	37.54
J-141	0.34	1,747.54	20.51
J-142	0.32	1,747.48	19.96
J-143	0.32	1,747.39	19.37
J-144	0.32	1,747.29	21.00
J-145	0.32	1,747.21	23.01
J-146	0.32	1,747.02	27.79
J-147	0.32	1,746.79	30.60
J-148	0.32	1,746.64	30.78
J-149	0.32	1,746.49	31.43
J-150	0.31	1,746.33	32.71
J-151	0.31	1,746.27	33.28
J-152	0.31	1,746.21	34.63
J-153	0.32	1,746.14	34.67
J-154	0.31	1,746.09	35.00
J-155	0.34	1,746.04	35.54
J-156	0.27	1,745.99	34.87
J-157	0.31	1,745.94	34.59
J-158	0.32	1,745.89	34.02
J-159	0.32	1,745.84	33.57
J-160	0.32	1,745.81	33.56
J-161	0.34	1,745.77	34.39
J-162	0.36	1,745.76	34.30
J-163	0.32	1,745.73	36.57
J-164	0.34	1,745.70	38.83
J-165	0.32	1,745.67	40.72
J-166	0.34	1,745.31	43.37
J-167	0.32	1,745.02	43.52
J-168	0.32	1,744.82	42.69
J-169	0.32	1,744.59	42.40
J-170	0.31	1,744.47	43.62
J-171	0.31	1,744.23	47.63
J-172	0.31	1,744.13	50.00
J-173	0.31	1,744.04	52.53
J-174	0.31	1,743.92	54.72

J-175	0.31	1,743.87	56.14
J-176	0.32	1,743.79	57.84
J-177	0.32	1,743.71	60.17
J-178	0.32	1,743.68	61.61
J-179	0.32	1,743.18	59.93
J-180	0.32	1,742.48	58.80
J-181	0.34	1,741.98	57.84
J-182	0.34	1,741.61	57.85
J-183	0.31	1,741.18	59.90
J-184	0.32	1,740.39	66.36
J-185	0.32	1,740.24	67.05
J-186	0.32	1,740.13	66.85
J-187	0.32	1,739.98	65.68
J-188	0.29	1,739.74	60.21
J-189	0.29	1,739.64	56.90
J-190	0.27	1,739.55	54.50
J-191	0.25	1,739.50	54.86
J-192	0.25	1,739.46	57.84
J-193	0.22	1,739.45	59.26
J-194	0.18	1,739.45	61.16
J-195	0.18	1,739.44	67.03
J-196	0.18	1,739.44	67.92
J-197	0.29	1,751.56	28.50
J-198	0.29	1,751.19	32.10
J-199	0.29	1,750.85	38.42
J-200	0.29	1,750.71	42.54
J-201	0.29	1,750.23	49.95
J-202	0.29	1,749.65	54.74
J-203	0.29	1,749.45	54.08
J-204	0.29	1,749.09	54.09
J-205	0.29	1,748.93	53.98
J-206	0.29	1,748.82	54.99
J-207	0.29	1,748.71	55.04
J-208	0.29	1,748.53	54.08
J-209	0.29	1,748.27	53.67
J-210	0.29	1,748.10	54.47
J-211	0.29	1,747.87	55.19
J-212	0.29	1,747.73	51.17

J-213	0.29	1,747.62	49.20
J-214	0.29	1,747.36	47.40
J-215	0.29	1,747.07	49.18
J-216	0.31	1,746.93	52.45
J-217	0.31	1,746.71	57.70
J-218	0.31	1,746.53	58.83
J-219	0.31	1,746.25	54.02
J-220	0.29	1,746.09	52.04
J-221	0.29	1,745.80	52.81
J-222	0.29	1,745.36	57.94
J-223	0.32	1,745.17	55.29
J-224	0.32	1,744.84	52.11
J-225	0.32	1,744.63	52.60
J-226	0.31	1,744.41	53.74
J-227	0.31	1,744.10	58.70
J-228	0.25	1,743.93	63.09
J-229	0.22	1,743.82	65.16
J-230	0.22	1,743.76	66.77
J-231	0.20	1,743.71	61.63
J-232	0.29	1,746.39	56.48
J-233	0.27	1,746.32	54.50
J-234	0.25	1,746.13	51.14
J-235	0.25	1,746.00	49.10
J-236	0.25	1,745.84	47.12
J-237	0.27	1,745.67	47.37
J-238	0.27	1,745.60	46.81
J-239	0.27	1,745.51	45.59
J-240	0.29	1,745.42	42.92
J-241	0.27	1,745.35	41.51
J-242	0.27	1,745.28	41.12
J-243	0.25	1,745.25	40.78
J-244	0.25	1,745.21	39.06
J-245	0.27	1,745.18	36.08
J-246	0.25	1,745.17	34.35
J-247	0.25	1,745.15	27.03
J-248	0.25	1,745.14	20.70
J-249	0.25	1,745.14	15.89
J-250	0.23	1,745.13	11.92

J-251	0.23	1,745.13	6.76
J-252	0.23	1,692.95	-7.15
J-253	0.22	1,692.85	-4.56
J-254	0.20	1,692.75	-1.52
J-255	0.22	1,692.69	4.36
J-256	0.25	1,692.64	5.10
J-257	0.25	1,692.59	12.78
J-258	0.22	1,692.56	18.59
J-259	0.20	1,692.55	23.28
J-260	0.22	1,692.55	28.39
J-261	0.29	1,644.73	-57.63
J-262	0.31	1,619.86	-77.29
J-263	0.29	1,593.83	-99.83
J-264	0.27	1,576.27	-115.67
J-265	0.29	1,561.92	-128.72
J-266	0.31	1,536.07	-153.54
J-267	0.29	1,477.83	-215.75
J-268	0.29	1,444.67	-248.56
J-269	0.27	1,421.53	-268.52
J-270	0.27	1,408.67	-277.55
J-271	0.27	1,376.83	-304.58
J-272	0.27	1,336.36	-341.94
J-273	0.25	1,324.99	-353.53
J-274	0.25	1,324.74	-353.22
J-275	0.27	1,324.28	-353.98
J-276	0.29	1,323.89	-357.87
J-277	0.27	1,323.74	-359.63
J-278	0.27	1,323.62	-360.43
J-279	0.27	1,323.48	-360.26
J-280	0.27	1,323.26	-359.57
J-281	0.27	1,323.05	-358.80
J-282	0.27	1,322.89	-357.36
J-283	0.27	1,322.79	-360.39
J-284	0.27	1,322.72	-358.85
J-285	0.27	1,322.70	-358.04
J-286	0.25	1,322.69	-358.75
J-287	0.25	1,322.68	-354.87
J-288	0.25	1,310.62	-370.28

J-289	25.20	1,290.68	-397.22
J-290	0.25	1,290.59	-402.66
J-291	0.23	1,290.56	-403.50
J-292	0.22	1,290.52	-401.81
J-293	0.22	1,290.51	-399.93
J-294	0.20	1,290.50	-399.99
J-295	0.20	1,290.49	-400.16
J-296	0.18	1,290.49	-398.98
J-297	0.08	1,761.02	191.67
J-298	0.07	1,760.83	185.01
J-299	0.07	1,760.77	186.40
J-300	0.08	1,760.70	187.23
J-301	0.08	1,760.60	189.51
J-302	0.08	1,760.52	190.27
J-303	0.08	1,760.42	190.55
J-304	0.08	1,760.36	191.41
J-305	0.08	1,760.33	191.79
J-306	0.07	1,760.28	192.35
J-307	0.07	1,760.24	193.22
J-308	0.04	1,760.23	193.04
J-309	0.05	1,760.23	193.13
J-310	0.03	1,760.22	192.07
J-311	0.04	1,760.21	192.26
J-312	0.05	1,760.21	193.55
J-313	0.04	1,760.20	193.08
J-314	0.04	1,760.20	190.58
J-315	0.03	1,760.20	192.14
J-316	0.09	1,749.16	171.91
J-317	0.07	1,749.16	167.29
J-318	0.07	1,749.15	165.24
J-319	0.07	1,749.15	163.33
J-320	0.05	1,749.15	161.85
J-321	0.05	1,749.15	161.34
J-322	0.11	1,749.28	173.69
J-323	0.11	1,749.27	173.44
J-324	0.11	1,749.27	173.05
J-325	0.11	1,749.26	172.89
J-326	0.09	1,749.26	173.51

J-327	0.05	1,749.26	172.97
J-328	0.05	1,749.26	173.00
J-329	0.04	1,749.26	169.24
J-330	0.22	1,652.55	-37.29
J-331	0.20	1,652.51	-36.09
J-332	0.20	1,652.47	-36.58
J-333	0.18	1,652.46	-35.60
J-334	0.18	1,652.45	-37.39
J-335	0.18	1,652.45	-37.94

Appendix I

Junctions (nodal) pressure result; for night flow/ low demand time

Label	Demand (Calculated) (l/s)	Calculated Hydraulic Grade (m)	Pressure (m H2O)
J-1	0.01	1,764.27	203.68
J-2	0.01	1,764.17	202.25
J-3	0.01	1,764.05	201.39
J-4	0.01	1,763.95	198.47
J-5	0	1,763.81	192.90
J-6	0	1,763.71	188.13
J-7	0.01	1,763.61	183.84
J-8	0	1,763.47	179.46
J-9	0	1,763.25	173.62
J-10	0	1,763.04	170.01
J-11	0	1,762.90	167.52
J-12	0	1,762.77	172.00
J-13	0	1,762.63	157.69
J-14	0	1,762.50	143.87
J-15	0	1,762.40	129.47
J-16	0	1,762.21	115.06
J-17	0	1,761.81	105.02
J-18	0	1,761.66	96.15
J-19	0	1,761.50	88.41
J-20	0	1,761.35	82.67
J-21	0	1,761.15	78.33
J-22	0	1,760.96	73.35

J-23	0	1,760.85	67.87
J-24	0	1,760.69	63.29
J-25	0	1,760.51	58.27
J-26	0	1,760.33	54.77
J-27	0	1,760.11	52.69
J-28	0	1,759.90	51.01
J-29	0	1,759.75	44.30
J-30	0	1,759.66	39.14
J-31	0	1,759.58	35.78
J-32	0.04	1,759.53	33.18
J-33	0.04	1,759.53	31.53
J-34	0.06	1,759.53	32.55
J-35	0.06	1,759.53	34.88
J-36	0.06	1,759.52	36.63
J-37	0.06	1,759.52	35.94
J-38	0.06	1,759.52	36.22
J-39	0.06	1,759.52	35.63
J-40	0.06	1,759.53	31.65
J-41	0.06	1,759.53	27.75
J-42	0.06	1,759.54	22.70
J-43	0.06	1,759.54	17.15
J-44	0.06	1,759.55	13.45
J-45	0.06	1,759.55	10.71
J-46	0.05	1,759.55	9.07
J-47	0.04	1,759.56	7.49
J-48	0.03	1,759.56	4.57
J-49	0.03	1,759.56	7.81
J-50	0.03	1,759.56	8.47
J-51	0.03	1,759.55	9.16
J-52	0.02	1,759.55	14.55
J-53	0.02	1,759.55	25.12
J-54	0.02	1,759.55	32.17
J-55	0.02	1,759.55	31.30
J-56	0.02	1,759.55	35.24
J-57	0.02	1,759.55	35.79
J-58	0.02	1,759.55	32.06
J-59	0.02	1,759.55	28.81
J-60	0.05	1,759.56	7.48

J-61	0.06	1,759.55	9.06
J-62	0.06	1,759.55	10.71
J-63	0.06	1,759.54	13.45
J-64	0.06	1,759.54	17.14
J-65	0.06	1,759.53	22.69
J-66	0.07	1,759.53	27.74
J-67	0.06	1,759.52	31.65
J-68	0.06	1,759.52	35.63
J-69	0.06	1,759.51	36.21
J-70	0.06	1,759.51	36.44
J-71	0.06	1,759.50	36.43
J-72	0.06	1,759.48	36.59
J-73	0.07	1,759.47	34.82
J-74	0.06	1,759.45	32.58
J-75	0.06	1,759.45	32.47
J-76	0.06	1,759.46	33.10
J-77	0.06	1,759.46	32.38
J-78	0.06	1,759.37	30.18
J-79	0.08	1,759.33	28.83
J-80	0.07	1,759.20	27.17
J-81	0.07	1,759.02	28.55
J-82	0.07	1,758.93	29.40
J-83	0.08	1,758.67	38.79
J-84	0.08	1,758.51	44.03
J-85	0.07	1,758.27	50.14
J-86	0.07	1,758.16	52.02
J-87	0.07	1,756.05	52.28
J-88	0.06	1,754.62	51.25
J-89	0.05	1,752.13	48.01
J-90	0.04	1,751.37	47.52
J-91	0.05	1,751.36	47.76
J-92	0.05	1,751.32	49.06
J-93	0.06	1,751.28	54.12
J-94	0.06	1,751.22	59.47
J-95	0.05	1,751.20	59.69
J-96	0.05	1,751.18	60.70
J-97	0.05	1,751.14	61.49
J-98	0.05	1,751.13	61.82

J-99	0.06	1,751.11	63.10
J-100	0.06	1,751.10	60.57
J-101	0.07	1,751.09	59.10
J-102	0.07	1,751.08	59.63
J-103	0.06	1,751.08	61.73
J-104	0.06	1,751.07	64.77
J-105	0.06	1,751.07	65.80
J-106	0.07	1,751.07	66.54
J-107	0.06	1,751.07	68.42
J-108	0.06	1,751.06	70.44
J-109	0.06	1,751.06	73.40
J-110	0.05	1,751.06	76.25
J-111	0.04	1,751.06	81.81
J-112	0.04	1,751.06	81.74
J-113	0.03	1,751.06	76.83
J-114	0.08	1,759.45	35.65
J-115	0.08	1,759.45	38.92
J-116	0.08	1,759.45	44.00
J-117	0.08	1,759.45	50.55
J-118	0.08	1,759.44	52.02
J-119	0.08	1,759.44	53.89
J-120	0.08	1,759.44	57.20
J-121	0.08	1,759.43	62.04
J-122	0.08	1,759.42	66.44
J-123	0.08	1,759.41	71.80
J-124	0.08	1,759.41	76.58
J-125	0.08	1,759.40	80.73
J-126	0.08	1,759.40	86.31
J-127	0.07	1,759.39	93.88
J-128	0.07	1,759.39	102.60
J-129	0.07	1,759.39	112.24
J-130	0.07	1,759.38	127.46
J-131	0.04	1,759.53	32.44
J-132	0.04	1,759.51	38.45
J-133	0.05	1,759.50	47.33
J-134	0.05	1,759.49	48.62
J-135	0.05	1,759.49	47.50
J-136	0.05	1,759.49	48.75

J-137	0.05	1,759.49	57.09
J-138	0.05	1,759.49	48.54
J-139	0.06	1,759.48	48.09
J-140	0.06	1,759.48	48.73
J-141	0.08	1,759.45	32.39
J-142	0.07	1,759.44	31.89
J-143	0.07	1,759.43	31.39
J-144	0.07	1,759.42	33.11
J-145	0.07	1,759.41	35.18
J-146	0.07	1,759.39	40.14
J-147	0.07	1,759.36	43.15
J-148	0.07	1,759.35	43.47
J-149	0.07	1,759.33	44.24
J-150	0.07	1,759.31	45.67
J-151	0.07	1,759.31	46.30
J-152	0.07	1,759.30	47.69
J-153	0.07	1,759.29	47.80
J-154	0.07	1,759.29	48.17
J-155	0.08	1,759.28	48.76
J-156	0.06	1,759.28	48.13
J-157	0.07	1,759.27	47.89
J-158	0.07	1,759.26	47.37
J-159	0.07	1,759.26	46.97
J-160	0.07	1,759.25	46.97
J-161	0.08	1,759.25	47.84
J-162	0.08	1,759.25	47.76
J-163	0.07	1,759.25	50.05
J-164	0.08	1,759.24	52.34
J-165	0.07	1,759.24	54.26
J-166	0.08	1,759.19	57.22
J-167	0.07	1,759.15	57.62
J-168	0.07	1,759.12	56.96
J-169	0.07	1,759.09	56.87
J-170	0.07	1,759.08	58.20
J-171	0.07	1,759.06	62.43
J-172	0.07	1,759.05	64.88
J-173	0.07	1,759.04	67.50
J-174	0.07	1,759.02	69.79

J-175	0.07	1,759.02	71.26
J-176	0.07	1,759.01	73.03
J-177	0.07	1,759.00	75.44
J-178	0.07	1,758.99	76.89
J-179	0.07	1,758.96	75.68
J-180	0.07	1,758.92	75.21
J-181	0.08	1,758.89	74.72
J-182	0.08	1,758.87	75.08
J-183	0.07	1,758.85	77.54
J-184	0.07	1,758.80	84.74
J-185	0.07	1,758.79	85.56
J-186	0.07	1,758.79	85.46
J-187	0.07	1,758.78	84.44
J-188	0.06	1,758.76	79.20
J-189	0.06	1,758.76	75.98
J-190	0.06	1,758.75	73.67
J-191	0.06	1,758.75	74.07
J-192	0.06	1,758.75	77.09
J-193	0.05	1,758.75	78.52
J-194	0.04	1,758.75	80.41
J-195	0.04	1,758.74	86.29
J-196	0.04	1,758.74	87.19
J-197	0.06	1,759.50	36.43
J-198	0.06	1,759.48	40.37
J-199	0.06	1,759.45	47.00
J-200	0.06	1,759.44	51.26
J-201	0.06	1,759.40	59.11
J-202	0.06	1,759.36	64.43
J-203	0.06	1,759.34	63.95
J-204	0.06	1,759.32	64.30
J-205	0.06	1,759.31	64.33
J-206	0.06	1,759.30	65.45
J-207	0.06	1,759.29	65.60
J-208	0.06	1,759.28	64.80
J-209	0.06	1,759.26	64.64
J-210	0.06	1,759.25	65.59
J-211	0.06	1,759.23	66.52
J-212	0.06	1,759.22	62.63

J-213	0.06	1,759.21	60.77
J-214	0.06	1,759.19	59.21
J-215	0.06	1,759.17	61.26
J-216	0.07	1,759.16	64.66
J-217	0.07	1,759.15	70.11
J-218	0.07	1,759.13	71.41
J-219	0.07	1,759.12	66.86
J-220	0.06	1,759.11	65.04
J-221	0.06	1,759.09	66.08
J-222	0.06	1,759.07	71.62
J-223	0.07	1,759.06	69.15
J-224	0.07	1,759.04	66.29
J-225	0.07	1,759.03	66.97
J-226	0.07	1,759.02	68.32
J-227	0.07	1,759.01	73.57
J-228	0.06	1,759.00	78.13
J-229	0.05	1,759.00	80.31
J-230	0.05	1,759.00	81.97
J-231	0.04	1,758.99	76.89
J-232	0.06	1,759.13	69.19
J-233	0.06	1,759.12	67.28
J-234	0.06	1,759.11	64.09
J-235	0.06	1,759.10	62.18
J-236	0.06	1,759.09	60.34
J-237	0.06	1,759.08	60.76
J-238	0.06	1,759.08	60.26
J-239	0.06	1,759.07	59.13
J-240	0.06	1,759.07	56.54
J-241	0.06	1,759.06	55.20
J-242	0.06	1,759.06	54.87
J-243	0.06	1,759.06	54.56
J-244	0.06	1,759.06	52.88
J-245	0.06	1,759.05	49.92
J-246	0.06	1,759.05	48.20
J-247	0.06	1,759.05	40.90
J-248	0.06	1,759.05	34.58
J-249	0.06	1,759.05	29.78
J-250	0.05	1,759.05	25.81

J-251	0.05	1,759.05	20.65
J-252	0.05	1,754.61	54.39
J-253	0.05	1,754.60	57.07
J-254	0.04	1,754.59	60.21
J-255	0.05	1,754.59	64.14
J-256	0.06	1,754.58	66.91
J-257	0.06	1,754.58	74.65
J-258	0.05	1,754.57	80.48
J-259	0.04	1,754.57	85.18
J-260	0.05	1,754.57	90.30
J-261	0.06	1,750.33	47.76
J-262	0.07	1,748.13	50.72
J-263	0.06	1,745.82	51.85
J-264	0.06	1,744.26	51.98
J-265	0.06	1,742.99	51.98
J-266	0.07	1,740.69	50.67
J-267	0.06	1,735.53	41.43
J-268	0.06	1,732.58	38.77
J-269	0.06	1,730.53	39.86
J-270	0.06	1,729.39	42.53
J-271	0.06	1,726.57	44.45
J-272	0.06	1,722.97	43.90
J-273	0.06	1,721.97	42.64
J-274	0.06	1,721.94	43.18
J-275	0.06	1,721.90	42.85
J-276	0.06	1,721.87	39.31
J-277	0.06	1,721.86	37.69
J-278	0.06	1,721.84	36.99
J-279	0.06	1,721.83	37.29
J-280	0.06	1,721.81	38.18
J-281	0.06	1,721.80	39.14
J-282	0.06	1,721.79	40.73
J-283	0.06	1,721.79	37.81
J-284	0.06	1,721.78	39.41
J-285	0.06	1,721.78	40.24
J-286	0.06	1,721.78	39.54
J-287	0.06	1,721.78	43.43
J-288	0.06	1,721.12	39.40

J-289	5.60	1,719.95	31.19
J-290	0.06	1,719.95	25.83
J-291	0.05	1,719.95	25.03
J-292	0.05	1,719.94	26.75
J-293	0.05	1,719.94	28.64
J-294	0.04	1,719.94	28.59
J-295	0.04	1,719.94	28.43
J-296	0.04	1,719.94	29.61
J-297	0.02	1,763.92	197.13
J-298	0.02	1,763.90	190.66
J-299	0.02	1,763.89	192.11
J-300	0.02	1,763.88	193.01
J-301	0.02	1,763.87	195.41
J-302	0.02	1,763.86	196.25
J-303	0.02	1,763.85	196.63
J-304	0.02	1,763.85	197.55
J-305	0.02	1,763.85	197.96
J-306	0.02	1,763.84	198.57
J-307	0.02	1,763.84	199.49
J-308	0.01	1,763.84	199.31
J-309	0.02	1,763.83	199.41
J-310	0.01	1,763.83	198.36
J-311	0.01	1,763.83	198.55
J-312	0.02	1,763.83	199.85
J-313	0.01	1,763.83	199.39
J-314	0.01	1,763.83	196.89
J-315	0.01	1,763.83	198.45
J-316	0.02	1,763.34	197.48
J-317	0.02	1,763.34	192.87
J-318	0.02	1,763.33	190.82
J-319	0.02	1,763.33	188.91
J-320	0.01	1,763.33	187.43
J-321	0.01	1,763.33	186.92
J-322	0.02	1,763.34	199.17
J-323	0.02	1,763.34	198.92
J-324	0.02	1,763.34	198.53
J-325	0.02	1,763.34	198.38
J-326	0.02	1,763.34	199.00

J-327	0.01	1,763.34	198.46
J-328	0.01	1,763.34	198.49
J-329	0.01	1,763.34	194.74
J-330	0.05	1,750.89	60.85
J-331	0.04	1,750.89	62.09
J-332	0.04	1,750.88	61.63
J-333	0.04	1,750.88	62.63
J-334	0.04	1,750.88	60.85
J-335	0.04	1,750.88	60.30

Appendix J

Pipe result; during peak demand time

Label	Length (m)	Diameter (mm)	Material	Hazen-Williams C	Discharge (l/s)	Pressure Pipe Head loss (m)	Head loss Gradient (m/km)	Velocity (m/s)
P-1	18.90	200	DCI	109	16.47	0.04	2.28	0.52
P-2	32.00	200	DCI	109	16.47	0.07	2.27	0.52
P-3	42.67	200	DCI	109	16.46	0.10	2.27	0.52
P-4	54.25	200	DCI	109	16.44	0.12	2.27	0.52
P-5	40.84	200	DCI	109	16.42	0.09	2.26	0.52
P-6	68.28	200	DCI	109	15.17	0.13	1.95	0.48
P-7	45.72	200	DCI	109	15.17	0.09	1.95	0.48
P-8	47.55	200	DCI	109	15.17	0.09	1.95	0.48
P-9	15.54	200	DCI	109	15.14	0.03	1.94	0.48
P-10	50.60	200	DCI	109	15.14	0.10	1.94	0.48
P-11	102.11	200	DCI	109	15.14	0.20	1.95	0.48
P-12	95.40	200	DCI	109	15.14	0.19	1.95	0.48
P-13	66.14	200	DCI	109	15.14	0.13	1.94	0.48
P-14	60.05	200	DCI	109	15.14	0.12	1.95	0.48
P-15	66.75	200	DCI	109	15.14	0.13	1.95	0.48
P-16	59.74	200	DCI	109	15.14	0.12	1.95	0.48
P-17	46.94	200	DCI	109	15.14	0.09	1.94	0.48
P-18	88.39	200	DCI	109	15.14	0.17	1.95	0.48
P-19	98.15	200	DCI	109	14.63	0.18	1.82	0.47

P-20	74.98	200	DCI	109	14.63	0.14	1.83	0.47
P-21	76.81	200	DCI	109	14.63	0.14	1.83	0.47
P-22	72.24	200	DCI	109	14.63	0.13	1.83	0.47
P-23	92.66	200	DCI	109	14.63	0.17	1.82	0.47
P-24	92.05	200	DCI	109	14.63	0.17	1.83	0.47
P-25	52.73	200	DCI	109	14.63	0.10	1.83	0.47
P-26	79.86	200	DCI	109	14.63	0.15	1.82	0.47
P-27	86.26	200	DCI	109	14.63	0.16	1.83	0.47
P-28	87.48	200	DCI	109	14.63	0.16	1.83	0.47
P-29	104.24	200	DCI	109	14.63	0.19	1.82	0.47
P-30	101.80	200	DCI	109	14.63	0.19	1.83	0.47
P-31	72.54	200	DCI	109	14.63	0.13	1.82	0.47
P-32	43.28	200	DCI	109	14.63	0.08	1.83	0.47
P-33	38.10	200	DCI	109	14.63	0.07	1.83	0.47
P-34	23.77	200	DCI	109	14.63	0.04	1.82	0.47
P-35	31.39	200	DCI	109	-16.01	0.07	2.16	0.51
P-36	27.13	200	DCI	109	-16.12	0.06	2.18	0.51
P-37	100.28	200	DCI	109	-17.63	0.26	2.58	0.56
P-38	94.18	200	DCI	109	-17.78	0.25	2.62	0.57
P-39	107.90	200	DCI	109	-17.96	0.29	2.67	0.57
P-40	56.39	200	DCI	109	-18.13	0.15	2.72	0.58
P-41	103.02	200	DCI	109	-20.04	0.34	3.27	0.64
P-42	91.44	200	DCI	109	-20.2	0.30	3.32	0.64
P-43	76.81	200	DCI	109	-20.36	0.26	3.37	0.65
P-44	72.54	200	DCI	109	-20.51	0.25	3.41	0.65
P-45	73.15	200	DCI	109	-20.66	0.25	3.46	0.66
P-46	45.42	200	DCI	109	-20.82	0.16	3.51	0.66
P-47	71.93	200	DCI	109	-20.97	0.26	3.56	0.67
P-48	48.16	200	DCI	109	-21.13	0.17	3.61	0.67
P-49	55.17	200	DCI	109	-21.27	0.20	3.65	0.68
P-50	85.34	200	DCI	109	-21.39	0.31	3.69	0.68
P-51	30.48	200	PVC	150	23.66	0.08	2.46	0.75
P-52	113.69	80	PVC	150	0.67	0.03	0.29	0.13
P-53	58.83	80	PVC	150	-0.59	0.01	0.23	0.12
P-54	68.88	80	PVC	150	-0.52	0.01	0.18	0.10
P-55	61.26	80	PVC	150	-0.44	0.01	0.13	0.09
P-56	91.44	80	PVC	150	-0.37	0.01	0.10	0.07
P-57	137.46	80	PVC	150	-0.31	0.01	0.07	0.06

P-58	95.71	80	PVC	150	-0.24	0	0.04	0.05
P-59	22.25	80	PVC	150	-0.19	0	0.03	0.04
P-60	54.25	80	PVC	150	-0.13	0	0.01	0.03
P-61	102.41	80	PVC	150	-0.09	0	0.01	0.02
P-62	104.24	80	PVC	120	-0.04	0	0	0.01
P-63	94.79	200	GI	120	22.91	0.33	3.51	0.73
P-64	52.73	200	GI	120	22.77	0.18	3.46	0.72
P-65	51.21	200	GI	120	22.61	0.18	3.42	0.72
P-66	70.10	200	GI	120	22.46	0.24	3.38	0.71
P-67	46.63	200	GI	120	22.29	0.16	3.33	0.71
P-68	75.90	200	GI	120	22.13	0.25	3.29	0.70
P-69	80.77	200	GI	120	21.95	0.26	3.24	0.70
P-70	70.41	200	GI	120	21.77	0.22	3.19	0.69
P-71	90.53	200	GI	120	21.6	0.28	3.15	0.69
P-72	80.47	200	GI	120	21.44	0.25	3.10	0.68
P-73	25.91	200	GI	120	21.27	0.08	3.06	0.68
P-74	52.12	150	GI	120	12.05	0.23	4.33	0.68
P-75	107.29	150	GI	120	11.88	0.45	4.22	0.67
P-76	96.01	150	GI	120	11.7	0.39	4.10	0.66
P-77	85.95	150	GI	120	11.52	0.34	3.98	0.65
P-78	18.29	200	GI	120	2.32	0	0.06	0.07
P-79	48.77	200	GI	120	2.14	0	0.04	0.07
P-80	11.58	200	GI	120	1.99	0	0.04	0.06
P-81	24.69	150	GI	120	-28.83	0.54	21.79	1.63
P-82	14.02	150	GI	120	28.66	0.30	21.55	1.62
P-83	37.80	150	GI	120	28.44	0.80	21.24	1.61
P-84	56.08	150	GI	120	28.24	1.18	20.97	1.60
P-85	28.35	150	GI	120	28.05	0.59	20.71	1.59
P-86	81.99	150	GI	120	27.85	1.68	20.44	1.58
P-87	53.34	150	GI	120	27.64	1.08	20.16	1.56
P-88	78.64	150	GI	120	27.43	1.56	19.88	1.55
P-89	35.97	150	GI	120	27.24	0.71	19.61	1.54
P-90	98.45	100	GI	120	27.05	13.74	139.55	3.44
P-91	67.67	100	GI	120	26.86	9.32	137.77	3.42
P-92	129.84	100	GI	120	25.47	16.2	124.8	3.24
P-93	39.93	100	GI	120	25.33	4.94	123.6	3.23
P-94	18.59	100	GI	120	4.22	0.08	4.47	0.54
P-95	57.61	100	GI	120	4.09	0.24	4.22	0.52

P-96	68.58	100	GI	120	3.95	0.27	3.95	0.50
P-97	105.46	100	GI	120	3.8	0.39	3.67	0.48
P-98	60.05	100	PVC	150	3.64	0.14	2.25	0.46
P-99	66.14	100	PVC	150	3.5	0.14	2.09	0.45
P-100	124.36	100	PVC	150	3.36	0.24	1.93	0.43
P-101	45.42	100	PVC	150	3.22	0.08	1.80	0.41
P-102	60.05	100	PVC	150	3.08	0.10	1.65	0.39
P-103	78.94	100	PVC	150	2.93	0.12	1.50	0.37
P-104	78.03	100	PVC	150	2.06	0.06	0.78	0.26
P-105	61.57	100	PVC	150	1.86	0.04	0.65	0.24
P-106	30.78	100	PVC	150	1.67	0.02	0.54	0.21
P-107	72.54	100	PVC	150	1.5	0.03	0.43	0.19
P-108	21.34	80	PVC	150	1.33	0.02	1.03	0.26
P-109	16.76	80	PVC	150	1.16	0.01	0.80	0.23
P-110	27.13	80	PVC	150	0.97	0.02	0.57	0.19
P-111	28.65	80	PVC	150	0.79	0.01	0.4	0.16
P-112	39.01	80	PVC	150	0.64	0.01	0.26	0.13
P-113	32.31	80	PVC	150	0.47	0	0.15	0.09
P-114	46.63	80	PVC	150	0.33	0	0.08	0.07
P-115	70.41	80	PVC	150	0.21	0	0.03	0.04
P-116	244.14	80	PVC	150	0.09	0	0.01	0.02
P-117	24.38	150	GI	120	3.52	0.01	0.44	0.20
P-118	45.72	150	GI	120	3.31	0.02	0.4	0.19
P-119	42.98	150	GI	120	3.09	0.02	0.35	0.17
P-120	59.74	150	GI	120	-2.88	0.02	0.31	0.16
P-121	102.72	150	GI	120	2.66	0.03	0.26	0.15
P-122	100.58	150	GI	120	2.45	0.02	0.23	0.14
P-123	90.22	150	GI	120	2.24	0.02	0.19	0.13
P-124	87.78	150	GI	120	2.02	0.01	0.16	0.11
P-125	101.19	100	GI	120	1.8	0.09	0.93	0.23
P-126	54.25	100	GI	120	1.58	0.04	0.73	0.20
P-127	88.39	100	GI	120	1.37	0.05	0.56	0.18
P-128	73.76	100	GI	120	1.17	0.03	0.41	0.15
P-129	73.76	100	GI	120	0.96	0.02	0.29	0.12
P-130	70.41	80	GI	120	0.75	0.04	0.54	0.15
P-131	81.38	80	GI	120	0.56	0.03	0.32	0.11
P-132	99.36	80	GI	120	0.37	0.01	0.15	0.07
P-133	102.11	80	GI	120	0.19	0	0.04	0.04

P-134	9.75	80	GI	120	1.35	0.02	1.62	0.27
P-135	57.30	80	GI	120	1.23	0.08	1.36	0.25
P-136	82.60	80	GI	120	1.12	0.09	1.14	0.22
P-137	53.34	80	GI	120	0.99	0.05	0.90	0.20
P-138	31.39	80	GI	120	0.86	0.02	0.69	0.17
P-139	16.76	80	GI	120	0.72	0.01	0.50	0.14
P-140	13.72	80	GI	120	0.57	0	0.33	0.11
P-141	44.81	80	GI	120	0.44	0.01	0.20	0.09
P-142	30.78	80	GI	120	0.31	0	0.10	0.06
P-143	28.35	80	GI	120	0.15	0	0.03	0.03
P-144	20.12	150	GI	120	9.03	0.05	2.54	0.51
P-145	15.54	150	GI	120	8.82	0.04	2.43	0.50
P-146	24.99	150	GI	120	8.63	0.06	2.33	0.49
P-147	28.04	150	GI	120	8.43	0.06	2.23	0.48
P-148	22.86	150	GI	120	8.23	0.05	2.14	0.47
P-149	60.96	150	GI	120	8.03	0.12	2.04	0.45
P-150	75.59	150	GI	120	7.83	0.15	1.95	0.44
P-151	51.21	150	GI	120	7.64	0.1	1.86	0.43
P-152	53.64	150	GI	120	7.44	0.1	1.77	0.42
P-153	62.48	150	GI	120	7.24	0.11	1.69	0.41
P-154	24.08	150	GI	120	7.05	0.04	1.60	0.40
P-155	24.08	150	GI	120	6.87	0.04	1.53	0.39
P-156	32.31	150	GI	120	6.68	0.05	1.45	0.38
P-157	25.60	150	GI	120	6.48	0.04	1.37	0.37
P-158	24.69	150	GI	120	6.29	0.03	1.30	0.36
P-159	24.99	150	GI	120	6.08	0.03	1.22	0.34
P-160	27.74	150	GI	120	5.92	0.03	1.16	0.33
P-161	33.83	150	GI	120	5.73	0.04	1.09	0.32
P-162	33.53	150	GI	120	5.53	0.03	1.03	0.31
P-163	17.68	150	GI	120	5.34	0.02	0.96	0.30
P-164	29.57	150	GI	120	5.14	0.03	0.90	0.29
P-165	7.32	150	GI	120	4.93	0.01	0.81	0.28
P-166	26.21	150	GI	120	4.71	0.02	0.76	0.27
P-167	31.09	150	GI	120	4.51	0.02	0.70	0.26
P-168	35.36	150	GI	120	4.3	0.02	0.64	0.24
P-169	59.44	100	GI	120	4.1	0.25	4.25	0.52
P-170	54.25	100	GI	120	3.9	0.21	3.86	0.50
P-171	41.15	100	GI	120	3.7	0.14	3.50	0.47

P-172	55.17	100	GI	120	3.5	0.17	3.16	0.45
P-173	30.78	100	PVC	150	3.3	0.06	1.88	0.42
P-174	71.32	100	PVC	150	3.11	0.12	1.68	0.40
P-175	34.44	100	PVC	150	2.93	0.05	1.50	0.37
P-176	36.58	100	PVC	150	2.74	0.05	1.33	0.35
P-177	52.73	100	PVC	150	2.55	0.06	1.17	0.33
P-178	25.60	100	PVC	150	2.37	0.03	1.02	0.30
P-179	54.56	100	PVC	150	2.18	0.05	0.87	0.28
P-180	70.41	100	PVC	150	1.98	0.05	0.73	0.25
P-181	27.13	100	PVC	150	1.78	0.02	0.60	0.23
P-182	38.71	80	PVC	150	3.08	0.19	4.90	0.61
P-183	62.18	80	PVC	150	2.88	0.27	4.33	0.57
P-184	50.60	80	PVC	150	2.68	0.19	3.79	0.53
P-185	43.28	80	PVC	150	2.47	0.14	3.26	0.49
P-186	59.44	80	PVC	150	2.27	0.16	2.77	0.45
P-187	127.10	80	PVC	150	2.08	0.3	2.36	0.41
P-188	28.35	80	PVC	150	1.88	0.06	1.96	0.37
P-189	26.82	80	PVC	150	1.68	0.04	1.60	0.33
P-190	45.11	80	PVC	150	1.49	0.06	1.27	0.30
P-191	94.79	80	PVC	150	1.29	0.09	0.97	0.26
P-192	53.64	80	PVC	150	1.11	0.04	0.74	0.22
P-193	62.48	80	PVC	150	0.94	0.03	0.54	0.19
P-194	52.43	80	PVC	150	0.77	0.02	0.37	0.15
P-195	59.44	80	PVC	150	0.62	0.01	0.25	0.12
P-196	16.15	80	PVC	150	0.46	0	0.15	0.09
P-197	24.08	80	PVC	150	0.33	0	0.08	0.07
P-198	85.34	80	PVC	150	0.22	0	0.04	0.04
P-199	52.43	80	PVC	150	0.11	0	0.01	0.02
P-200	13.41	150	GI	120	10.8	0.05	3.53	0.61
P-201	57.91	150	GI	120	10.62	0.2	3.43	0.60
P-202	54.86	150	GI	120	10.45	0.18	3.33	0.59
P-203	22.86	150	GI	120	10.27	0.07	3.22	0.58
P-204	82.60	150	GI	120	10.1	0.26	3.12	0.57
P-205	102.41	150	GI	120	9.92	0.31	3.02	0.56
P-206	35.66	150	GI	120	9.74	0.1	2.92	0.55
P-207	67.67	150	GI	120	9.57	0.19	2.83	0.54
P-208	31.09	150	GI	120	9.39	0.08	2.73	0.53
P-209	23.47	150	GI	120	9.22	0.06	2.64	0.52

P-210	22.25	150	GI	120	9.04	0.06	2.54	0.51
P-211	38.10	150	GI	140	8.86	0.07	1.84	0.50
P-212	58.22	150	GI	120	8.69	0.14	2.36	0.49
P-213	40.23	150	GI	120	8.51	0.09	2.27	0.48
P-214	54.25	150	GI	120	8.34	0.12	2.19	0.47
P-215	35.97	150	GI	120	8.16	0.08	2.11	0.46
P-216	28.65	150	GI	120	7.98	0.06	2.02	0.45
P-217	71.02	150	GI	120	7.81	0.14	1.94	0.44
P-218	81.38	150	GI	120	7.63	0.15	1.86	0.43
P-219	40.23	150	GI	120	7.46	0.07	1.78	0.42
P-220	67.67	150	GI	120	7.27	0.12	1.7	0.41
P-221	55.17	150	GI	120	7.08	0.09	1.62	0.40
P-222	38.10	100	GI	120	3.72	0.13	3.53	0.47
P-223	23.47	100	GI	120	3.53	0.08	3.22	0.45
P-224	45.11	100	GI	120	3.35	0.13	2.92	0.43
P-225	76.50	100	GI	120	3.18	0.2	2.64	0.40
P-226	36.58	100	GI	120	3	0.09	2.38	0.38
P-227	70.10	100	GI	120	2.8	0.15	2.10	0.36
P-228	49.38	100	GI	120	2.61	0.09	1.83	0.33
P-229	58.22	100	GI	120	2.41	0.09	1.58	0.31
P-230	94.49	100	GI	120	2.22	0.13	1.36	0.28
P-231	61.26	100	GI	120	2.03	0.07	1.16	0.26
P-232	43.59	100	GI	120	1.88	0.04	1.00	0.24
P-233	24.08	100	GI	120	1.75	0.02	0.87	0.22
P-234	26.82	100	GI	120	1.62	0.02	0.75	0.21
P-235	16.15	100	GI	120	1.49	0.01	0.65	0.19
P-236	31.09	100	PVC	150	3.18	0.05	1.75	0.4
P-237	17.68	100	PVC	150	3	0.03	1.57	0.38
P-238	49.99	100	PVC	150	2.84	0.07	1.42	0.36
P-239	39.62	100	PVC	150	2.68	0.05	1.28	0.34
P-240	52.12	100	PVC	150	2.53	0.06	1.15	0.32
P-241	64.92	100	PVC	150	2.38	0.07	1.02	0.30
P-242	31.39	100	PVC	150	2.21	0.03	0.89	0.28
P-243	42.67	100	PVC	150	2.05	0.03	0.77	0.26
P-244	52.43	100	PVC	150	1.88	0.03	0.66	0.24
P-245	51.21	100	PVC	150	1.71	0.03	0.55	0.22
P-246	52.12	100	PVC	150	1.54	0.02	0.46	0.20
P-247	33.83	100	PVC	150	1.38	0.01	0.37	0.18

P-248	47.85	100	PVC	150	1.22	0.01	0.3	0.16
P-249	52.12	100	PVC	150	1.07	0.01	0.23	0.14
P-250	21.34	100	PVC	150	0.9	0	0.17	0.11
P-251	57.61	100	PVC	150	0.75	0.01	0.12	0.10
P-252	49.07	100	PVC	150	0.59	0	0.08	0.08
P-253	64.31	100	PVC	150	0.44	0	0.05	0.06
P-254	76.20	100	PVC	150	0.29	0	0.02	0.04
P-255	47.24	100	PVC	150	0.14	0	0.01	0.02
P-256	47.85	80	GI	120	1.22	0.06	1.33	0.24
P-257	57.91	80	GI	120	1.08	0.06	1.06	0.21
P-258	68.88	80	GI	120	0.95	0.06	0.83	0.19
P-259	51.21	80	GI	120	0.83	0.03	0.65	0.16
P-260	54.56	80	GI	120	0.69	0.03	0.47	0.14
P-261	116.13	80	GI	120	0.54	0.03	0.29	0.11
P-262	97.84	80	GI	120	0.39	0.02	0.16	0.08
P-263	78.03	80	GI	120	0.25	0.01	0.07	0.05
P-264	83.21	80	GI	120	0.13	0	0.02	0.03
P-265	26.21	80	GI	120	20.99	6.78	258.66	4.18
P-266	56.39	80	GI	120	20.81	14.36	254.66	4.14
P-267	60.05	80	GI	120	20.62	15.04	250.44	4.10
P-268	41.15	80	GI	120	20.45	10.14	246.5	4.07
P-269	34.14	80	GI	120	20.28	8.29	242.82	4.04
P-270	62.48	80	GI	120	20.11	14.93	238.94	4.00
P-271	143.26	80	GI	120	19.92	33.64	234.84	3.96
P-272	82.91	80	GI	120	19.75	19.15	231.01	3.93
P-273	58.83	80	GI	120	19.57	13.37	227.21	3.89
P-274	33.22	80	GI	120	19.4	7.43	223.68	3.86
P-275	83.52	80	GI	120	19.24	18.39	220.16	3.83
P-276	107.90	80	GI	120	19.07	23.38	216.68	3.79
P-277	30.78	80	GI	120	18.91	6.56	213.22	3.76
P-278	34.14	80	GI	120	2.29	0.15	4.27	0.46
P-279	71.32	80	GI	120	2.13	0.27	3.75	0.42
P-280	68.88	80	GI	120	1.97	0.22	3.23	0.39
P-281	31.70	80	GI	120	1.79	0.09	2.71	0.36
P-282	31.39	80	GI	120	1.63	0.07	2.28	0.32
P-283	42.06	80	GI	120	1.46	0.08	1.86	0.29
P-284	87.78	80	GI	120	1.3	0.13	1.49	0.26
P-285	99.97	80	PVC	150	1.13	0.08	0.77	0.23

P-286	109.42	80	PVC	150	0.97	0.06	0.57	0.19
P-287	99.36	80	PVC	150	0.8	0.04	0.41	0.16
P-288	88.70	80	PVC	150	0.64	0.02	0.27	0.13
P-289	62.79	80	PVC	150	0.47	0.01	0.15	0.09
P-290	66.14	80	PVC	150	0.31	0	0.07	0.06
P-291	106.68	80	PVC	150	0.15	0	0.02	0.03
P-292	50.29	80	PVC	150	16.47	5.49	109.18	3.28
P-293	71.02	80	PVC	150	16.31	7.62	107.29	3.25
P-294	61.87	80	PVC	150	0.91	0.03	0.51	0.18
P-295	39.32	80	PVC	150	0.76	0.01	0.37	0.15
P-296	52.43	80	PVC	150	0.62	0.01	0.25	0.12
P-297	34.44	80	PVC	150	0.48	0.01	0.16	0.10
P-298	44.20	80	PVC	150	0.35	0	0.09	0.07
P-299	58.22	80	PVC	150	0.23	0	0.04	0.05
P-300	50.29	80	PVC	150	0.11	0	0.01	0.02
P-301	18.29	80	PVC	150	-1.23	0.02	0.90	0.25
P-302	114.60	80	PVC	150	1.18	0.09	0.82	0.23
P-303	39.32	80	PVC	150	1.13	0.03	0.76	0.22
P-304	47.85	80	PVC	150	1.08	0.03	0.70	0.21
P-305	82.91	80	PVC	150	1.02	0.05	0.64	0.20
P-306	67.67	80	PVC	150	0.97	0.04	0.57	0.19
P-307	97.54	80	PVC	150	0.91	0.05	0.51	0.18
P-308	65.23	80	PVC	150	0.85	0.03	0.45	0.17
P-309	27.74	80	PVC	150	0.8	0.01	0.4	0.16
P-310	35.66	75	GI	120	0.74	0.03	0.73	0.17
P-311	38.10	75	GI	120	0.69	0.02	0.64	0.16
P-312	20.12	80	PVC	150	-0.39	0	0.10	0.08
P-313	28.04	80	PVC	150	0.36	0	0.09	0.07
P-314	50.29	80	PVC	150	0.32	0	0.07	0.06
P-315	32.92	80	PVC	150	0.3	0	0.07	0.06
P-316	41.76	80	PVC	150	0.27	0	0.05	0.05
P-317	77.11	80	PVC	150	0.24	0	0.04	0.05
P-318	78.03	80	PVC	150	0.21	0	0.03	0.04
P-319	45.72	80	PVC	150	0.18	0	0.03	0.04
P-320	19.81	80	PVC	150	0.25	0	0.05	0.05
P-321	82.91	80	PVC	150	0.2	0	0.03	0.04
P-322	86.56	80	PVC	150	0.15	0	0.02	0.03
P-323	112.47	80	PVC	150	0.11	0	0.01	0.02

P-324	57.00	80	PVC	150	0.07	0	0	0.01
P-325	93.88	80	PVC	150	0.03	0	0	0.01
P-326	26.82	80	PVC	150	0.41	0	0.11	0.08
P-327	29.87	80	PVC	150	0.34	0	0.08	0.07
P-328	24.08	80	PVC	150	0.28	0	0.06	0.05
P-329	67.67	80	PVC	150	0.21	0	0.03	0.04
P-330	43.89	80	PVC	150	0.14	0	0.02	0.03
P-331	56.08	80	PVC	150	0.09	0	0.01	0.02
P-332	57.00	80	PVC	150	0.06	0	0	0.01
P-333	85.95	80	PVC	150	0.02	0	0	0
P-334	93.27	80	PVC	150	0.7	0.03	0.32	0.14
P-335	83.82	80	PVC	150	0.57	0.02	0.22	0.11
P-336	87.78	80	PVC	150	0.45	0.01	0.14	0.09
P-337	82.91	80	PVC	150	0.33	0.01	0.08	0.07
P-338	75.29	80	PVC	150	0.22	0	0.04	0.04
P-339	91.44	80	PVC	150	0.11	0	0.01	0.02
P-340	14.33	150	GI	120	30.53	0.35	24.23	1.73
P-341	15.85	150	GI	120	1.73	0	0.12	0.10

Appendix K

Pipe result; during low demand time/night flow

Label	Length (m)	Diameter (mm)	Material	Hazen-Williams C	Discharge (l/s)	Pressure Pipe Head loss (m)	Head loss Gradient (m/km)	Velocity (m/s)
P-1	18.90	200	DCI	109	16.72	0.04	2.34	0.53
P-2	32.00	200	DCI	109	16.72	0.07	2.34	0.53
P-3	42.67	200	DCI	109	16.7	0.10	2.33	0.53
P-4	54.25	200	DCI	109	16.67	0.13	2.33	0.53
P-5	40.84	200	DCI	109	16.64	0.09	2.32	0.53
P-6	68.28	200	DCI	109	14.67	0.13	1.84	0.47
P-7	45.72	200	DCI	109	14.67	0.08	1.84	0.47
P-8	47.55	200	DCI	109	14.67	0.09	1.84	0.47
P-9	15.54	200	DCI	109	14.63	0.03	1.83	0.47
P-10	50.60	200	DCI	109	14.63	0.09	1.82	0.47

P-11	102.11	200	DCI	109	14.63	0.19	1.82	0.47
P-12	95.40	200	DCI	109	14.63	0.17	1.83	0.47
P-13	66.14	200	DCI	109	14.63	0.12	1.82	0.47
P-14	60.05	200	DCI	109	14.63	0.11	1.82	0.47
P-15	66.75	200	DCI	109	14.63	0.12	1.83	0.47
P-16	59.74	200	DCI	109	14.63	0.11	1.83	0.47
P-17	46.94	200	DCI	109	14.63	0.09	1.83	0.47
P-18	88.39	200	DCI	109	14.63	0.16	1.83	0.47
P-19	98.15	200	DCI	109	14.63	0.18	1.82	0.47
P-20	74.98	200	DCI	109	14.63	0.14	1.83	0.47
P-21	76.81	200	DCI	109	14.63	0.14	1.83	0.47
P-22	72.24	200	DCI	109	14.63	0.13	1.83	0.47
P-23	92.66	200	DCI	109	14.63	0.17	1.83	0.47
P-24	92.05	200	DCI	109	14.63	0.17	1.83	0.47
P-25	52.73	200	DCI	109	14.63	0.10	1.83	0.47
P-26	79.86	200	DCI	109	14.63	0.15	1.82	0.47
P-27	86.26	200	DCI	109	14.63	0.16	1.83	0.47
P-28	87.48	200	DCI	109	14.63	0.16	1.83	0.47
P-29	104.24	200	DCI	109	14.63	0.19	1.82	0.47
P-30	101.80	200	DCI	109	14.63	0.19	1.83	0.47
P-31	72.54	200	DCI	109	14.63	0.13	1.83	0.47
P-32	43.28	200	DCI	109	14.63	0.08	1.83	0.47
P-33	38.10	200	DCI	109	14.63	0.07	1.82	0.47
P-34	23.77	200	DCI	109	14.63	0.04	1.83	0.47
P-35	31.39	200	DCI	109	-16.01	0.07	2.16	0.51
P-36	27.13	200	DCI	109	-16.12	0.06	2.18	0.51
P-37	100.28	200	DCI	109	-17.62	0.26	2.58	0.56
P-38	94.18	200	DCI	109	-17.78	0.25	2.62	0.57
P-39	107.90	200	DCI	109	-17.95	0.29	2.67	0.57
P-40	56.39	200	DCI	109	-18.13	0.15	2.72	0.58
P-41	103.02	200	DCI	109	-20.09	0.34	3.29	0.64
P-42	91.44	200	DCI	109	-20.25	0.30	3.33	0.64
P-43	76.81	200	DCI	109	-20.41	0.26	3.38	0.65
P-44	72.54	200	DCI	109	-20.56	0.25	3.43	0.65
P-45	73.15	200	DCI	109	-20.72	0.25	3.48	0.66
P-46	45.42	200	DCI	109	-20.87	0.16	3.53	0.66
P-47	71.93	200	DCI	109	-21.02	0.26	3.57	0.67
P-48	48.16	200	DCI	109	-21.18	0.17	3.62	0.67

P-49	55.17	200	DCI	109	-21.32	0.20	3.67	0.68
P-50	85.34	200	DCI	109	-21.44	0.32	3.71	0.68
P-51	30.48	200	PVC	150	23.60	0.10	3.20	0.75
P-52	113.69	80	PVC	150	0.67	0.03	0.29	0.13
P-53	58.83	80	PVC	150	-0.59	0.01	0.23	0.12
P-54	68.88	80	PVC	150	-0.52	0.01	0.18	0.10
P-55	61.26	80	PVC	150	-0.44	0.01	0.13	0.09
P-56	91.44	80	PVC	150	-0.37	0.01	0.10	0.07
P-57	137.46	80	PVC	150	-0.31	0.01	0.07	0.06
P-58	95.71	80	PVC	150	-0.24	0	0.04	0.05
P-59	22.25	80	PVC	150	-0.19	0	0.03	0.04
P-60	54.25	80	PVC	150	-0.13	0	0.02	0.03
P-61	102.41	80	PVC	150	-0.09	0	0.01	0.02
P-62	104.24	80	GI	120	-0.04	0	0	0.01
P-63	94.79	200	GI	120	22.86	0.33	3.49	0.73
P-64	52.73	200	GI	120	22.71	0.18	3.45	0.72
P-65	51.21	200	GI	120	22.56	0.17	3.41	0.72
P-66	70.10	200	GI	120	22.41	0.24	3.36	0.71
P-67	46.63	200	GI	120	22.24	0.15	3.32	0.71
P-68	75.90	200	GI	120	22.08	0.25	3.27	0.70
P-69	80.77	200	GI	120	21.90	0.26	3.23	0.70
P-70	70.41	200	GI	120	21.71	0.22	3.17	0.69
P-71	90.53	200	GI	120	21.55	0.28	3.13	0.69
P-72	80.47	200	GI	120	21.38	0.25	3.09	0.68
P-73	25.91	200	GI	120	21.22	0.08	3.04	0.68
P-74	52.12	150	GI	120	12.05	0.23	4.33	0.68
P-75	107.29	150	GI	120	11.88	0.45	4.22	0.67
P-76	96.01	150	GI	120	11.7	0.39	4.1	0.66
P-77	85.95	150	GI	120	11.52	0.34	3.98	0.65
P-78	18.29	200	GI	120	2.32	0	0.05	0.07
P-79	48.77	200	GI	120	2.14	0	0.05	0.07
P-80	11.58	200	GI	120	1.99	0	0.04	0.06
P-81	24.69	150	GI	120	-28.83	0.54	21.79	1.63
P-82	14.02	150	GI	120	28.66	0.30	21.55	1.62
P-83	37.80	150	GI	120	28.44	0.80	21.24	1.61
P-84	56.08	150	GI	120	28.24	1.18	20.97	1.60
P-85	28.35	150	GI	120	28.05	0.59	20.71	1.59
P-86	81.99	150	GI	120	27.85	1.68	20.44	1.58

P-87	53.34	150	GI	120	27.64	1.08	20.16	1.56
P-88	78.64	150	GI	120	27.43	1.56	19.88	1.55
P-89	35.97	150	GI	120	27.24	0.71	19.61	1.54
P-90	98.45	100	GI	120	27.05	13.74	139.55	3.44
P-91	67.67	100	GI	120	26.86	9.32	137.77	3.42
P-92	129.84	100	GI	120	25.47	16.20	124.8	3.24
P-93	39.93	100	GI	120	25.33	4.94	123.6	3.23
P-94	18.59	100	GI	120	4.22	0.08	4.48	0.54
P-95	57.61	100	GI	120	4.09	0.24	4.22	0.52
P-96	68.58	100	GI	120	3.95	0.27	3.95	0.50
P-97	105.46	100	GI	120	3.8	0.39	3.67	0.48
P-98	60.05	100	PVC	150	3.64	0.14	2.25	0.46
P-99	66.14	100	PVC	150	3.5	0.14	2.09	0.45
P-100	124.36	100	PVC	150	3.36	0.24	1.93	0.43
P-101	45.42	100	PVC	150	3.22	0.08	1.8	0.41
P-102	60.05	100	PVC	150	3.08	0.10	1.65	0.39
P-103	78.94	100	PVC	150	2.93	0.12	1.5	0.37
P-104	78.03	100	PVC	150	2.06	0.06	0.78	0.26
P-105	61.57	100	PVC	150	1.86	0.04	0.65	0.24
P-106	30.78	100	PVC	150	1.67	0.02	0.53	0.21
P-107	72.54	100	PVC	150	1.50	0.03	0.43	0.19
P-108	21.34	80	PVC	150	1.33	0.02	1.03	0.26
P-109	16.76	80	PVC	150	1.16	0.01	0.8	0.23
P-110	27.13	80	PVC	150	0.97	0.02	0.57	0.19
P-111	28.65	80	PVC	150	0.79	0.01	0.39	0.16
P-112	39.01	80	PVC	150	0.64	0.01	0.27	0.13
P-113	32.31	80	PVC	150	0.47	0	0.15	0.09
P-114	46.63	80	PVC	150	0.33	0	0.08	0.07
P-115	70.41	80	PVC	150	0.21	0	0.03	0.04
P-116	244.14	80	PVC	150	0.09	0	0.01	0.02
P-117	24.38	150	GI	120	3.52	0.01	0.44	0.20
P-118	45.72	150	GI	120	3.31	0.02	0.4	0.19
P-119	42.98	150	GI	120	3.09	0.01	0.35	0.17
P-120	59.74	150	GI	120	-2.88	0.02	0.31	0.16
P-121	102.72	150	GI	120	2.66	0.03	0.27	0.15
P-122	100.58	150	GI	120	2.45	0.02	0.23	0.14
P-123	90.22	150	GI	120	2.24	0.02	0.19	0.13
P-124	87.78	150	GI	120	2.02	0.01	0.16	0.11

P-125	101.19	100	GI	120	1.80	0.09	0.93	0.23
P-126	54.25	100	GI	120	1.58	0.04	0.73	0.20
P-127	88.39	100	GI	120	1.37	0.05	0.56	0.18
P-128	73.76	100	GI	120	1.17	0.03	0.41	0.15
P-129	73.76	100	GI	120	0.96	0.02	0.29	0.12
P-130	70.41	80	GI	120	0.75	0.04	0.54	0.15
P-131	81.38	80	GI	120	0.56	0.03	0.31	0.11
P-132	99.36	80	GI	120	0.37	0.01	0.15	0.07
P-133	102.11	80	GI	120	0.19	0	0.04	0.04
P-134	9.75	80	GI	120	1.35	0.02	1.60	0.27
P-135	57.30	80	GI	120	1.23	0.08	1.36	0.25
P-136	82.60	80	GI	120	1.12	0.09	1.14	0.22
P-137	53.34	80	GI	120	0.99	0.05	0.90	0.20
P-138	31.39	80	GI	120	0.86	0.02	0.70	0.17
P-139	16.76	80	GI	120	0.72	0.01	0.49	0.14
P-140	13.72	80	GI	120	0.57	0	0.34	0.11
P-141	44.81	80	GI	120	0.44	0.01	0.2	0.09
P-142	30.78	80	GI	120	0.31	0	0.11	0.06
P-143	28.35	80	GI	120	0.15	0	0.03	0.03
P-144	20.12	150	GI	120	9.03	0.05	2.54	0.51
P-145	15.54	150	GI	120	8.82	0.04	2.43	0.50
P-146	24.99	150	GI	120	8.63	0.06	2.33	0.49
P-147	28.04	150	GI	120	8.43	0.06	2.23	0.48
P-148	22.86	150	GI	120	8.23	0.05	2.14	0.47
P-149	60.96	150	GI	120	8.03	0.12	2.04	0.45
P-150	75.59	150	GI	120	7.83	0.15	1.95	0.44
P-151	51.21	150	GI	120	7.64	0.10	1.86	0.43
P-152	53.64	150	GI	120	7.44	0.09	1.77	0.42
P-153	62.48	150	GI	120	7.24	0.11	1.69	0.41
P-154	24.08	150	GI	120	7.05	0.04	1.61	0.40
P-155	24.08	150	GI	120	6.87	0.04	1.53	0.39
P-156	32.31	150	GI	120	6.68	0.05	1.46	0.38
P-157	25.60	150	GI	120	6.48	0.04	1.37	0.37
P-158	24.69	150	GI	120	6.29	0.03	1.30	0.36
P-159	24.99	150	GI	120	6.08	0.03	1.22	0.34
P-160	27.74	150	GI	120	5.92	0.03	1.16	0.33
P-161	33.83	150	GI	120	5.73	0.04	1.10	0.32
P-162	33.53	150	GI	120	5.53	0.03	1.03	0.31

P-163	17.68	150	GI	120	5.34	0.02	0.96	0.30
P-164	29.57	150	GI	120	5.14	0.03	0.90	0.29
P-165	7.32	150	GI	120	4.93	0.01	0.81	0.28
P-166	26.21	150	GI	120	4.71	0.02	0.76	0.27
P-167	31.09	150	GI	120	4.51	0.02	0.70	0.26
P-168	35.36	150	GI	120	4.30	0.02	0.64	0.24
P-169	59.44	100	GI	120	4.10	0.25	4.25	0.52
P-170	54.25	100	GI	120	3.90	0.21	3.86	0.50
P-171	41.15	100	GI	120	3.70	0.14	3.50	0.47
P-172	55.17	100	GI	120	3.50	0.17	3.16	0.45
P-173	30.78	100	PVC	150	3.30	0.06	1.88	0.42
P-174	71.32	100	PVC	150	3.11	0.12	1.68	0.40
P-175	34.44	100	PVC	150	2.93	0.05	1.50	0.37
P-176	36.58	100	PVC	150	2.74	0.05	1.33	0.35
P-177	52.73	100	PVC	150	2.55	0.06	1.17	0.33
P-178	25.60	100	PVC	150	2.37	0.03	1.02	0.30
P-179	54.56	100	PVC	150	2.18	0.05	0.87	0.28
P-180	70.41	100	PVC	150	1.98	0.05	0.73	0.25
P-181	27.13	100	PVC	150	1.78	0.02	0.6	0.23
P-182	38.71	80	PVC	150	3.08	0.19	4.9	0.61
P-183	62.18	80	PVC	150	2.88	0.27	4.33	0.57
P-184	50.60	80	PVC	150	2.68	0.19	3.79	0.53
P-185	43.28	80	PVC	150	2.47	0.14	3.26	0.49
P-186	59.44	80	PVC	150	2.27	0.16	2.77	0.45
P-187	127.10	80	PVC	150	2.08	0.30	2.36	0.41
P-188	28.35	80	PVC	150	1.88	0.06	1.96	0.37
P-189	26.82	80	PVC	150	1.68	0.04	1.6	0.33
P-190	45.11	80	PVC	150	1.49	0.06	1.27	0.30
P-191	94.79	80	PVC	150	1.29	0.09	0.97	0.26
P-192	53.64	80	PVC	150	1.11	0.04	0.74	0.22
P-193	62.48	80	PVC	150	0.94	0.03	0.54	0.19
P-194	52.43	80	PVC	150	0.77	0.02	0.37	0.15
P-195	59.44	80	PVC	150	0.62	0.01	0.25	0.12
P-196	16.15	80	PVC	150	0.46	0	0.14	0.09
P-197	24.08	80	PVC	150	0.33	0	0.08	0.07
P-198	85.34	80	PVC	150	0.22	0	0.04	0.04
P-199	52.43	80	PVC	150	0.11	0	0.01	0.02
P-200	13.41	150	GI	120	10.80	0.05	3.54	0.61

P-201	57.91	150	GI	120	10.62	0.20	3.43	0.60
P-202	54.86	150	GI	120	10.45	0.18	3.33	0.59
P-203	22.86	150	GI	120	10.27	0.07	3.22	0.58
P-204	82.60	150	GI	120	10.10	0.26	3.12	0.57
P-205	102.41	150	GI	120	9.92	0.31	3.02	0.56
P-206	35.66	150	GI	120	9.74	0.10	2.93	0.55
P-207	67.67	150	GI	120	9.57	0.19	2.82	0.54
P-208	31.09	150	GI	120	9.39	0.08	2.73	0.53
P-209	23.47	150	GI	120	9.22	0.06	2.64	0.52
P-210	22.25	150	GI	120	9.04	0.06	2.54	0.51
P-211	38.10	150	GI	140	8.86	0.07	1.84	0.5
P-212	58.22	150	GI	120	8.69	0.14	2.36	0.49
P-213	40.23	150	GI	120	8.51	0.09	2.28	0.48
P-214	54.25	150	GI	120	8.34	0.12	2.19	0.47
P-215	35.97	150	GI	120	8.16	0.08	2.1	0.46
P-216	28.65	150	GI	120	7.98	0.06	2.02	0.45
P-217	71.02	150	GI	120	7.81	0.14	1.94	0.44
P-218	81.38	150	GI	120	7.63	0.15	1.86	0.43
P-219	40.23	150	GI	120	7.46	0.07	1.78	0.42
P-220	67.67	150	GI	120	7.27	0.11	1.70	0.41
P-221	55.17	150	GI	120	7.08	0.09	1.62	0.40
P-222	38.10	100	GI	120	3.72	0.13	3.54	0.47
P-223	23.47	100	GI	120	3.53	0.08	3.21	0.45
P-224	45.11	100	GI	120	3.35	0.13	2.92	0.43
P-225	76.50	100	GI	120	3.18	0.20	2.64	0.40
P-226	36.58	100	GI	120	3.00	0.09	2.38	0.38
P-227	70.10	100	GI	120	2.8	0.15	2.1	0.36
P-228	49.38	100	GI	120	2.61	0.09	1.83	0.33
P-229	58.22	100	GI	120	2.41	0.09	1.58	0.31
P-230	94.49	100	GI	120	2.22	0.13	1.36	0.28
P-231	61.26	100	GI	120	2.03	0.07	1.16	0.26
P-232	43.59	100	GI	120	1.88	0.04	1.00	0.24
P-233	24.08	100	GI	120	1.75	0.02	0.87	0.22
P-234	26.82	100	GI	120	1.62	0.02	0.75	0.21
P-235	16.15	100	GI	120	1.49	0.01	0.65	0.19
P-236	31.09	100	PVC	150	3.18	0.05	1.75	0.40
P-237	17.68	100	PVC	150	3.00	0.03	1.57	0.38
P-238	49.99	100	PVC	150	2.84	0.07	1.42	0.36

P-239	39.62	100	PVC	150	2.68	0.05	1.28	0.34
P-240	52.12	100	PVC	150	2.53	0.06	1.15	0.32
P-241	64.92	100	PVC	150	2.38	0.07	1.02	0.30
P-242	31.39	100	PVC	150	2.21	0.03	0.89	0.28
P-243	42.67	100	PVC	150	2.05	0.03	0.77	0.26
P-244	52.43	100	PVC	150	1.88	0.03	0.66	0.24
P-245	51.21	100	PVC	150	1.71	0.03	0.55	0.22
P-246	52.12	100	PVC	150	1.54	0.02	0.46	0.20
P-247	33.83	100	PVC	150	1.38	0.01	0.37	0.18
P-248	47.85	100	PVC	150	1.22	0.01	0.30	0.16
P-249	52.12	100	PVC	150	1.07	0.01	0.23	0.14
P-250	21.34	100	PVC	150	0.90	0	0.17	0.11
P-251	57.61	100	PVC	150	0.75	0.01	0.12	0.10
P-252	49.07	100	PVC	150	0.59	0	0.08	0.08
P-253	64.31	100	PVC	150	0.44	0	0.04	0.06
P-254	76.20	100	PVC	150	0.29	0	0.02	0.04
P-255	47.24	100	PVC	150	0.14	0	0.01	0.02
P-256	47.85	80	GI	120	1.22	0.06	1.33	0.24
P-257	57.91	80	GI	120	1.08	0.06	1.06	0.21
P-258	68.88	80	GI	120	0.95	0.06	0.83	0.19
P-259	51.21	80	GI	120	0.83	0.03	0.65	0.16
P-260	54.56	80	GI	120	0.69	0.03	0.47	0.14
P-261	116.13	80	GI	120	0.54	0.03	0.29	0.11
P-262	97.84	80	GI	120	0.39	0.02	0.16	0.08
P-263	78.03	80	GI	120	0.25	0.01	0.07	0.05
P-264	83.21	80	GI	120	0.13	0	0.02	0.03
P-265	26.21	80	GI	120	20.99	6.78	258.66	4.18
P-266	56.39	80	GI	120	20.81	14.36	254.66	4.14
P-267	60.05	80	GI	120	20.62	15.04	250.44	4.1
P-268	41.15	80	GI	120	20.45	10.14	246.49	4.07
P-269	34.14	80	GI	120	20.28	8.29	242.82	4.04
P-270	62.48	80	GI	120	20.11	14.93	238.93	4.00
P-271	143.26	80	GI	120	19.92	33.64	234.84	3.96
P-272	82.91	80	GI	120	19.75	19.15	231.01	3.93
P-273	58.83	80	GI	120	19.57	13.37	227.21	3.89
P-274	33.22	80	GI	120	19.40	7.43	223.67	3.86
P-275	83.52	80	GI	120	19.24	18.39	220.16	3.83
P-276	107.90	80	GI	120	19.07	23.38	216.68	3.79

P-277	30.78	80	GI	120	18.91	6.56	213.22	3.76
P-278	34.14	80	GI	120	2.29	0.15	4.27	0.46
P-279	71.32	80	GI	120	2.13	0.27	3.75	0.42
P-280	68.88	80	GI	120	1.97	0.22	3.23	0.39
P-281	31.70	80	GI	120	1.79	0.09	2.72	0.36
P-282	31.39	80	GI	120	1.63	0.07	2.27	0.32
P-283	42.06	80	GI	120	1.46	0.08	1.86	0.29
P-284	87.78	80	GI	120	1.30	0.13	1.49	0.26
P-285	99.97	80	PVC	150	1.13	0.08	0.77	0.23
P-286	109.42	80	PVC	150	0.97	0.06	0.57	0.19
P-287	99.36	80	PVC	150	0.80	0.04	0.41	0.16
P-288	88.70	80	PVC	150	0.64	0.02	0.27	0.13
P-289	62.79	80	PVC	150	0.47	0.01	0.15	0.09
P-290	66.14	80	PVC	150	0.31	0	0.07	0.06
P-291	106.68	80	PVC	150	0.15	0	0.02	0.03
P-292	50.29	80	PVC	150	16.47	5.49	109.18	3.28
P-293	71.02	80	PVC	150	16.31	7.62	107.29	3.25
P-294	61.87	80	PVC	150	0.91	0.03	0.51	0.18
P-295	39.32	80	PVC	150	0.76	0.01	0.36	0.15
P-296	52.43	80	PVC	150	0.62	0.01	0.25	0.12
P-297	34.44	80	PVC	150	0.48	0.01	0.16	0.10
P-298	44.20	80	PVC	150	0.35	0	0.09	0.07
P-299	58.22	80	PVC	150	0.23	0	0.04	0.05
P-300	50.29	80	PVC	150	0.11	0	0.01	0.02
P-301	18.29	80	PVC	150	-1.94	0.04	2.08	0.39
P-302	114.60	80	PVC	150	1.85	0.22	1.90	0.37
P-303	39.32	80	PVC	150	1.77	0.07	1.76	0.35
P-304	47.85	80	PVC	150	1.69	0.08	1.62	0.34
P-305	82.91	80	PVC	150	1.61	0.12	1.46	0.32
P-306	67.67	80	PVC	150	1.52	0.09	1.32	0.30
P-307	97.54	80	PVC	150	1.43	0.12	1.18	0.28
P-308	65.23	80	PVC	150	1.34	0.07	1.05	0.27
P-309	27.74	80	PVC	150	1.25	0.03	0.92	0.25
P-310	35.66	75	GI	120	1.17	0.06	1.68	0.26
P-311	38.10	75	GI	120	1.09	0.06	1.48	0.25
P-312	20.12	80	PVC	150	-0.61	0	0.24	0.12
P-313	28.04	80	PVC	150	0.56	0.01	0.21	0.11
P-314	50.29	80	PVC	150	0.51	0.01	0.17	0.10

P-315	32.92	80	PVC	150	0.47	0	0.15	0.09
P-316	41.76	80	PVC	150	0.43	0.01	0.13	0.09
P-317	77.11	80	PVC	150	0.37	0.01	0.10	0.07
P-318	78.03	80	PVC	150	0.33	0.01	0.08	0.07
P-319	45.72	80	PVC	150	0.29	0	0.06	0.06
P-320	19.81	80	PVC	150	0.25	0	0.05	0.05
P-321	82.91	80	PVC	150	0.20	0	0.03	0.04
P-322	86.56	80	PVC	150	0.15	0	0.02	0.03
P-323	112.47	80	PVC	150	0.11	0	0.01	0.02
P-324	57.00	80	PVC	150	0.07	0	0	0.01
P-325	93.88	80	PVC	150	0.03	0	0	0.01
P-326	26.82	80	PVC	150	0.41	0	0.11	0.08
P-327	29.87	80	PVC	150	0.34	0	0.08	0.07
P-328	24.08	80	PVC	150	0.28	0	0.06	0.05
P-329	67.67	80	PVC	150	0.21	0	0.03	0.04
P-330	43.89	80	PVC	150	0.14	0	0.02	0.03
P-331	56.08	80	PVC	150	0.09	0	0.01	0.02
P-332	57.00	80	PVC	150	0.06	0	0	0.01
P-333	85.95	80	PVC	150	0.02	0	0	0
P-334	93.27	80	PVC	150	0.70	0.03	0.32	0.14
P-335	83.82	80	PVC	150	0.57	0.02	0.22	0.11
P-336	87.78	80	PVC	150	0.45	0.01	0.14	0.09
P-337	82.91	80	PVC	150	0.33	0.01	0.08	0.07
P-338	75.29	80	PVC	150	0.22	0	0.04	0.04
P-339	91.44	80	PVC	150	0.11	0	0.01	0.02
P-340	14.33	150	GI	120	30.53	0.35	24.23	1.73
P-341	15.85	150	GI	120	1.78	0	0.12	0.10