

Hydraulic Modeling and Improvement of Addis Ababa Water Supply System (The Case of Bole Bulbula)

**Saleamlak Muluken Fitaye
June, 2015**



ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING
HYDRAULIC MODELING AND IMPROVEMENT OF ADDIS ABABA
WATER SUPPLY SYSTEM

(The Case of Bole Bulbula)

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

(Major in Hydraulic Engineering)

By: Saleamlak Muluken
Advisor: Geremew Sahilu (Dr.Eng)

June 2015
Addis Ababa, Ethiopia



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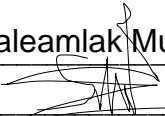
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Chairman (department of graduate committee)	Signature
	
	
	June, 2015 Addis Ababa, Ethiopia

Declaration

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

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ABSTRACT

In this study, Addis Ababa Water distribution system for case study of Bole Bulbula supply system was assessed. The main objective of this study is to improve the Bole Bulbula water supply distribution system and control its operation, Water CAD software was used as tool to model water distribution system analysis. The modeling effort included both hydraulic and water quality modeling. Simulation results for maximum and minimum pressures were used as base tool to evaluate the hydraulic performance; and simulation result for water age and minimum residual chlorine were used as base to assess water quality transformation in distribution systems. Modeling results showed violation of maximum and minimum pressure requirements. Along with this, water quality simulation results illustrated water quality deterioration due to availability of minimum residual chlorine which is below WHO guideline.

The model analysis result shows the different problems of the system. These are aged pipes, oversized and undersized pipes, low and high pressures and water quality status. The system should be modified using the design criteria of velocity, pressure and residual chlorine. High pressures in the existing system caused by customers at too low demand have to be identified and solution is established using pressure-reducing valves. To retrieve the situation there is a need to intervene. Modification in operation and design will improve the current situation of the case study water distribution system.

Key Words: Water distribution system, modeling, Hydraulic performance, Water quality, Maximum pressure, Minimum pressure, Water age, Residual chlorine, Bole Bulbula, Addis Ababa.

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Abbreviations and Acronyms

AAWSA	Addis Ababa Water and Sewerage Authority
BBR1	Bole Bulbula Reservoir 1
CSA	Central Statistical Agency
C	Hazen-Williams coefficient
CT	Collection Tank
DEM	Digital Elevation Model
DCI	Ductile cast iron
DN	Nominal diameter of pipe
Fig.	Figure
GW3	Ground water 3
GW1	Ground water 1
GW2	Ground water 2
GC	Gregorian Calendar
GIS	Geographical Information System
GS	Galvanized Steel
HDPE	High Density Polyethylene
HL	Head Loss
HGL	Hydraulic Gradient Line
Km	Kilo Meter
m	Meter
m ³ /s	meter cubic per second
L	Length
l/s	liter per second
NGO	Non Governmental Organization
UFW	Unaccounted for water
PVC	Polyvinyl chloride pipe
PRV	Pressure Reducer Valve
R-1	Reservoir 1
WHO	World Health Organization

1. INTRODUCTION

1.1 Background

The Addis Ababa Water and Sewerage Authority is a public institution in the city, which is responsible for the supply of potable water. The Authority currently has eight branch offices and head office at Megenagna. The branch offices are Gurd Shola, Megenagna, Arada, Gulele, Addis Ketema, Nifas Silk, Mekanisa, and Akaki branch office.

Bole Bulbula water supply distribution and billing system is managed, operated and controlled by AAWSA, megenagna branch office. Water supply Source for the study area is from Akaki well fields to the storage tank GW3. From the GW3 reservoir water delivered to the Bole Bulbula tank and distribution main line by gravity system. Current population in the study area from (CSA, 2007) is male 10792 and female 10831 total 21623. The projected Population for 2014 year is male 12525 and female 12688 total numbers 25213. Out of these number of population, total customers are 4109, 3681 domestic, 413 non domestic and 15 public tap or standpipe have their own service line connection from AAWSA, megenagna branch office.

Water distribution systems are designed to adequately satisfy the water requirements for a combination of domestic, commercial, industrial, and fire fighting purposes. The system should be capable of meeting the demands placed on it at all times and at satisfactory hydraulic performance. It should enable reliable operation during irregular situations and perform adequately under varying demand loads (TAHAL, 2015).

Many water supply distribution systems in most AAWSA's branch office suffer from the deficiency of water supply quantities and sharp deficiency in the pressure, so that to achieve the consumer demand at satisfactory levels, it must improve and increase the efficiencies of the water distribution operating and management systems. The continuous and repeated deficiency in the performance of present and future water supply networks became one of the most critical issues in the water supply sector that requires immediate action. As the demand on water increases due to the population growth rate, and the increase in per capita consumption, the defect in the performance of the water network led to the negative influence in most of the socio economic sectors. This occurs because of the aged pipe system especially in the old parts of the Addis Ababa city.

The water shortage and the conditions of topographic in most of AAWSA's branch offices forces to divide the water distribution networks in the serving area into several pressure zones through which water is pumped alternatively. This procedure of operating was not considered in the design assumptions, and means that every zone, and so that the network will be under the action of intermittent pumping.

Pipe network system in Addis Ababa city is approaching a century. Population is growing rapidly with expansion of the city. Due to burden on the water distribution system now it is facing many problems. Analyses of pipe systems using models are a recent approach to evaluate the performance of water distribution network.

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

This study is to investigate the state of the existing water distribution systems of Bole Bulbula water supply network system and to evaluate the hydraulic performance of the supply network under varying conditions of supply.

1.2 Statement of the Problem

Currently Addis Ababa faces a serious deficit in the water supply due to increased population and expanded economic activities in and around the subsystems. There are some areas in the existing distribution system with static heads in excess of 140m, which is 60 m over and above the maximum permissible static head (according to the accepted design criteria in the 1994 Review Report, TAHAL, 2015). These high static heads cannot at present be controlled, partly due to the loop system and partly due to the poor condition of the pressure reducing valves. There are also areas where pressure reducing valves or break pressure tanks/reservoirs is not installed.

Even though water production is improved in the last few years still there is high water shortage. There are instants in which water shortage is accelerated by undesirable pressure within distribution systems. There are also high amount of leakage and pipe failure (due to unmaintained maximum pressure) as well as provision of insufficient supply (due to unmaintained minimum pressure) are situations which propagate water shortage within distribution system.

Most of existing Bole Bulbula subsystem network layout is not properly laid, that is obstacles for maintenance, transfer and replacement of old pipes and broken pipe if it is needed. All water supply network pipe line was installed before existing road access and residential building is constructed just only using the Addis Ababa GIS master plan. Currently, water distribution lines are found under drainage line, toilets, ditches, and building and in the residential building compound. Due to those problems arise in the hydraulic network performance; to maintenance and water quality get deteriorated.

Bole Bulbula subsystem pipe network was designed for residential demand but now a day the supply coverage area is dramatically expanded with a construction of new small and medium industries, commercials, institutions and multiple condominium houses. Furthermore additional demand load from adjacent boundaries, which were not considered before, when the existing water supply designed, are included at the sub systems. There is the gap between present water supply and demand.

1.3 Research Questions

Research questions that will be addressed in this thesis are the following:

- ❖ What is the existing water supply situation in the study area?
- ❖ What is the gap between water demand and available water supply?
- ❖ What are the key hydraulic parameters affecting the performance efficiency of the water distribution network?
- ❖ What is percentage of water losses in the subsystems?
- ❖ What is the water quality situation in the study area?

1.4 Research Objective

1.4.1 General objective:

The main aim of this research is to evaluate the water distribution network system of Addis Ababa city for the case study of Bole Bulbula supply system; using Water Cad modeling package, improving the case study water supply distribution service system with hydraulically and economically efficient.

1.4.2 Specific objectives:

To fulfill the above general objective the following specific objectives are;

- ❖ To identify key problems of the water supply distribution system.
- ❖ To analyze the existing water supply network.
- ❖ To recommend feasible improvement measures.

1.5 Significance of the Study

The significance of the paper is to save some amount of unaccounted for water (UFW) by managing the existing and improved system hydraulic parameters (pressure, velocity and residual chlorine concentration) based on model simulation results.

The paper will be important to model and upgrade the other subsystems of Addis Ababa water distribution systems easily by applying the same procedures. Hopefully, the insights that can be drawn from this study will initiate further research on similar other sites and will contribute to solving the existing problems of water distribution system.

The model can be used to solve ongoing problems, analyze proposed operational changes, and

prepare for unusual events. By comparing model results with field operations, the operator can determine the cause of problems in the system and formulate solutions that will work correctly the first time, instead of resorting to trial-and-error changes in the actual system, like: low-pressure problems, finding closed valves, and low demand problems. In general, the research will be significant for AAWSA to improve the performance of the existing subsystem and to reduce the deficit of supply. Modeling and analysis practice for secondary distribution line enables an engineer or site supervisor to control a site from practical engineering point of view; enables identification and characterization of the system hydraulically.

Addis Ababa Water Sewerage Authority, especially policy making bodies, and the city municipality can use the findings of this thesis for designing a more effective method of water supply thereby contributing to narrowing the knowledge gap between supply and demand for safe water supply service and the research findings can also initiate other researchers to further study the delivery of similar urban services area.

1.6 Overview of the Thesis

The thesis content consists of five chapters as structured below.

Chapter one: contains general background, the problem statement, the research objective, research questions, description of the study area and the outline of the research.

Chapter two: contains literature reviews related to water supply system modeling, water loss, leakage and pressure, review the works in related to this thesis in both local and others.

Chapter three: is devoted to the methodology used in data collection and preparation and analysis modeling output for water supply network used to reach at findings and conclusion.

Chapter four: on the other hand discusses and results the model out puts, analyzes water supply coverage, water loss, demand, gap identified in the system, calibration and validation , compare the results with actual value and proposed the feasible improving methods. Simulates the model after proposed solutions, assesses the output of the model with hydraulic and water quality parameters.

Chapter five: deals with conclusion and Proposed solutions forwarding general approach AAWSA has to follow to improve and design new and existing water supply based on results and findings of the study in the sub system distribution systems.

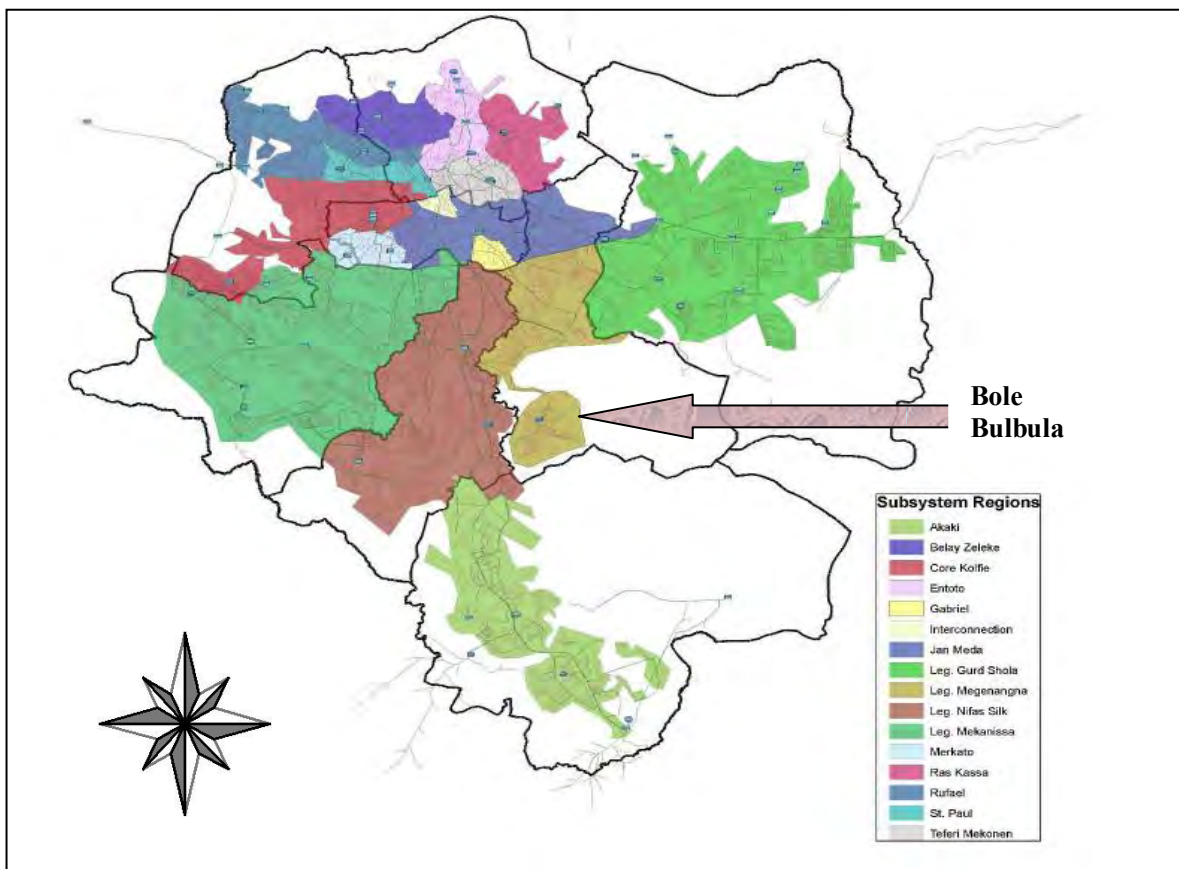
1.7 Location of the Study Area

Bole Bulbula service zone forms south eastern part of the city of Addis Ababa. It is located within the UTM coordinates of (473520, 477977) east and (987552, 993526) north and the average elevation is about 2240Masl. Total number of population is about 25213 (CSA, 2007) and estimated area 10.8km². As shown in Table 1.1 below, the months from June to mid-September is the main rainy season during which days and nights are cool by local standards. Average annual rainfall is 1184mm, of which about 80% falls between June and September, the months of July and August being the wettest. The hottest and driest months are usually April and May. The short rains fall during March to mid April, characterized by relatively cool nights and warm days.

Table1.1 Climate data of Addis Ababa city

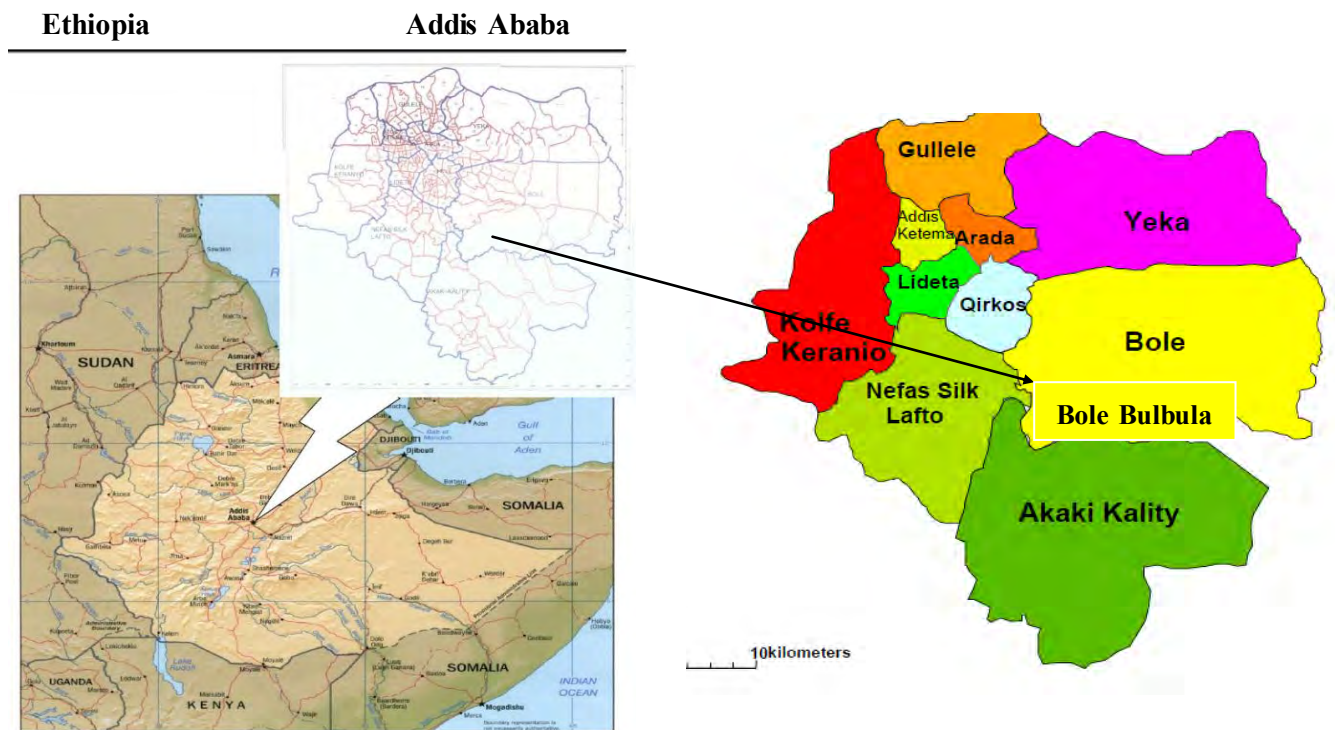
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average High Temp °c	23.0	24.3	24.8	24.2	24.4	20.0	17.9	20.0	21.3	22.3	22.6	22.8	22.8
Average low Temp °c	6.0	9.0	11.6	12.0	12.3	11.2	11.3	11.2	11.0	9.9	8.7	8.1	10.6
Rainfall in mm	16.8	36	68.2	88.8	76	123.5	259.4	278	174.1	41.1	8.3	10.2	1,180.4
Average rainy days	5	3	7	10	10	20	27	26	18	4	1	1	132

Source: (National Meteorological Agency, World Meteorological organization 2014)



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

Figure 1.1 Addis Ababa sub system regions supplied by water distribution network



Source :(Mosisa, 2005)

Figure 1.2 Location of the study area

1.8 Existing Water Supply Sources of Addis Ababa City

Currently the city of Addis Ababa gets its water supply from both surface water and ground water sources. There are three main surface water dams as sources for the surface water supply. These are Gefersa, Legedadi and Dire dam. The ground water source is from Akaki ground water (Akaki well field) and from spring and wells within and near Addis Ababa. There are two conventional water treatment facilities, namely Legedadi water treatment plant and Gefersa water treatment plant to supply the city treated water from the above different sources. The location of the Addis Ababa water supply sources is shown in Figure.1.3.

Gefersa dam is situated 18 km west of Addis Ababa; Legedadi dam is situated 25 km east of Addis Ababa; and Akaki well field is situated south east of Akaki town and about 22 km south of Addis Ababa. Figure 1.3 showing Akaki well field, Gefersa and Legedadi dams.

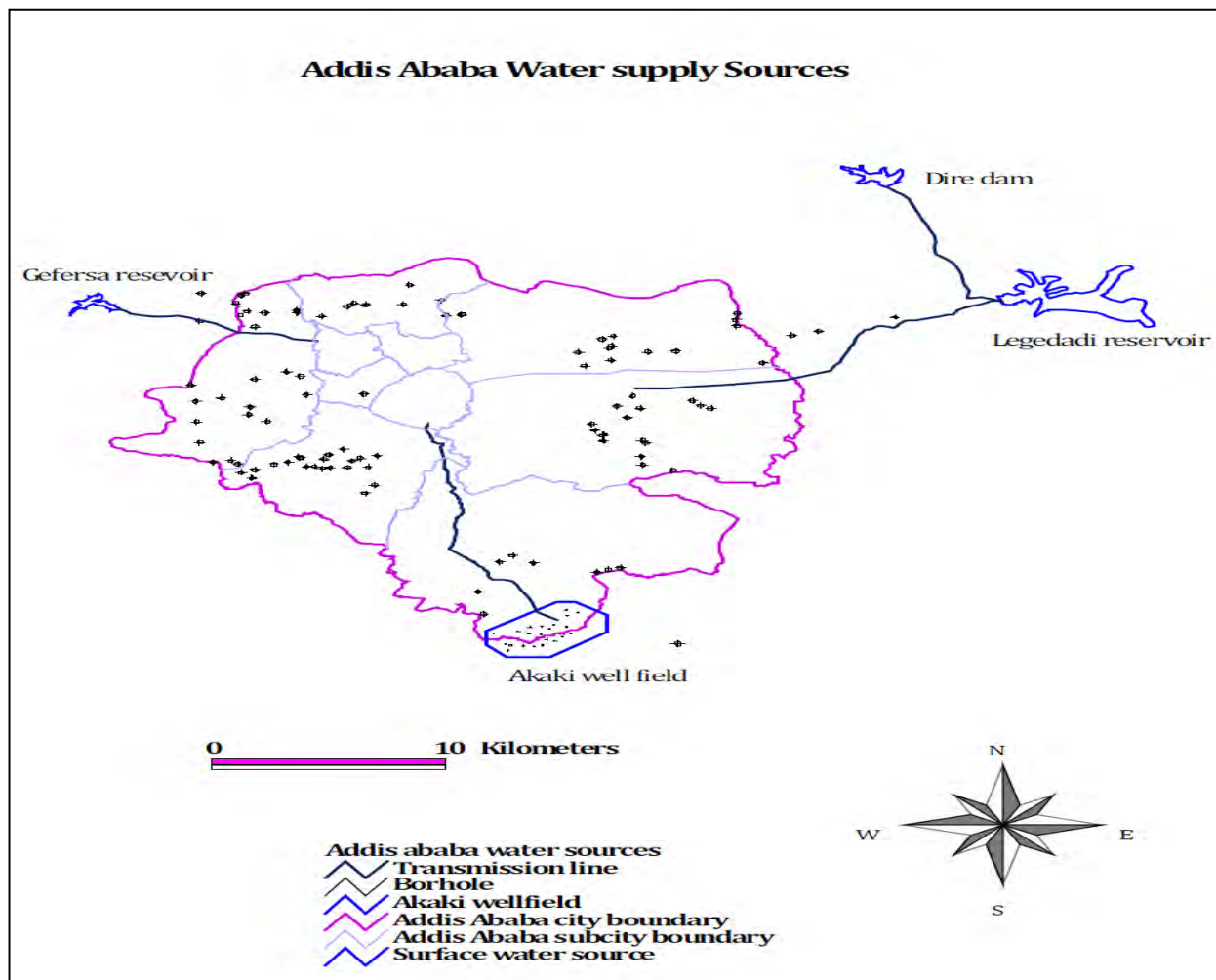


Figure 1.3 Map of Addis Ababa water supply sources

The annual report of 2010 Legedadi, ground, and Gefersa water production case teams indicate that the highest source of water supply of Addis Ababa is Legedadi dam (treatment plant) which was 60,276,776m³/year with 61 percent of the total water supply. The next is Akaki well field and wells within as well as near the city, which was 27,716,174m³/year and contributes 28 percent of the total water supply. Gefersa dam (treatment plant) production was 10,462,777m³/year, contributing 11 percent of the total production. According to the three principal sources, the city has three main subsystems namely: Legedadi, Gefersa, and Akaki subsystem (TAHAL, 2015).

Legedadi subsystem includes supplies from Legedadi water treatment plant to service reservoirs of Kotebe terminal, karalo, Ankorcha, Jan Meda, Gebrial Palace, Teferi Mekonnen, Entoto, AAWSA main office, Belay Zeleke, Police Hospital, Army hospital and Kasa Gebre; and to pumping stations at Ureal and Mexico square.

Gefersa subsystem includes supplies from Gefersa water treatment plant to service reservoirs of Rufael, St. Paul, and Ras Hailu.

Akaki subsystem includes the supply of water from Akaki well field to CT, GW1, GW2, GW3, GW5, Bole Bulbula service reservoir and Lebu service reservoir. The three subsystems have additional ground water well sources apart from their principal sources. The thesis focused on the Bole Bulbula subsystem.

The location of Addis Ababa water supply subsystems is shown in Figure 1.4.

Table 1.2 Addis Ababa city water sources and daily production

Source	Unit	Quantity(m ³ /day)
Legedadi and Dire dam	m ³ /day	195,000
Gefersa	m ³ /day	30,000
Akaki Wells field old	m ³ /day	32,000
Akaki Well field-Phase 2	m ³ /day	73,000
Akaki Well field -Phase 3A	m ³ /day	70,000
Akaki Well field -Phase 3B	m ³ /day	70,000
City springs & wells	m ³ /day	88,000
Deep wells	m ³ /day	41,000
Total production	m ³ /day	599,000

Source :(AAWSA, Business plan 2011, Growth and Transformation plan 01, 2015)



Figure 1.4 Map of Addis Ababa water supply subsystems

1.9. Existing Situation of Water Distribution System

The current water distribution system, Bole Bulbula subsystem consist all the main components of a water distribution system (sources, transmission, distribution, service line equipment and accessories) in the system, water is distributed to consumers by gravity distribution system from the source.

1.9.1 The System Water Source

The system is supplied pumping from Akaki ground water wells field to the GW3 (ground water collection tank 3) and release to Bole Bulbula service area by gravity system method. Figure 1.5 shows water source of the Bole Bulbula subsystem.

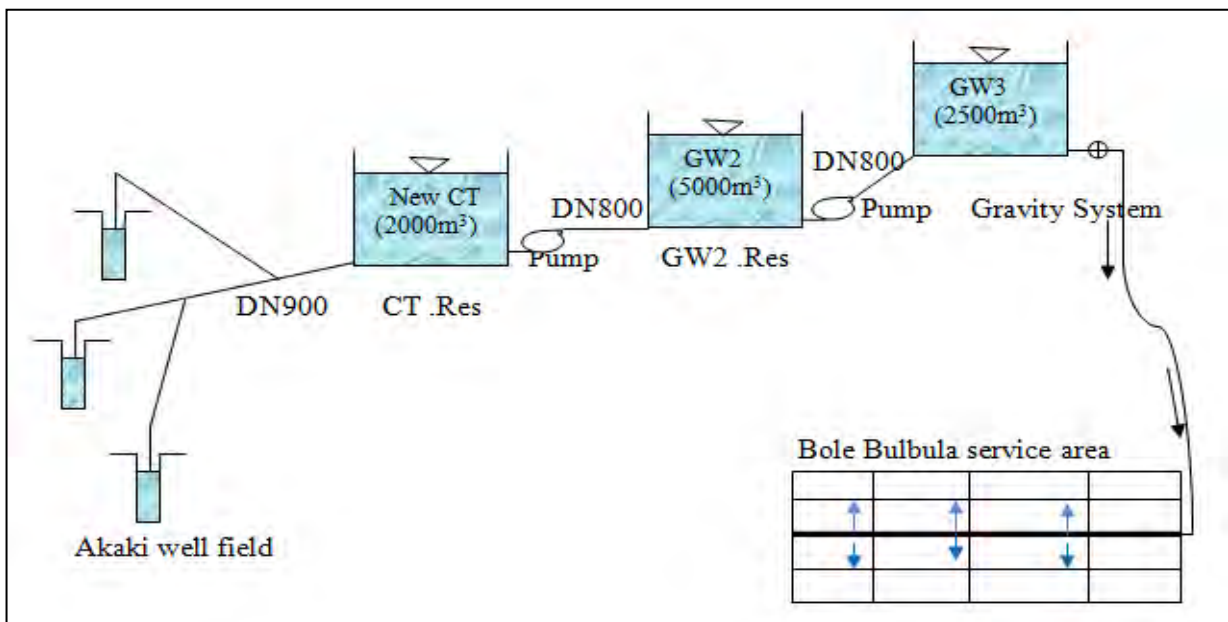


Figure 1.5 Water sources of the system (not scaled drawing)

1.9.2 Water Transmission Facilities

The system transmission main, gravity flow type is composed of different size pipelines with different material and diameter of pipe size:

- ❖ The first is DN 400mm, installed in 2005; and
- ❖ The other line also DN 350mm, 300mm, 250mm, 200mm and DN 150mm DCI material are installed in 2005.

The transmission mains convey water from Gotera (GW3) reservoir in to Bole Bulbula reservoir by gravity. From Bole Bulbula reservoir to service area water supplied again by gravity system. The transmission main is also composed of accessory equipments, a numbers of air release and fire hydrant valves. These are shown below in Table 1.5.

1.9.3 The Secondary Network of Bole Bulbula Water Supply System

The existing secondary network of the study area is no longer capable of providing the necessary needs and quantities of water due to the increasing of water demand as a result of increasing the density of inhabitants. Most of the lines in the distribution network which installed in the past have a DN of 2" and smaller.

1.9.4 Network Pipe Coverage in the System

Water supply network pipe coverage in the study area by size, length and material type is identified as below here in. The length of the entire distribution system including transmission lines is approximately 55748m and comprises all pipe diameters from DN (40mm) up to DN (400mm). A length of 23601m can be considered as mains in the distribution network (63mm HDPE pipe about 42.3%). The Table 1.3 below shows the network coverage by material type, size and length of pipe.

Table 1.3 Transmission and distribution network coverage in the system

S.no	Diameter(mm)	Material type	Length(m)	Percentage (%)
1	400	Ductile Iron	4564.08	8.2
2	350	Ductile Iron	196.29	0.4
3	300	Ductile Iron	343.82	0.6
4	250	Ductile Iron	389.22	0.7
5	200	Ductile Iron	787.92	1.4
6	150	Ductile Iron	3805.74	6.8
7	110	HDPE	4030.7	7.2
8	90	HDPE	769.93	1.4
9	75	HDPE	4654.59	8.3
10	63	HDPE	23600.08	42.3
11	50	PVC	2738.92	4.9
12	50	Galvanized iron	238.66	0.4
13	40	HDPE	9627.74	17.3
Total			55747.69	100

1.9.5 Water Distribution Facilities

The system components are service reservoir, pipe networks and accessory equipments. Water distribution facilities include reservoir or tank, different function type of valves and regulating devices such as air release and drainage valves in the study area system.

1.9.5.1 Storage Facilities

Two reservoirs represent for Bole Bulbula subsystem: the larger has a capacity of 2500 m³, and circular shape and made of reinforced concrete. It was constructed in 1997, the smaller is new, and has a capacity of 2000 m³, circular shape and reinforced concrete, it was constructed in 2005. GW3 storage facility is situated at Gotera hill near to Gotera ring road, and has the level of 2304 m.a.s.l.

Bole Bulbula Reservoir 1 (BBR1)

This storage facility is situated at center of Bole Bulbula hill; the bottom of the reservoir is set at 2272 m.a.s.l. It was constructed in 2005, has a capacity of 2000 m³, circular shape, from the reinforced concrete. The purpose of construction this storage facility is improving the supply conditions and increasing the pressure in the distribution network.

Table 1.4 Bole Bulbula subsystem service reservoir descriptions

S.no	Name	No. of tanks	Year of Built	Construction materials	Coordinates		Base Elevation(m)	Height (m)	Capacity (m ³)
					x	y			
1	GW3	1	1997	RC	473656	992760	2304	6	2500
2	BBR1	1	2005	RC	476145	989999	2272	6	2000

Source: (AAWSA, 2015)

1.9.5.2 Valves and Regulating Devices

As of the transmission main of the system the distribution facility is composed of accessory equipments such as; control, air release and fire hydrant valves. Use the following Table 1.5.

Important valves are normally installed in chambers. About 90% of the valves were never operated because their locations were not recorded or construction work executed later buried them completely, most of the valves with DN over 110 mm are located in chambers. Many of them are out of operation or difficult to operate and needed to be replaced. The average depth of valves in underground chambers is 0.8 to 1.0 meters. There is no pressure regulating devices in the distribution system, although the variation of altitude is large.

Table 1.5 Location of the air release valves and fire hydrant

S.no	Accessory Equipment name	Location		Connected from
		Easting	Northing	
1	Air release valve	476023.6	991132.8	350mm DCI
2	Fire hydrant	476094.5	988454.0	110mm HDPE

Source: (AAWSA, 2015)

1.9.6 Tertiary Network – Delivery to the customer

1.9.6.1 General

The work for the tertiary network is not performed according to standards. Private lines are connected to distribution pipes, which to satisfy the most reliable water supply, and some private line is not connected through the shortest route. This process results in service lines more than 100 meter length and above. The houses along the service lines will connect their service lines directly to the service line and not to the distribution main, which adding the complex to the system.

1.9.6.2 Connection to the Supply Network

The average private line connection length in Bole Bulbula is about 12meters long, which is approximately 4 times the standard length of service lines compare to similar towns. At present most of the house connection lines are connected directly to the main or secondary pipes, and for the diameters of the secondary pipes less than DN 110 mm, the connection is performed by installing a threaded tee – piece, after the connection, a stop cock is usually installed for safety reasons.

About 95% of the tertiary network system is laid below the ground. In some cases, the rocky subsoil conditions made lying in/on trenches. The water supply service authority department performs all works of connection. All costs covered by the customer, including materials, excavation and labor costs needed for the house connection. Table 1.6 below shows existing private pipe by size and length.

Table 1.6 Existing private pipe connections by size and length of pipe

S.no	Diameter (inch)	Length (m)	Percent (%)
1	1/2"	23832	49.00
2	3/4"	23640	48.61
3	1"	1032	2.12
4	1 1/2"	48	0.10
5	2"	84	0.17
Total length (m)		48636	100

Table 1.7 Bole Bulbula costumer categories

S.no	Costumer Category	Number of Connections
1	Domestic	3681
2	Non-domestic	413
3	Public tap /stand pipe	15
Total		4109

2. LITERATURE REVIEW

2.1 Introduction

This chapter seeks to provide an evaluation of previous work done on hydraulic modeling and its application to urban water distribution networks. Also provide herein are details of the available hydraulic modeling technologies and software with model calibration and validation, their relevance, and details of their applicability in the AAWSA situation. The chapter also gives the definitions for key terms adopted in the study and theoretical approaches about the main hydraulic network evaluation of governing parameters and conclusion.

2.2 Definition

The following definitions were adopted for this research:

Modeling

Network Modeling is the process of building, verifying and operating network models of distribution systems, which provide valuable insights into operational practice (Halcrow, 2002).

Water distribution modeling: is a critical part of designing and operating water distribution systems that are capable of serving communities reliably, efficiently, and safely, both now and in the future. The availability of increasingly sophisticated and accessible models allows these goals to be realized more fully than ever before (Walski et al. 2003).

Model calibration: is the process of comparing the model results to field observations and, if necessary, adjusting the data describing the system until model predicted performance reasonably agrees with measured system performance over a wide range of operating conditions (Walski et al. 2003).

2.3 History of Hydraulic Modeling

The science on which water network hydraulic analysis is based first suggested by Hardy Cross using an iterative method (Cross, 1936). It is what was used throughout the water industry for about forty years (USEPA, 2005). The advent of computer –based hydraulic simulation leveraged the power of the computer of the computer to solve Hardy’s complex equations and permutations required to adequately simulate a water distribution network. By 1980s these superior computer –based techniques had witnessed significant proliferation (word, cited in USEPA, 2005).

Practical application of hydraulic modeling progressed significantly in the 1990s with the introduction of the public domain EPANET model (Rossman, 2000) and other Windows-based commercial water distribution system models.

Early simulation packages simulated the hydraulic parameters of a water network under steady state conditions (constant demand and network operations). However, advance in applications development now allow for the construction of models that reflect both the temporal and spatial behavior of the network, known as Extended Period Simulation (EPS) models. Hydraulic modeling functionality has therefore become essential in the global water industry and is now an integral part of most water system design, master planning, and fire flow analysis, particularly in the developed world (Walski et al .2003)

2.4 Applications of Water Distribution Models

Most water distribution models (WDMs) can be used to analyze a variety of other pressure piping systems, such as industrial cooling systems, oil pipelines, or any net-work carrying an incompressible, single-phase, Newtonian fluid in full pipes. Municipal water utilities, however, are by far the most common application of these models. Models are especially important for WDSs due to their complex topology, frequent growth and change, and sheer size. It is not uncommon for a system to supply hundreds of thousands of people (large networks supply millions); thus, the potential impact of a utility decision can be tremendous (Walski et al .2003). Water distribution network simulations are used for a variety of purposes, such as:

- ❖ Long-range master planning, including both new development and rehabilitation
- ❖ Fire protection studies
- ❖ Water quality investigations
- ❖ Energy management
- ❖ System design
- ❖ Daily operational uses including operator training, emergency response, and troubleshooting

2.5 Modeling a System Using Water CAD

The quality input data to develop the water distribution model are very essential. Water CAD is hydraulic simulation software, distributed by Bentley Systems. Once the spatial model is built, the parameters that need to be defined for each model components include:

- ❖ Nods: Elevations and the base demands
- ❖ Pipes: Pipe diameters, lengths and the friction coefficient factors. By default Water CAD considers the pipe material of having a Hazen William friction coefficient factor
- ❖ Tanks: Base Elevation, the minimum and maximum levels, diameter of the tank
- ❖ Pumps: The most important parameter defining the pump operation is the pump curve. Other input needed is the elevation of the pump
- ❖ Reservoir: Elevation

After all the parameters required to run the simulation are entered into the model, the successful simulation run provides solution for the following:

- ❖ Pressure at every single element in the system
- ❖ Flows at every point of time in the system
- ❖ Velocities in the pipes
- ❖ Levels in the tanks
- ❖ Pump cycles
- ❖ Water age and constituent concentration.

Additionally it has the capability of performing the analysis of the system for the steady state scenarios and for an extended period of any length. The other capabilities of the software are as follows:

- ❖ Evaluate the hydraulics for different demands at a single node with varying time patterns
- ❖ Solve for different frictional head losses using Hazen-William, Darcy-Weisbach or the Chezy-Manning equations
- ❖ “Can determine immediate inefficiencies in the system” (Haestad Methods, 1999)
- ❖ Determine fire flow capacities for hydrants
- ❖ Model tanks, including those which are not circular
- ❖ Model various valve operations
- ❖ Perform energy cost calculations
- ❖ Model fire sprinklers, irrigation systems, leakages and pressure dependent demands at any particular node (Haestad Methods, 1999)

2.6 Types of Water Distribution Simulation

Simulation refers to the process of imitating the behavior of one system through the functions another. In our case, the term simulation refers to the process of using a mathematical representation or real system, called a model (Bentley, 2008).

Simulation can be used to predict system responses to under a wide range of conditions without disrupting the actual system, and solutions can be evaluated before time, money, and materials are invested in a real-world project.

There are two most basic types of simulations that a model may perform, depending on what the modeler is trying to observe or predict.

These are:

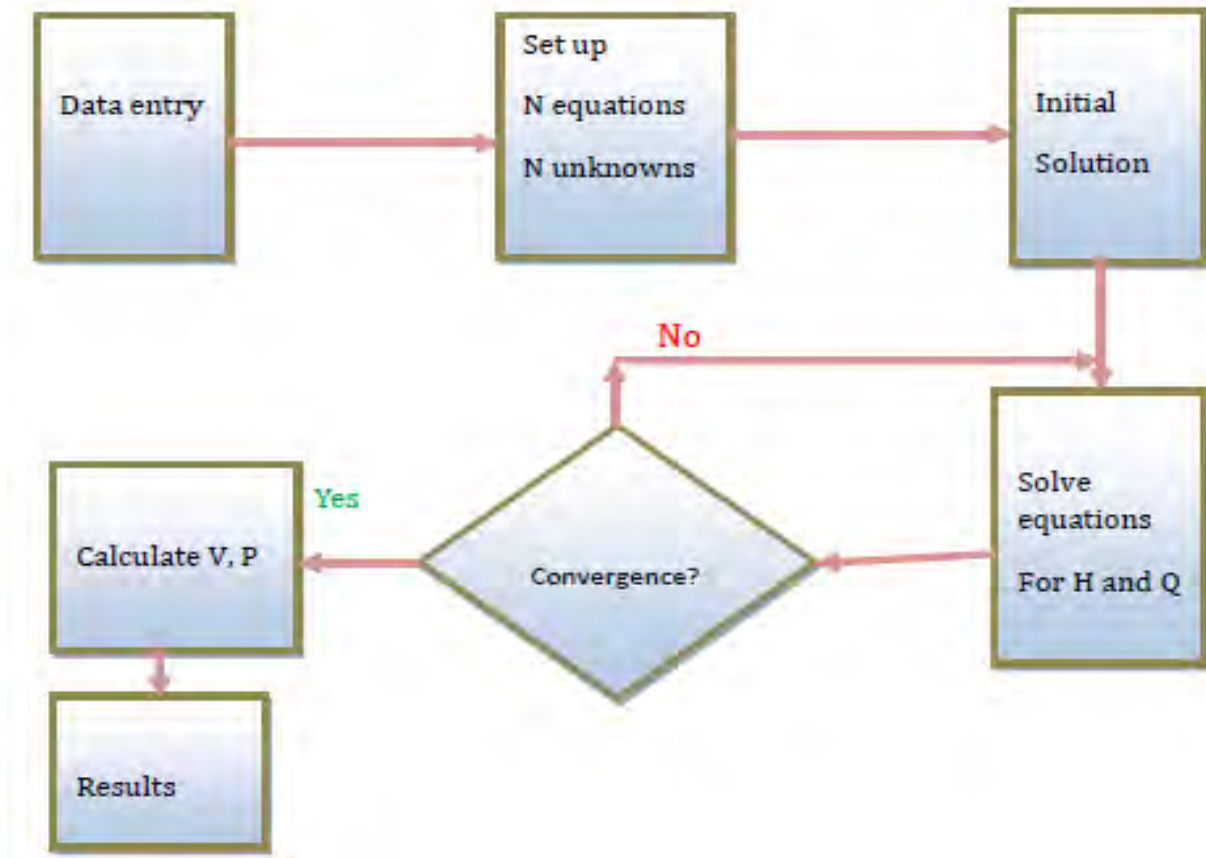
- ❖ Steady state simulation.
- ❖ Extended period simulation (EPS).

2.6.1 Steady State Simulation

It computes the state of the system (flows, pressures, pump operating attributes, valve position, and so on) assuming that hydraulic demands and boundary conditions do not change with respect to time. The flow chart of steady state simulation is shown in Figure 2.1.

A steady- state simulation provides information regarding the equilibrium flows, pressures, and other variables defining the state of the network for a unique set of hydraulic demands and boundary conditions.

Steady-state models are generally used to analyze specific worst-case conditions such as peak demand times, fire protection usage, and system component failures in which the effects of time are not particularly significant.



Source: (Bentley, 2008)

Figure 2.1 Flow chart for steady state simulation

2.6.2 Extended Period Simulation

Extended period simulation tracks a system over time, and it is a series of linked steady state run. The flow chart of extended period simulation is shown in Figure 2.2.

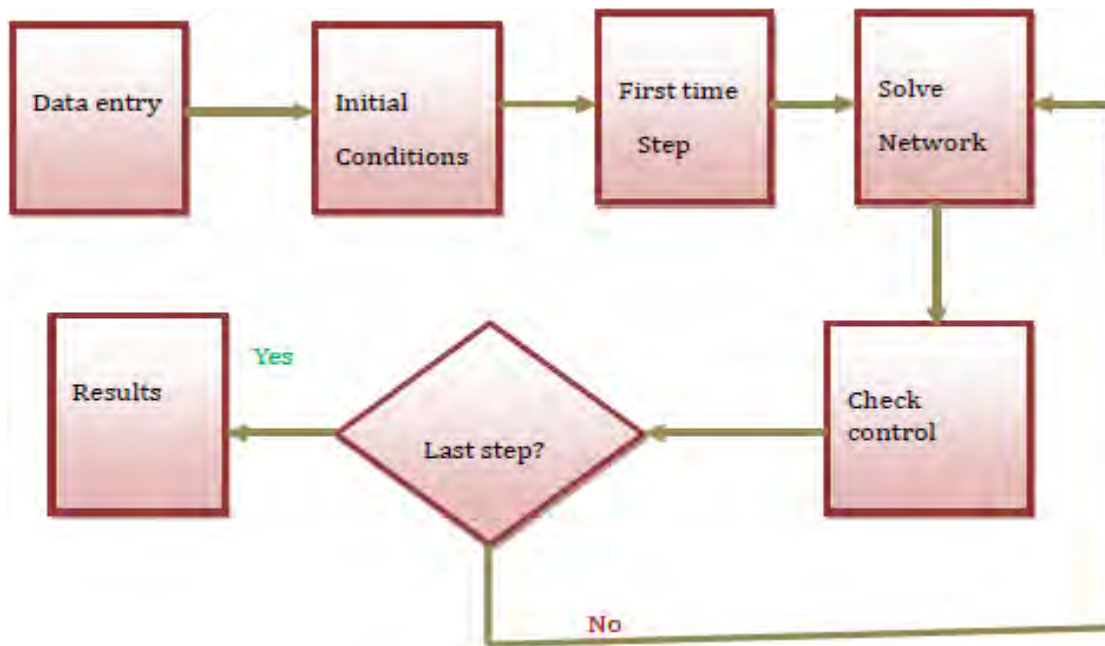
The need to run extended period simulation is because the system operations change over time.

- ❖ Demands vary over the course of the day.
- ❖ Pumps and wells go on and off.
- ❖ Valves open and close.
- ❖ Tanks fill and draw.
- ❖ Water quality

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

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

Using an EPS model we can simulate based on the peak, minimum and average day demands.



Source: (Bentley 2008)

Figure 2.2 Flow chart for extended period simulation

In hydraulic simulation modeling a distribution network is considered to be one in which all elements are connected to each other, every element is influenced by its neighbors, and each element is consistent with the condition of all other elements. These conditions are mainly controlled by two laws: Law of Conservation of Mass and Law of Conservation of Energy. “Thus the total mass of water entering the system should be equal to the total mass of water leaving the system, and the sum of the flows at any given node should be equal to zero. The principle of conservation of energy is mainly dictated by the Bernoulli’s equation, which states that the difference in the energy between any two points should be the same regardless of the path taken” (Haestad Methods, 1999).

A typical network in hydraulic model consists of the following components

- ❖ Nodes linking the pipes

- ❖ Pipes
- ❖ Storage tanks
- ❖ Reservoirs
- ❖ Pumps

Additional appurtenances like valves (Haestad Methods, 1999; Rossman, 2000). The junctions or nodes represent points having particular base demands. Tanks are those points in model, which can have a specific storage capacity that varies with time. Reservoirs in a hydraulic model are assumed to be an infinite source of water (Haestad Methods, 1999; Rossman 2000).

In addition to evaluating the hydraulics of the system, the hydraulic simulation models can also evaluate the water quality. “The hydraulic models mainly consider two principles of transport mixing and decay while computing the water quality in the system. Network hydraulic solutions are utilized to compute water quality”, (Haested Methods, 1999). WaterCAD uses the equations developed by Grayman, Rossman and Geldreich (2000) for determining the transport of constituents through the pipe, mixing at the nodes and the tanks and decay of constituents.

2.7 Principles of Network Hydraulics

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. (Walsik et al 2003). According to (K, Swamee and Sharman, 2009, E, EPA, 2005; Walski et al.; 2003; Larry, W. Mays, 2000). Interconnections of hydraulic elements are defined in concepts of conservation of mass and energy. Two basic equations that govern in Water CAD modeling network of these interconnections:

- ❖ Conservation of mass or continuity principle.
- ❖ Conservation of energy or energy principle.

2.7.1 Conservation of Mass

The principle of conservation of mass (as shown in Figure 2.3) 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 (Walski et al, 2003).

For steady incompressible flow:

Net flow into junction = Use at junction.

Mass in = Mass out

$$\sum_{\text{pipes}} Q_i - U = 0 \quad (2.1)$$

Where

Q_i = inflow to node in i -th pipe (L^3/T)

U = water used at node (L^3/T)

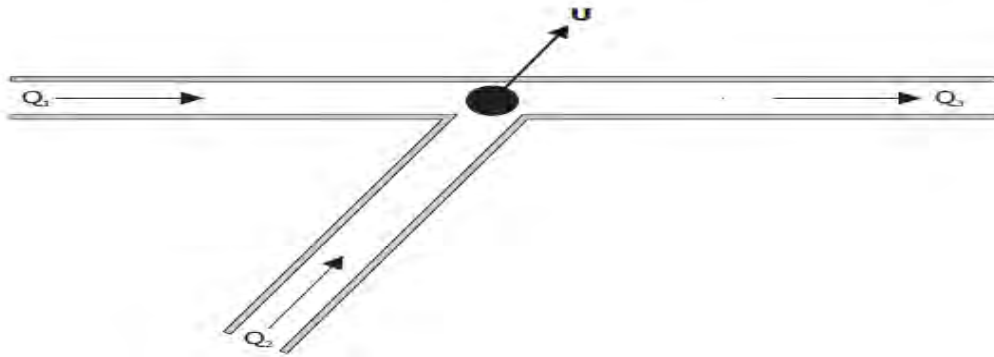


Figure 2.3 Conservation of mass principles

The conservation of mass equation is applied to all junction nodes and tanks in a network, and one equation is written for each of them.

$$\sum_{\text{pipes}} Q_i - U - \frac{dS}{dt} = 0 \quad (2.2)$$

Where

Q_i = inflow to node in i -th pipe (L^3/T)

U = water used at node (L^3/T)

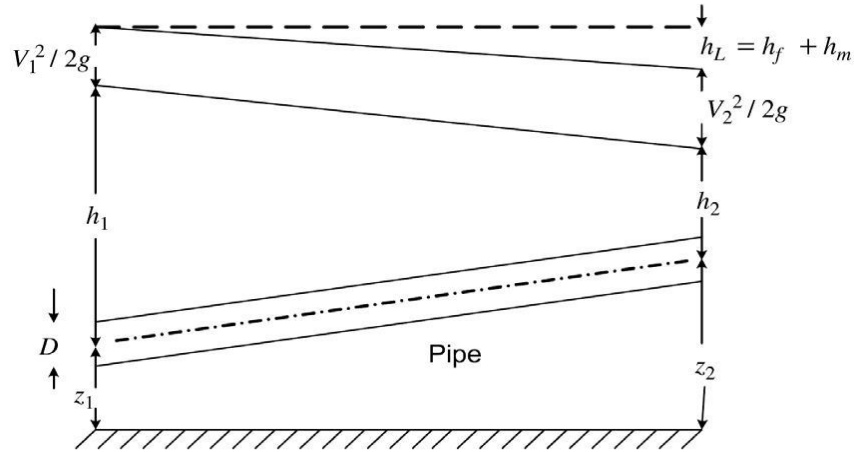
$\frac{dS}{dt}$ = change in storage (L^3/T)

2.7.2 Conservation of Energy

The principle of conservation of energy dictates that the difference in energy between two points must be the same regardless of the path is taken (Bernoulli, 1738 cited in Walski et. al., 2003).

The Energy equation is known as Bernoulli's equation. It consist the pressure head, elevation head, and velocity head. There may be also energy added to the system (such as by a pump), and energy removed from the system (due to friction). The changes in energy are referred to as head gains and head losses.

In hydraulics, energy is converted to energy per unit weight (ft-lb/lb) of water, reported in length units (ft) called “head”. Balancing the energy across any two points in the system, the energy equation will be as follow: Figure 2.4 shows head losses in a pipeline.



Source: (Swamee, 2008)

Figure 2.4 Forms of energy in water pipes

$$Z_1 + P_1 / \gamma_1 + V_1^2 / 2g + \sum ha = Z_2 + P_2 / \gamma_2 + V_2^2 / 2g + \sum hf + \sum hm \quad (2.3)$$

Where:

P = the pressure (lb²/ft²)

γ = the specific weight of the fluid (lb/ft³ or N/m³)

z = the elevation at the centroid (ft or m)

V = the fluid velocity (ft/s or m/s)

g = gravitational acceleration (ft/s or m/s²)

h_L = the combined head loss (ft or m)

h_f = friction loss (ft, m)

h_m = head loss due to minor loss (ft, m)

h_l = head loss due to pipe friction ($h_f + h_m$), (ft, m)

h_a = head added by pumps

There are three forms of energy:

- ❖ Pressure head - p / γ
- ❖ Velocity head - $V^2 / 2g$
- ❖ Elevation head - z

2.8 Water Quality Modeling

In water distribution network system, water quality transformation and deterioration can occur in the bulk water phase and through interaction with pipe wall. These transformations may be physical, chemical, or microbiological in nature (W. Mays, 2000). Transport, mixing and decay are the fundamental physical and chemical processes typically represented in water quality model' (Walski et al., 2003). In similar way, (Rossman et al., 2000) state the phenomena occurring in the distribution system which are represented in a typical water quality model.

For water quality integrity to be compromised, specific reactions must occur that introduce undesirable compounds or microbes into the bulk fluid of the distribution system. These reactions can occur either at the solid liquid interface of the pipe wall or in solution. Obvious microbial examples include the growth of bio films and detachment of these bacteria within distribution system pipes and the proliferation of nitrifying organisms. Important chemical reactions include the leaching of toxic compounds from pipe materials, internal corrosion, scale formation and dissolution, and the decay of disinfectant residual that occurs over time as water moves through the distribution system (NRC, 2006).

The two main mechanisms for water quality deterioration are interactions between the pipe wall and the water, and reaction within the bulk water itself. As the bulk water travels through the distribution system, it undergoes various chemicals, physical and aesthetic transformations, impacting water quality. Depending on the water flow rate, finished water quality, pipe materials and deposited materials (i.e., sand, iron, manganese), these transformations will proceed to a greater or lesser extent (EPA, 2004).

2.8.1 Advective Transport in Pipe

A dissolved substance will travel down the length of a pipe with the same average velocity as the carrier fluid, while at the same time reacting (either growing or decaying) at some given rate. Longitudinal dispersion is usually not an important transport mechanism under most operating conditions. This means there is no intermixing of mass between adjacent parcels of water traveling down a pipe (W. Mays, 2000)

According to (Walski et al 2003), advective transport within a pipe can be represented with the following equation:

$$\frac{\partial c_i}{\partial t} = \frac{\partial Q_i \cdot \partial c_i}{A_i \cdot \partial x} + \theta(C_i), \quad i=1 \text{-----} p \quad (2.4)$$

Where, C_i = concentration in pipe (M/L)

Q_i = flow rate in pipe i (L³/T)

A_i = cross sectional area of pipe i (L²)

$\theta(C_i)$ = reaction term (M/L³/T)

The above equation shows concentration within a pipe i as a function of distance along its length (x) and time (t)

The advective transport equation is a function of discharge divided by cross-sectional area. It is equal to the mean velocity of the fluid. Therefore, the bulk fluid is transported down the length of the pipe with a velocity that is directly proportional to the average discharge (Walski et al., 2003).

2.8.2 Water Age Analysis

Many water distribution systems experience long retention times or increased water age, in part due to the need to satisfy fire fighting requirements. Although not a specific degradation process, water age is a characteristic that affects water quality; because, many deleterious effects are time dependent (NRC, 2006). Typically, the loss of disinfectant residuals and the formation of Disinfection by-products (DBPs) are due to increased water age.

The chemical processes that can affect distribution system water quality are a function of water chemistry and the physical characteristics of the distribution system itself (for example, pipe material and age). More generally, however, these processes occur over time, making residence time in the distribution system a critical factor influencing water quality (Walski et al., 2003). The cumulative residence time of water in the system, or water age, has come to be regarded as a reliable surrogate for water quality. Water age is of particular concern when quantifying the effects of storage tank turnover on water quality. It is also beneficial for evaluating the loss of disinfectant residual and the formation of disinfection by products in distribution systems.

The chief advantages of water age analysis when compared to a constituent analysis is that once the hydraulic model has been calibrated, no additional water quality calibration procedures are required. The water age analysis, however, will not be as precise as a constituent analysis in determining water quality; nevertheless, it is an easy way to leverage the information embedded in the calibrated hydraulic model. Consider a project in which utility is analyzing mixing in a tank and its effect on water quality in an area of a network experiencing water quality problems. If a hydraulic model has been developed and adequately calibrated, it can immediately be used to

evaluate water age. The water age analysis may indicate that excessively long residence times within the tank are contributing to water quality degradation. Using this information, a more precise analysis can be planned (such as an evaluation of tank hydraulic dynamics and mixing characteristics, or a constituent analysis to determine the impact on disinfectant residuals), and preliminary changes in design or operation can be evaluated (Walski et al., 2003).

2.9 Model Calibration and Validation

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

2.9.1. Hydraulic Model Calibration

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

2.9.2 Water Quality Model Calibration

Subsequent to the proper calibration of a hydraulic model, additional calibration in a water quality model may be required. The following parameters are used by water quality models that may require some degree of calibration (EPA):

- ❖ Initial conditions: Defines the water quality parameter (concentration) at all locations in the distribution system at the simulation.
- ❖ Reaction Coefficients: Describes how water quality may vary over time due to chemical, biological or physical reactions occurring in the distribution system.
- ❖ Source Quality: Define the water quality characteristics of the water source over the time period being simulated.

2.9.3 Calibration and Validation Using Time Series Data

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

2.10 Water Demand

The consumption or use of water, also known as water demand, is the driving force behind the hydraulic dynamics occurring in water distribution systems. Anywhere that water can leave the system represents a point of consumption, including a customer's faucet, a leaky main, or an open fire hydrant (Jeffrey .A). Water demand estimation is one of the basic inputs to select source of water supply and to find the amount of water required to fill the gap between supply and demand of the subsystem.

Three questions related to water consumption must be answered when building a hydraulic model:

- (1) How much water is being used: peak and daily average?
- (2) Where are the points of consumption located?
- (3) How does the usage change as a function of time? This chapter addresses these questions for each of the three basic demand types described below.

- ❖ Customer demand is the water required to meet the non-emergency needs of users in the system. This demand type typically represents the metered portion of the total water consumption.
- ❖ Unaccounted-for water (UFW) is the portion of total consumption that is “lost” due to system leakage, theft, unmetered services, or other causes.
- ❖ Fire flow demand is a computed system capacity requirement for ensuring adequate protection is provided during fire emergencies.

Determining demands is not a straightforward process like collecting data on the physical characteristics of a system. Some data, such as billing and production records, can be collected

directly from the utility but are usually not in a form that can be directly entered into the model. For example, metering data are not grouped by node. Once this information has been collected, establishing consumption rates is a process requiring study of past and present usage trends and, in some cases, the projection of future ones.

The total water supply of a city is usually distributed among the following four major classes of consumers: domestic, industrial, commercial, and public. Overestimating the water demand it is a cause for uneconomic investments and operational costs. In spite of uncertainties, planners have developed methods, which are used in forecast. But must be clear that forecast is not a prediction. Inappropriate or unintended assumptions may be made. For projection of water demand many factors may intervene. Inexactness in population projection or changes in the mix of house hold types. Forecast is made for various horizons: short, medium or long term, time extrapolation, coefficient method for unit use and per capita demand method. Hence for this particular study because of the shortage of data available per capital demand is adopted.

Per capita demand method

This is the most widely used for long time by utilities. The method assumes that only one variable, the population, provides adequate information on the water use and the development of use.

2.10.1 Classification of Demand

In the forecast of the water demand the following needs are generally taken into account:

(i) domestic/residential (ii) commercial, (iii) institutional (iv) industrial, (v) public (vi) fire-fighting.

1. Domestic Demand

Domestic users: it consists of water furnished to houses, apartments, hotels, and water for drinking, bathing, washing, sanitary, and lawn -sprinkling purposes. Naturally the domestic consumption in different towns differs from the domestic consumption in Addis Ababa. The difference depends on climate, standard of living, household size etc.

The study has also tried to analyze the quantities for every of the domestic uses and found that the indoor consumption only is divided as below (TAHAL, 2015).

Table 2.1 Domestic use of water demand

Home Uses	Water Use Per Person	
	Gallons	Percent
Toilet	32	45
Bathing /Personal Hygiene	21	30
Laundry /Dishes	14	20
Dirking /Cooking	3	5
Total	70	100

Source :(TAHAL, 2015)

The study also considered the daily distribution of the supply and found as following:

- ❖ Low usage 23:00 – 05:00hrs.
- ❖ High morning 05:00 – 11:00hrs.
- ❖ Moderate 11:00 – 18:00hrs.
- ❖ High evening 18:00 – 23:00hrs

The hourly distribution pattern is found to be common to many other towns around the world and reflects the general human behavior: mornings for cooking and personal hygiene bring a high consumption, high mornings and afternoons the people are mostly out of their homes for gaining their existence and the house consumption is therefore lower, late afternoons and evenings are devoted to evening meals, evening/night hygiene and leisure and therefore a second daily peak is registered. Night hours are used for rest/sleep and again the consumption is low and reaches the minimum of the day (TAHAL, 2015). Domestic use accounts for between 30 and 60% (50 to 60 gal per capita per day) of total water consumption in an average city (TAHAL, 2015).

2. Non-domestic Demand

a. Institutional and Commercial Demand

This refers to water demand of institutions, and similar facilities such as schools, hospital, hotels, etc. and commercial enterprises. Nonresidential water demand is the water consumed by users other than single or multifamily residential units (Design manual, 2009). They include:

- ❖ Commercial facilities (retail or wholesale businesses, restaurants, hotels, office buildings, and car washes).
- ❖ Industrial
- ❖ Public facilities (schools, public hospitals, governmental offices, parks, landscaped roads, and cemeteries).

- ❖ Other large users, such as farms with irrigated crops.
- ❖ Recreational users (campgrounds, parks, and seasonal rental units).

The following daily unit demands are applied in this category:

Day schools	5 l/pupil
Boarding schools	80 l/pupil
Public offices	5 l/m ² built area
Workshop/shop	5 l/m ² business area
Church/Mosques	5 l/ worshipper
Hospitals	150 l/bed
Hotels	100 l/bed
Theaters/Cinema houses	5 l/seat
Bus stations	10 l/user
Abattoir	300 l/cow
Public latrine	5 l/user

Normally, the demand for such facilities is calculated according to their number or built areas assumed and/or projected in the town. In any case, a minimum of 30% of the average daily domestic demand will be considered as being a widely accepted figure (TAHAL, 2015).

b. Industrial Demand

Industrial demand for water can be divided into four categories.

- (1) Cooling water demand usually abstracted direct from rivers or estuaries and returned to the same with little loss. None is used from the public supply.
- (2) Major industrial demand – factories using upward of 1000m³/day for such industries as paper making, chemical manufacturing, production of iron and steel.
- (3) Large industrial demand – factories using 100-500m³/day for food processing ,vegetable washing, drinks bottling ,chemical products ,etc. these demands are often met from the public supply.
- (4) Medium to small industrial demand – factories and all kinds of small manufacturers using less than 50m³/day ,the great majority taking their from the public supply.

c. Agricultural Demand

Most water for crop irrigation, horticulture, greenhouses, etc, is taken direct from rivers or boreholes because it does not need to be treated. The principal use of the public supply is for the watering of animals via cattle troughs, for cleaning down premises, and for milk bottling (Twort

et al 2000).

3. Public Demand

Public demand relates to water required for other purposes than residential, industrial, commercial and institutional. In statistics in this category is being considered the water used at the head works (sanitary facilities, backwashing, flushing distribution systems, etc). Are also included in this category the public gardens and parks, washing the streets, firefighting, etc. This quantity is small in comparison with the residential. The inner use of the head works is based on practice and efficiency of the plant as guaranteed by the manufacturer and is assessed to be on the range of 5-7% of the total output if operations conform to the manufacturer's operational guide. The use for gardening and parks in Addis Ababa is also not very substantial at this point in time but should be taken into account for future development. The $3\text{ l/m}^2/\text{ day}$ it is a normally accepted figure. The public demand is therefore taken into account, as a percentage of the residential 15% appears to be in the right range (Twort et al, 2000)

4. Unaccounted-For Water Demand (UFW)

Ideally, if individual meter readings are taken for every customer, they should exactly equal the amount of water that is measured leaving the treatment facility. In practice, however, this is not the case. Although inflow does indeed equal outflow, not all of the outflows are metered. These "lost" flows are referred to as unaccounted-for water (UFW).

There are many possible reasons why the sum of all metered customer usage may be less than the total amount of water produced by the utility. The most common reasons for discrepancies are leakage, errors in measurement, and unmetered usage. Ideally, customer demands and unaccounted-for water should be estimated separately. In this way, a utility can analyze the benefits of reducing unaccounted-for water.

Unaccounted-for water must be loaded into the model just like any other demand. However, the fact that it is unaccounted-for means that the user does not know where to place it. Usually, the user simply calculates total unaccounted-for water and divides that quantity equally among all nodes. If the modeler knows that one portion of a system has a greater likelihood of leakage because of age, then more unaccounted-for water can be placed within that section.

Leakage: Leakage is frequently the largest component of UFW and includes distribution losses from supply pipes, distribution and trunk mains, services up to the meter, and tanks. The amount of leakage varies from system to system, but there is a general correlation between the age of a

system and the amount of UFW. New systems may have as little as 5 percent leakage, while older systems may have 40 percent leakage or higher. Leakage tends to increase over time unless a leak detection and repair program is in place.

Other factors affecting leakage include system pressure (the higher the pressure, the more leakage), burst frequencies of mains and service pipes, and leakage detection and control policies. These factors make leakage very difficult to estimate, even without the complexity of approximating other UFW causes. If better information is not available, UFW is usually assigned uniformly around the system (Walski, 2003).

5. Fire Fighting Water Demand

The amount of water used for firefighting is termed as fire demand. Although, the amount of water used in fire fighting is a negligible part of the combined uses of water but the rate of flow and the volume required may be so high during fire that it is a deciding factor for pumps, reservoirs and distribution mains.

Standards in the world relate to number of simultaneously fire incidence, duration, flow, insurance conditions, kind of construction, density of buildings, occupancy, size of buildings, etc. The needed fire flow (NFF) is to be determined by the local fire officials. These have the experience and knowledge of the local construction materials, densities, probability based on statistics, etc (TAHAL, 2015).

2.10.2 Demand Multipliers

By definition, baseline demands during a steady-state simulation do not change over time. However, in reality, water demand varies continuously over time according to several time scales:

- ❖ **Daily.** Water use varies with activities over the course of a day.
- ❖ **Weekly.** Weekend patterns are different from weekdays.
- ❖ **Seasonal.** Depending on the extent of outdoor water use or seasonal changes, such as tourism, consumption can vary significantly from one season to another.
- ❖ **Long-term.** Demands can grow due to increases in population and the industrial base, changes in unaccounted-for water, annexation of areas previously without service, and regionalization of neighboring water systems.

The modeler needs to be cognizant of the impacts of temporal changes on all of these scales.

These time-varying demands are handled in the model by either

- Steady-state runs for a particular condition, or
- Extended-period model runs

For extended-period simulations, the model requires both baseline demand data and information on how demands vary over time. Modeling of these temporal variations is described in the next section.

In steady-state runs, the user can build on the baseline demand by using multipliers and/or assigning different demands to specific nodes. Fortunately, the entire demand allocation need not be redone.

The following are some examples of demand events frequently considered:

- ❖ **Average-day demand:** The average rate of demand for an average day (past, present, or future) (TAHAL, 2015). The sum of the design demand of domestic, commercial, institutional, industrial, public and unaccounted for water (losses).
- ❖ **Maximum-day demand:** The average rate of use on the maximum usage day (past, present, or future). It is the highest demand of any one 24-hour period over any specified year.
- ❖ **Peak-hour demand:** The average rate of usage during the maximum hour of usage (past, present, or future). The highest demand of any one hour over a day.
- ❖ **Maximum day of record:** The highest average rate of demand for the historical record (Walski, 2003).

2.10.3 Time Varying Demands

Water usage in municipal water distribution systems is inherently unsteady due to continuously varying demands. In order for an extended period simulation to accurately reflect the dynamics of the real system, these demand fluctuations must be incorporated into the model.

The temporal variations in water usage for municipal water systems typically follow a 24-hour cycle called a diurnal demand pattern. However, system flow experience changes not only on a daily basis, but also weekly and annually. As one might expect, weekend usage patterns often differ from weekday patterns. Seasonal differences in water usage have been related to climatic variables such as temperature and precipitation, and also to the changing habits of customers, such as outdoor recreational and agricultural activities occurring in the summer months.

Diurnal Curves

Each city has its own unique level of usage that is a function of recent climatic conditions and the time of day. Economic growth also influences demands, but its effect occurs over periods longer than the typical modeling time horizon, and it is accounted for using future demand projections. Figure 4.2 illustrates a typical diurnal curve for a residential area. There is relatively low usage at night when most people sleep, increased usage during the early morning hours as people wake up and prepare for the day, decreased usage during the middle of the day, and finally, increased usage again in the early evening as people return home.

For other water utilities and other types of demands, the usage pattern may be very different. For example, in some areas, residential irrigation occurs overnight to minimize evaporation, which may cause peak usage to occur during the predawn hours. For small towns that are highly influenced by a single industry, the diurnal pattern may be much more pronounced because the majority of the population follows a similar schedule. For example, if a large water-using industry runs 24 hours per day, the overall demand pattern for the system may appear relatively flat because the steady industrial usage is much larger than peaks in the residential patterns.

2.11 Pressure and Leakage

In many water network systems, even though the total demand and the total loss of water can be known rather easily, information about the possible influence of local pressure upon demand is sadly lacking that as a result creates difficulty to assess and compare the demand and loss of water in its spatial distribution. Pressure distribution system on the one hand contributes to the increase of leakage, when it is more, and on the other hand when it is low contributes to the shortage of water that as a result causes for unequal distribution of water among residents. To alleviate such problems, some water authorities develop a zoning scheme whereby the complete water distribution network is broken down in to manageable segments that can be easily metered and monitored and analyzed. The leakage from water distribution systems has been shown to be directly proportional to the square root of the distribution system pressure as indicated by the relationship below (Wallingford HR., 2003).

$$\text{Leakage} \propto (\text{distribution system pressure})^{1/2} \quad (2.5)$$

Burst rates are also a function of pressure. The strength of the relationship, and the quantification of it, is not as well understood as the relationship between flow rate and pressure.

However, there is still considerable evidence to show that burst frequency is very sensitive to pressure. Evidence shows that the rate of increase of bursts is more than linearly proportional to pressure. Indeed it has even been suggested that there could be a cubic relationship that burst frequency proportional to pressure cubed (Farley and Trow, 2003 cited in Desalegne B. 2005).

In the past the conventional view was that leakage from water distribution systems is relatively insensitive to pressure, as described by the orifice equation:

$$q = C_d A \sqrt{2gh} \quad (2.6)$$

Where, q is the leakage flow rate, C_d the discharge coefficient, A the orifice area, g acceleration due to gravity and h the pressure head. In applying this equation and more general form is used:

$$q = ch^\alpha \quad (2.7)$$

Where c ($0.074 \text{ L/s/m}^{1/2}$) is the leakage coefficient and $\alpha = 0.5$ the leakage exponent (Walski et al, 2006).

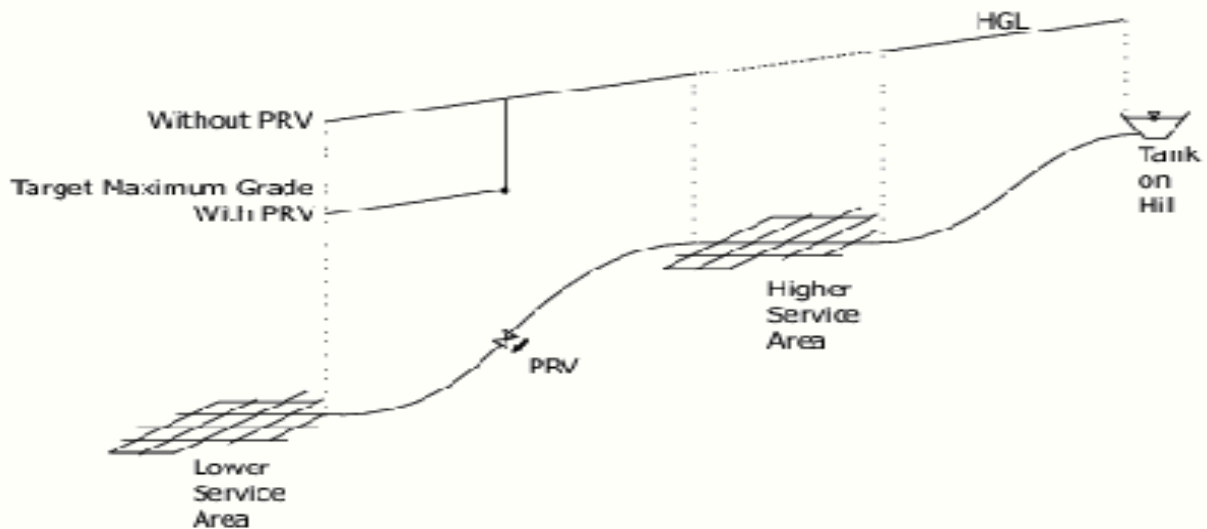
Pressure variation in distribution network is caused, among others, by changes of demand of users. The demand usually reaches a peak in the morning when people are at home and preparing their meal and its second peak in the evening. If one compares daily diagram for total demand of the whole system with corresponding data captured at the level of (relatively small) demand management areas one will discover that the first has much smaller amplitude in comparison with the later. The minimum night flow (MNF) is relatively higher and the morning/evening peaks are less prominent (Obradovic, 2000 cited in Desalegne B. 2005).

Frequent starts and stops of pumps, closure and openings of control valves that induce water hammer are also some of the causes to be mentioned for pipe breakage and water loss through leakage. The position of reservoirs also has a great impact on the pressure distribution. ‘Distribution Losses’ is the sum of losses from four different parts of the distribution system; trunk mains, service reservoirs, distribution mains and communication pipes. The combination of these assets in individual companies and supply areas are widely variable, as are the variations of pressure which are known to significantly affect leakage (Lambert and Wallace, 1993 cited in Desalegne B. 2005).

The elevation at which it is desirable to position a service reservoir depends upon both the distance of the reservoir from the distribution area and the elevation of the highest buildings to

be supplied. If the distribution area varies widely in elevation it may be necessary to use two or more service reservoirs at different levels, so that the lower areas do not receive an unduly high pressure. Generally, 45 to 75 meters static pressure is that which best suits the domestic distribution systems. Pressure below 45 meters will be likely to cause trouble in supplying extensive distribution areas; pressure above 90 meters, tend to result in excessive leakage losses (Twort A.C. et al., 1994).

The critical points which would first run dry if pressure is reduced are usually areas located at the highest elevation and excessive pressures can be reduced by adjusting the speed of pumps in areas supplied by pumping, installing a pressure reduction valves (PRV) and dividing the system in to different pressure zones. Pressure control valves are sometimes installed in outlet mains from service reservoirs in order to reduce the pressure to low lying zones, or to limit increases of pressure at night to reduce leakage. Pressure reducing valves (PRVs) throttle automatically to prevent the downstream hydraulic grade from exceeding a set value, and are used in situations where high downstream pressures could cause damage (Walski et al., 2003). Figure 2.5 below illustrates a connection between pressure zones without a PRV, the Hydraulic grade in the upper zone could cause pressures in the lower zone to be high enough to burst pipes or cause relief valves to open



Source: (Walski, Chase & Savic, 2003)

Figure 2.5 Schematic networks illustrating the use of a pressure reducing valve

In making a decision to install pressure control devices it should be born in mind that if the device fails to operate, which usually happened if the equipment is not properly maintained, then the downstream mains will be subjected to a sudden increase. Reducing pressure on the

other hand may make existing leaks more difficult to find, because they make less noise, or do not come up to the surface. Therefore, pressure reduction should be coordinated with leakage detection and repair operations (Farley and Trow, 2003 cited in Desalegne B. 2005).

2.11.1 Negative Pressures

Situations that may give rise to negative pressures should always be avoided. Faecal organisms and culturable human viruses may be present in groundwater adjacent to a pipeline and drawn into a pipe during transient low or negative pressures (Lechevallier et al., 2003 cited in Mosissa 2008). Hydraulic models can be used to identify where, when and how negative pressures may occur. Preventative measures such as system reinforcement may then be identified and implemented. Until such measures are effective, staff responsible for the daily operation of the network should be informed of these situations and hence where, when and how contamination of the network may occur. 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);
- ❖ Equipment failures (e.g. pumps and valves,).

2.11.2 Pressure Management

Pressure transients and extremely high peak pressures are major causes of failures and leaks in the distribution network. From the results presented, the pressure management approach seems to help maintain average pressures throughout the system, eliminating extreme transients in pressure during peak hours and preventing pipe damage. The district metered area approach can also contribute to pressure management since it can eliminate negative pressures within the network, which can potentially allow contaminants entering the system if leak exist. Adequate installed and maintained pressure reduction valves could provide the distribution network with an easy, cost-effective leak prevention method significantly reducing the risk of leakage (Faraj, 2013). Pressure management is one of the fundamental elements of a well-organized leakage management strategy. It should be an integral part of the strategy because it has a number of benefits such as

- ❖ it reduces amount of leakage to help meet water conservation targets

- ❖ improves the reliability and continuity of supply by reducing pipe breaks
- ❖ reduces pressure fluctuations to achieve more consistent water pressure across the system
- ❖ Extends the life of our water supply pipes and assets.

2.12 Water Loss in the Subsystem

Water Losses refer to the total amount of water flowing into the water supply network from a water treatment plant, borehole system or imported bulk total amount of water that consumers (domestic, commercial, industrial and institutions) are authorized to use (the Authorized Consumption) (USAID,2010).

Water losses are categorized as either real or apparent:

Real Losses, also referred to as physical losses, are actual losses of water from the system. When performing financial calculations related to real losses, the water is priced at the cost of production rate since it is not available for a consumer to use and costs only what it takes to produce. Correcting real losses will result in lower operating cost through reduced production requirements and reduced water process chemical and electrical use

Apparent losses, also referred to as commercial losses, occur when water that should be included as revenue generating water appears as a loss due to theft or calculation error. Apparent losses consist of unauthorized consumption, metering calibration errors and data handling errors (EPA, 2004).

Revenue Water is water that is consumed and for which the utility receives payment. Revenue water consumption volume is measured or estimated. Revenue water includes metered and un-metered billed authorized consumption.

Non-Revenue Water (NRW) is water that is not billed and no payment is received. It can be either authorized, unauthorized or result from a water loss. Authorized NRW consists of unbilled metered consumption and unbilled un-metered consumption.

$$NRW = \text{System Input Volume} - \text{Billed Authorized Consumption} \quad (2.8)$$

Non-revenue water is becoming the standard term replacing unaccounted-for water (UFW) in many water balance calculations and is the term recommended by the International Water Association in preference to UFW. It is a term that can be clearly defined, unlike the unaccounted-for water term, which often represents different components to the various water

suppliers (Wagelin et al 2007).

Neither the term “unaccounted-for-water” nor the use of percentages as measures of water loss is sufficient to completely describe the nature and extent of distribution system water loss. Unaccounted-for-water is a term that has been historically used in the United States to quantify water loss from distribution systems. Unaccounted-for-water, expressed as a percentage, is calculated as the amount of water produced by the PWS minus the metered customer use divided by the amount of water produced multiplied by 100, or (EPA, 2009).

The American Water Works Association has identified three major categories of “losses” in a water distribution system. These categories are:

1. Accounted for losses
2. Real losses
3. Apparent losses

Accounted for losses occur at metered locations. Water meters are typically placed at service connections to monitor the amount of water that a billable customer uses and may also be placed on service connections to non-paying customers who put the water to beneficial use. Non-billable customers typically include municipal users and the fire stations. All water that is metered, whether billable or un-billable can be identified and quantified by the utility so that accurate records of water usage can be recorded. All usage of water which is metered, regardless of billable or un-billable, is classified as accounted for losses.

Real losses are the physical losses of water from the distribution system which cannot be tracked by the utility. Typically they occur because the utility did not meter the quantity of water leaving the plant. These losses inflate the water utility’s production costs and stress water resources since they represent water that is extracted and treated, yet never reaches beneficial use. Examples of this type of loss include leakage, storage overflows and breaks in the water mains.

The third type of water loss, apparent losses, is the losses that occur in utility operations due to customer meter inaccuracies, billing system data error, unauthorized consumption and authorized un-metered consumption. This is water which is consumed but not properly measured, accounted or paid for. These losses cost utilities revenue and distort data on customer consumption patterns. Authorized un-metered consumption losses are typically put to beneficial use by the municipality or utility and are commonly used for flushing water mains and fire fighting (Brown, 2007).

2.13 Review of Related Works

The following are review of scholarly research conducted on related areas:

Several researches and studies have been made to study the behavior of water distribution systems, and to reach an optimal solutions and assumptions in order to improve the hydraulic performance, cost effective, and to increase the efficiencies of the water supply networks.

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

(Vairavamoorthy et al., 1998) studied the leakage reduction in water distribution systems depending on optimal valve control. The inclusion of pressure- dependent leakage terms in network analysis allows the application of formal optimization techniques to identify the most effective means of reducing water losses in distribution systems. They describe the development of an optimization method to minimize leakage in water distribution systems through the most effective settings of flow reduction valves.

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

The built and calibrated model showed to be fairly accurate and is key issue in decision-making for water supply management. The simulation model allowed a better knowledge of the network's physical structure working as a worth tool for inventory updating and anomalies mitigation. New operating configurations have been proposed to achieve excessive pressure reduction and a sustainable distribution of pressure reducing valves on technical points economically more

favorable. The control of pressure within the network nodes and the reduction of water losses in the system is noteworthy as it is one of the more complex problems to deal with concerning water supply networks (Alves.Z, 2013).

(Vanzyl et al., 2014) this paper summarized the main theory of factors that influence the pressure-leakage relationships in water distribution systems. Pipe material behavior (i.e. expanding leak areas with increasing pressure) is the main factor responsible for the high leakage exponents observed in field studies, but leak hydraulics, soil hydraulics, water demand and the way individual leaks combine in a pressure management zone can also influence this relationship.

(Byakika et al., 2006) studied the hydraulic impact of water supply network expansions. The research enabled improved understanding, and quantification of the exact impact that water supply expansions have on network hydraulics. The science of the parameters that affect flow and pressure was analyzed and understood. In the research result shows the key indicators of customer satisfaction were chiefly pressure, velocity and head loss. The findings of the research show that according to the current water production, even already existing customers cannot be guaranteed reliable supply of the pressures of at least 1 bar at all times in some sections of Zone.

The research intended to study the relationship between network expansions and the pressures. Pressures were found to fall with an increase in extensions. Terminal water pressures at most customers' premises were less than one bar, considering that at the nodes pressures are just about 20m. The hydraulic grade line between the nodes and the ultimate point of consumption continuously falls. It should be remembered that the recommended terminal water pressures should be at least 20m. Fallen pressures are due to higher abstractions from the network, attributed to high demand. The discharge from the pipes is much higher than intended. Head loss increases with discharge according to the Darcy-Weisbach formula. Higher pressures can be achieved by regulating the amount of water going out of the network. This is by regulating the extent of extensions to consumers. The fallen pressures can also be revived by installing booster stations at strategic locations. Proper marking and observance of hydraulic pressure zones would also help manage water supply in the respective areas.

Pipe velocities were also found to fall with increasing extensions. Pipe velocities are low, generally below 1.0 m/s, and this affects the quantity of water received by the customer. Since

Flow rate (discharge) = Cross sectional area x velocity, flow is majorly a function of velocity, the area being constant. Velocity range can also be adopted as a design criterion. Low velocities are not preferred for hygienic reasons, while too high velocities cause exceptional head-losses. The best solution would be to increase the capacity of the production plant and the sizes of the transmission and distribution mains. Reliability of supply is low. Customers receive intermittent supply, and others hardly ever receive water, to the extent that these areas are labeled “dry zones”.

Extensions should be carefully planned before execution. The design criteria for hydraulic gradients depends on the adopted minimum and maximum pressures, the distance over which the water needs to be transported, local topographic circumstances and the size of the network, including possible future extensions. Going by the then situation, no major extensions should be made on the network. Instead, rationalization of the network has got to be carried out. By this, some pipes may be replaced with different pipe sizes, and valves have got to be optimally operated.

(Mazanek et al., 2014) The properly made and calibrated model can bring about substantial saving due to the elimination of wrong capital investments, by providing the capability to test various solutions, as well as to compare the effects of each of them. It also enables the design of solutions concerning periodically shutting down select water pipe sections for the duration of repairs or making new capital investments (e.g. extending the network) in a manner that causes the least possible nuisance to the users. From the performed analysis with the use of computer modeling, simulation results were obtained based on which of the following concluding remarks regarding the network concerned have been formulated:

1. The analysis of the distribution of velocity, made on the existing water pipe network model, has shown that in the majority of lines the velocity values are lower than the recommended value of 0.5m/s. In a large number of lines, even at that time of the maximum water demanded, conditions prevail, which cause stagnation of the water the velocity is lower than 0.1 m/s.
2. Using fire hydrants for flushing the network allows the flow velocity to be periodically increased, while not adversely affecting the supply of water to the users.
3. The developed hydraulic model provides a useful tool in the operation of the water pipe network to be analyzed at increased water withdrawals or during planned over hauls For

example, it has been verified that cutting off the flow on a select network section will not adversely affect network operation; despite some decrease in water pipe pressure, the water will reach all the users in the required quantity and under the proper pressure

Review of Scholarly Research for Addis Ababa City Water Supply Context:

The other research reviewed was conducted by Mosissa Meressa Gamtessa and titled “Pressure Modeling for Leakage Reduction in Addis Ababa Water Supply System Mains (The case study, Saint Paul and Rufael subsystem)”. The intention of the researcher was to generate a water supply mains model representing the existing states of the city water supply mains pressure in selected sub distribution systems of Saint Paul and Rufael and to evaluate the effect of the obtained pressures on leakage. The researcher attempted to analyze leakage at city level in order to quantify real loss and model pressure mains in selected sub –city. In his findings, he found from leakage analysis part that water leakage in the city is 35.67%. From pressure modeling section, he found excessive pressure at some nodes with pressure of 80m almost all the day, above the recommended maximum for leakage.

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

The present study is similar to reviewed research for Addis Ababa context in many aspects. The place in which the research conducted, conceptual frame work, approach of data collection, method of data analysis and tools used for analysis is almost the same. But the current study is different in its scope. Unlike the above two research, it is not limited to Hydraulic modeling. It includes also hydraulic and water quality modeling, supply and demand gap analysis and water loss at the same time, which was neglected in the previous studies. The fate of water quality constituents in the study water supply distribution system is investigated besides pressure modeling.

2.14 Conclusion

This literature review identified and discussed hydraulic theory, model input characterization, model selection and application, hydraulic modeling software, and model calibration as the key considerations for successful hydraulic simulation. Important observations from the review included the application in hydraulic simulation of the fundamental equations for hydraulic analysis. Subsequent chapters illustrate methodologies and activities derived from this consideration, which were used to construct the model and perform the required accuracy analysis.

3. RESEARCH METHODOLOGY

3.1 Introduction

Based on the research objectives and questions stated in the introduction chapter the method how the research was carried out is discussed in this chapter. The methods of data collection and data preparation are also discussed in this chapter. Generally the research is divided in to two major parts, to model and analysis the existing Bole Bulbula water distribution network system and to suggest improved network. Monthly water production and consumption data is used to evaluate the water loss at all levels. After identified the characteristics of water line network, the hydraulic performance parameters is tried to be evaluate using the different desirable criterion that have an impact to the water distribution network in the systems.

3.2 Research Process

The approaches adopted for each of the system components to perform the model are described below.

- ❖ . Literature review
- ❖ Collection of all the existing water distribution system and other related available data.
- ❖ Generate missed data for modeling system
- ❖ Built the existing water distribution layout using Auto CAD 2007 tools software for Water CAD model representation.
- ❖ Data entered into the built model
- ❖ Check the status of the valves in the model (closed or regulated) considered according to status.
- ❖ The model is going to be simulated for both single period and extended period.
- ❖ The existing water supply network simulated model will be calibrated by direct field measurement with the sample hydraulic parameters (pressure, velocity, residual chlorine and water age etc.)
- ❖ The water supply network model which is simulated using Water CAD also has to be validated using different techniques.
- ❖ Run the simulation for the purpose of analysis.

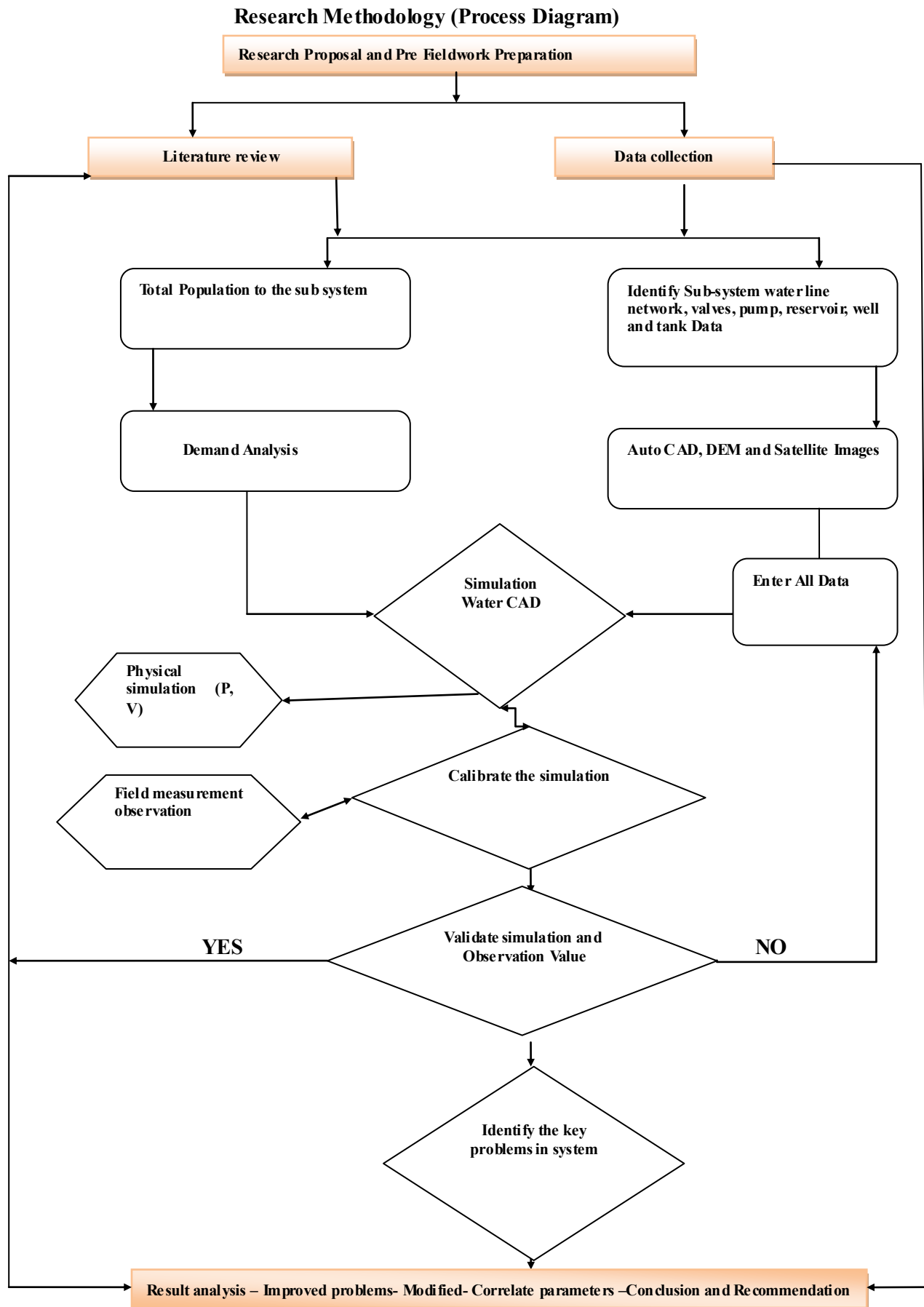


Figure 3.1 Research process diagram**3.3 Data Collection**

Prior to the fieldwork, cadastral information prepared by the Addis Ababa municipality about 10 years ago use as a base for the selection of the study area. It is planned to collect secondary data from AAWSA and the other similar offices of the city administrative and the like . Supportive qualitative information through discussion with local experts of AAWSA direct concerned different technical staff and departments.

3.3.1 Secondary Data Collection**3.3.1.1 The Study Area Water Line Network**

A digital water network for the entire study area including their attribute like the size, age and material of the pipes collected in AutoCAD format. The collected pipe network mainly comprises of main pipes and secondary pipes that covers the major part of the area. The data on the network would be found from two sources within Megenagna branch office and AAWSA head office.

3.3.1.2 The Study Area Water Reservoirs

In order to evaluate the water supply coverage and the water loss, customers' monthly consumption data has to be collected from AAWSA water consumption bill data preparation section . There are more than 4109 number of customers within the study area . Beside to consumption (meter readings), the data includes information on Wereda and Kebele and unique number and the information on location the water reservoir collect in conjunction with the main water network on the study area . The reservoir's data including their capacity, years of construction and material of construction also has been collected. The locations of some of the reservoirs are not exactly indicated in the network, and the document found from the planning department indicates only the surrounding where they are located. Some of the reservoirs serve as transfer point to other reservoirs located elsewhere in addition to serving as a distribution to the surrounding areas.

3.3.1.3 Contour of the Study Area

Although a 5 meter interval contour is available before the fieldwork, it has a basic problem like discontinuity in the contour lines and most of the contour lines are missing their elevation values. For this reason getting other sources necessary that a 20 meter

interval of contour with its corresponding digital elevation model (DEM) is found from the planning department of AAWSA.

3.3.1.4 Water Production

According to, the information found during discussion with the AAWSA experts, no other water sources for Bole Bulbula distribution network system. As there was no organized data, the water production collected from the Akaki well field to ground water collection tank (GW3) which is the sources to system. Beside to the water production for the entire study area data on monthly water distributed to systems has been collected from water meter installed at the source reservoir outlet.

3.3.1.5 Water Consumption

In order to evaluate the water supply coverage and the water loss, monthly consumption billed data required. There are more than 4109 customer numbers in the system, out of this 3681 is domestic and 413 non-domestic and 15 is stand pipe. These customers within the entire area have been considered to estimate domestic water supply coverage, water loss, and demand and gap analysis purpose.

3.3.1.6 Cadastral Information

The data includes information on buildings, parcels and blocks for each Kebeles which are located in former Weredas. The data was about 10 years old that was not updated in between.

3.3.1.7 Population and other documents

Beside to a census document of the country (10 years old), number of population by each Kebele projected for the desired year has to also collect from the central statistical agency (CSA). Besides to these, some relevant documents collect from the water authority.

3.3.2 Primary Data Collection

There are many parameters measured directly to estimate water loss amount and for model calibration and simulation. The amount of water production measure from the main water release tanks which is the head of the subsystem and most parameters also has to be measured directly to the most significant values costumers tap to evaluate nodal pressure and water quality analysis. Please see the checklist for the discussion with the experts in Appendix A.

3.3.2.1 Sampling Size and Location

Having developed the sampling design problem defining the limiting constraints for the sampling frame, systematic random sampling was done to obtain two distinct sets of field measurements. The sizes of samples selected for the study were 2% of for all the network junctions, as indicated in the literature review see Table 4.8 the criteria for sample size selection in order to evaluate the calibration of the model and observed data.

Sampling location

Atypical network representation of a water network may include hundreds or thousands of links and nodes. Ideally, during the water distribution model calibration process is adjusted for each link and each node. However, only a small percentage of representative sample measurements can be made available for the use of model calibration due to the limited financial and labor requirements for data collection. Therefore, it is most important to have a comprehensive methodology and efficient tool that can assist the engineer in achieving a highly accurate model under practical conditions (Bentley, 2008).

Selection of sampling sites is typically a compromise between selecting sites that provide the greatest amount of information and sites that are most amenable to sampling. Sites should be spread throughout the study area and should reflect a variety of situations of interest, such as transmission mains and local lines, areas served directly from a source, and areas under the influence of tanks. In addition, sampling taps should be placed close to mains.

Data collection can be classified as either point reading (grab samples) or continuous monitoring. Point reading involves collecting data for a single location at a specific point in time, and continuous monitoring involves collecting data at a single location over time. For point readings, samples should be collected at locations where the parameter being measured is steady so that the sample measurement is representative of the location over a long period.

Five representative samples according to (USEPA, 2005, Calibration Guidelines) see Table 4.8 measurements to the water main spread throughout the study area have been selected for the calibration. It was difficult to take measurement at a direct connection to the water main nodes, due to size of pressure gauge available in AAWSA, which is 25mm.

The measurements were taken at a location other than the direct connection to the water mains,

nearer to the supply main nodes at homes faucet. The locations of the representative samples of a supply main nodes and the corresponding home faucet (field test) are shown in Table 4.9 and 4.10 and Figure 4.3. As a result, 100% of the field test measurements were within ± 2 m, showing an acceptable level of pressure calibration criteria. The comparison of model simulated and field test are shown Table 4.9 and 10 and Figure 4.4 and 4.5.

This is carried out to examine the levels of accuracy between the model and the actual physical network. Field test locations for this exercise are identified through a process known as the sampling design problem which essentially defines the limiting calibration criteria that delineate the test-location sample space (Walski, 2003). Test-location sampling is done randomly and the following limiting criteria often used (AWWA, 1999).

1. Sampling points should be at the extremities of the network, a considerable distance from the Boundary nodes in the network (reservoirs and tanks).
2. Selected points should also have relatively high discharges and pressures.

The actual values of the minimum distance from boundary nodes, minimum discharge, and minimum pressure are relative and unique to a given model. They are therefore selected having considered the system hydraulics and constraints of the modeling environment (Kapelan, 2003). However, prior to testing reconnaissance must be carried out to assess the suitability of the selected test sites. Reconnaissance is done by physically examining the network to establish which mains and junctions in the network are actually accessible for testing purposes. Accessible mains and junctions then define the sample space from which field measurements can be taken. Additionally, during reconnaissance the modeler should establish under what conditions pump operators turn on a pump, and under what conditions valves are opened or closed. There is also need to establish which facilities represented in the model are actually operational. It is necessary to establish whether some facilities are off-line for maintenance or repair.

Sampling size

In general, international proposed guidelines stipulate that for a medium to highly detailed network model (medium to low skeletonization), the following limits should be adopted modeling based on (USEPA,2005) model calibration criteria guidelines for modeling pressure and flow criteria as mentioned below :

To use the Table 4.8 first select the aim or intended use list then fix the sample nodes to be observed. For this thesis the study area water supply network is already existed in this case prefer

intended use would be operations. According to operational case criteria the sample size and calibration of node pressure, flow and water quality criteria set up as shown below (USEPA, 2005).

Pressure:

1. Number of pressure reading 10%-2% of nodes and accuracy of pressure readings ± 2 psi(1.4m)
2. Number of flow reading in the pipe 2% of pipes and accuracy of flow readings $\pm 5\%$.
3. Water quality number of pressure reading nodes 2% of nodes and accuracy of pressure reading 5%.

3.4 Data Preparation

3.4.1 Water Line Network

The data on study area water network that collects from two sources are in Auto CAD format, one of it from technical department of AAWSA head and Megenagna branch office . Before exporting the Auto CAD format network in to Water CAD reviewing the network in its original format was necessary that Auto CAD software has been installed in order to do so. While the network are reviewed in its original format, the pipe diameter, year of construction (replacement) and its material type is found written as an annotation that makes it difficult to export as it is in to Water CAD. On the other hand a specific code has been assigned as a layer to each annotation. After reviewing which type of code does represent to which description in Auto CAD, the network has been exported to Water CAD.

3.4.2 Domestic Water Supply Coverage

Water supply coverage is usually evaluated based on the quantity, quality, paying capacity of the people, distance, etc., but the intention of this research is not to evaluate all these but related to the quantity of supply and level of connection that are related to the water loss. In this part of the analysis, the number of domestic connections per family and the average daily per capita consumption are used to analyze the domestic water supply coverage for the entire system. Access to water supply may be evaluated using the amount of water consumed and the level of connection. For evaluating the amount of water consumption, the annual water consumption is converted to average daily per capita consumption using the population data of Bole Bulbula subsystem. The number of domestic connections per family has been also used for

analyzing the level of connection as elaborated below.

1. Average Daily Per Capita Consumption

The volume of water consumed for domestic purpose has been aggregated to all customers' of the system so as to analyze the distribution of the water coverage in the study area. Evaluating the domestic water supply coverage using volume of consumption may not allow realizing the distribution comparison among the study area (Desalegn, 2005).

$$\text{Per Capita Consumption (l/p/d)} = \frac{\text{Annual Consumption (m}^3\text{)} * 1000 \text{ l/m}^3}{\text{Population number of system/365 days}} \quad \text{-----(3.1)}$$

2. Level of Connection per Family

Level of water connection is an important element on the one hand for evaluating the level of water coverage that will be the focus of this section and on the other hand it has a direct impact on the water loss that will be dealt separately. According to AAWSA ,megenagna branch office billed data ,the total numbers of connections or water meters with in the study area are about 4109 that among these, 3681 are domestic customers , 413 non-domestic customers and 15 standing pipe or public taps. According to CSA, statistical report on employment of survey of Addis Ababa, 2014, average house hold family size of 3.8 is used for Bole Bulbula, calculating the average number of connection per family in Bole Bulbula area, using the following expression.

$$\text{Connection per family} = \frac{\text{Total number of connection}}{(\text{Total Population number /Average family size})} \quad \text{----- (3.2)}$$

3.4.3 Water Loss Calculation

Neither the term “unaccounted-for-water” nor the use of percentages as measures of water loss is sufficient to completely describe the nature and extent of distribution system water loss. Unaccounted-for-water is a term that has been historically used in the United States to quantify water loss from distribution systems. Unaccounted-for-water, expressed as a percentage, is calculated as the amount of water produced by the PWS minus the metered customer use divided

by the amount of water produced multiplied by 100.

$$(Unaccounted - for - Water) \% = \frac{(Water Produced - Metered Water Used)}{Water Produced} * 100$$

----- (3.3)

3.4.4 Water Demand Estimation

The consumption or use of water, also known as water demand, is the driving force behind the hydraulic dynamics occurring in water distribution systems. Anywhere that water can leave the system represents a point of consumption, including a customer's faucet, a leaky main, or an open fire hydrant (Jeffrey .A). Water demand estimation is one of the basic inputs to select source of water supply and to find the amount of water required to fill the gap between supply and demand of the subsystem.

Three questions related to water consumption must be answered when building a hydraulic model:

- (1) How much water is being used: peak and daily average?
- (2) Where are the points of consumption located?
- (3) How does the usage change as a function of time? This chapter addresses these questions for each of the three basic demand types described below.

- ❖ Customer demand is the water required to meet the non-emergency needs of users in the system. This demand type typically represents the metered portion of the total water consumption.
- ❖ Unaccounted-for water (UFW) is the portion of total consumption that is “lost” due to system leakage, theft, unmetered services, or other causes.
- ❖ Fire flow demand is a computed system capacity requirement for ensuring adequate protection is provided during fire emergencies.

Determining demand is not a straightforward process like collecting data on the physical characteristics of a system. Some data, such as billing and production records, can be collected directly from the utility but are usually not in a form that can be directly entered into the model. For example, metering data are not grouped by node. Once this information has been collected, establishing consumption rates is a process requiring study of past and present usage trends and, in some cases, the projection of future ones.

The total water supply of a city is usually distributed among the following four major classes of consumers: domestic, industrial, commercial, and public. Overestimating the water demand it is a cause for uneconomic investments and operational costs. In spite of uncertainties, planners have developed methods, which are used in forecast. But must be clear that forecast is not a prediction. Inappropriate or unintended assumptions may be made. For projection of water demand many factors may intervene. Inexactness in population projection or changes in the mix of house hold types. Forecast is made for various horizons: short, medium or long term, time extrapolation, coefficient method for unit use and per capita demand method. Hence, for this particular study because of the shortage of data available per capital demand is adopted.

Per capita demand method

This is the most widely used for long time by utilities. The method assumes that only one variable, the population, provides adequate information on the water use and the development of use.

3.4.4.1 Baseline Demand

Most modelers start by determine baseline demands to which a variety of peaking factors and demand multipliers can be applied, or to which new land developments and customers can be added. Baseline demands typically include both customer demands and unaccounted –for water. Usually, the average day demand in the current year is the baseline from which other demand distribution is built. (Walski et al 2003). Average per capita demand for the study area has been adopted from water demand production and consumption relationship. In this study base line demand is estimated in considering the current per capita demand calculation; see the calculation procedures below here:

$$\text{Per Capita Consumption (l|p|d)} = \frac{\text{Annual Consumption (m}^3\text{)} * 1000 \text{ l/m}^3}{\text{Population number of system/365days}} \quad \text{----- (3.4)}$$

3.4.4.2 Fire Fighting Water Demand

The amount of water used for firefighting is termed as fire demand. Although, the amount of water used in fire fighting is a negligible part of the combine uses of water but the rate of flow and the volume required may be so high during fire that it is a deciding factor for pumps, reservoirs and distribution mains.

Standards in the world relate to number of simultaneously fire incidence, duration, flow, insurance conditions, kind of construction, density of buildings, occupancy, size of buildings, etc. The needed fire flow (NFF) is to be determined by the local fire officials. These have the experience and knowledge of the local construction materials, densities, probability based on statistics, etc (TAHAL, 2015).

Many formulas can be used to estimate the amount of water needed for fire and the most applicable formula is used all over the world as follows to calculate the fire fighting water demand:

National Board of Fire Underwriters (NBFU) for communities less than 200,000 inhabitants

$$Q_F = 231.6\sqrt{P}(1 + 0.01\sqrt{P}) \quad (3.5)$$

Where, Q_F = fire demand (m³/hr)

P=Population in 1000's

Note: this formula is used for sizing reservoir taking the community as whole and should not be used for distribution system pipes.

The number of expected fires that may occur simultaneously is calculated using the following formula:

$$\text{No. of fire hydrants} = \frac{\sqrt{P}}{3} \quad (3.6)$$

Where, P= is the population in thousands

Lately the City of Addis Ababa has made a first attempt to regularize the firefighting within the city. The recommendations refer to:

Location: at corner of streets to serve two directions and only on road wider than 6 m.

Spacing: according to the population density between 150-500m.between two successive hydrants.

Connections : on mains or distribution pipes equal or higher than DN 150 mm.

Head: pressure in network of 30-50m. The pressure zones provide for higher heads in the peak hour as the difference in topographical levels is 80 m. and AAWSA should be able to supply only buildings not higher than 3-4 floors. During fire occurrence the meaning of “peak hour” could be waived and water diverted to needing areas on the account of regular areas of supply higher head could be obtained in certain areas by operating the valves. On the other side higher investments in the network, high in any case in a water supply system, could be avoided if the fire brigades

are endowed with suitable mobile pumps.

Big buildings: These must be prepared with local firefighting facilities (internal hydrants, sprinkler installations, suitable storage reservoirs, etc.) and the plumbing code of practice must be applied.

Table 3.1 Required fire flow durations

Required fire flow (L/min)	Duration (hr)
<9000	2
11,000-13,000	3
15,000-17,000	4
19,000-21,000	5
23,000-26,000	6
26,000-30,000	7
30,000-34,000	8
34,000-38,000	9
38,000-45,000	10

Source :(AWWA, 1992)

By using above equation for firefighting water demand formula, the estimated quantity is 19014.8 lit/min from the Table 3.1 above the flow duration will be 5 hour need in a day in the subsystem.

3.4.4.3 Nodal Demand Calculation

Demand allocation to consumption points are estimated using the following procedures

1. Population size for each node.
3. Water demand is projected based on the current, design and future
4. Location of nodal demand or consumption points is selected for demand allocating in the study area.
5. Service areas for each consumption point are delineated.
6. The delineated areas are overlapped to the GIS based Auto CAD.
7. Nodal demand is calculated using the following formulae. (Bentley, 2008

$$N_d = \sum(P_i * d_j) \quad (3.7)$$

Where;

N_d = Nodal demand

P_i = population in each nodes of the service area

d_j = per capital demand for each pressure zones of the service area

i = subscript referring to the i -th nodes in the service area

j = subscript referring to the j -th pressure zone in the service area

3.4.4.4 Projecting Future Water Demand

Water distribution models are created not only to solve the problems of today, but also to prevent problems in the future. With almost any endeavor, the future holds a lot of uncertainty, and demand projection is no exception. Long range planning may include the analysis of a system for 5- 10 and 20-35 year time frames. When performing long term planning analyses, estimating future demands is an important factor influencing the quality of information provided by the model (Walski, 2003).

The most of conceptually simple routinely used approach is to estimate water use (Q_t) at a future time (t) by multiplying the future population (P_t) by a per capita water use rate (r_t) as follows

$$Q_t = r_t P_t \quad (3.8)$$

Where,

Q_t = Estimate water demand

r_t = Per capita water demand

P_t = future projected population, for future time (t)

Per capita water use rates can be estimated based on water use records for a particular city, or alternatively, regional or national use rates can be obtained from the literature (Walski, 2003).

Transfer and distribution Main Lines

A transfer main is defined as a conduit for the conveyance of treated water from reservoir to reservoir. The capacity of a transmission main is determined by the maximum daily water demand.

The capacity of main distribution grids is determined by the peak hour demand.

Pressure and Velocity

The design criteria used in the design of pressure zone boundaries, nodal pressure during the period of peak demand, and optimum velocities of the transfer and distribution mains are as follows:

Velocity in the Mains (TAHAL, 2015)

Maximum velocity of main transfer lines < 2.5 m/s.

- ❖ Maximum velocities of distribution mains < 2 m/s to prevent erosion and high head loss
- ❖ Minimum distribution lines 0.6m/s to prevent water sedimentation
- ❖ Minimum velocity at service taps 0.05m/s

Hydraulic Calculations

Based on the Hazen-Williams formula and friction factor (C) of are varied based on the material type example DCI, GS, PVC, 120,130 and 150 respectively once if the material type inter software it automatically calculated friction factor.(Bently,2008)

Pressure (TAHAL, 2015).

- ❖ Minimum static head is 20 m or 2bar, which can supply a 4-storey building from the distribution system.
- ❖ Maximum static head within a pressure zone was limited to 80m.

3.5 Modeling the Existing Distribution System

To analyze and improve the existing water distribution system, a model was developed utilizing Water CAD software (Water CAD for Auto CAD software). Water CAD is selected for this study because of the following reason;

- ❖ It is aided with good quality of manual.
- ❖ Its integration with other external software's, like Auto CAD; Microsoft excel, Global Mapper and GIS applications.
- ❖ It requires less effort and shorter time to build a model than others do.
- ❖ AAWSA has a license of Water CAD 6.5 version software.

3.5.1 Existing Data

Existing available data describing the system have been gathered to generate the system water distribution modeling these parameters are basic for hydraulic modeling some of them are mentioned below herein:

3.5.1.1 Water Supply Networks

From the system map of the network, the following information was available and collected from AAWSA. The water distribution network is available in Auto CAD software having the following system information:

- ❖ The existing water distribution network Layout.
- ❖ Pipeline data like material type, size, and length and year of installation.
- ❖ Locations of other system components like reservoirs, tanks and valves in the network.
- ❖ Background information such as:
 - Addis Ababa city roadways and 2005 Areal map.
 - AAWSA branch boundary.

3.5.1.2. Collection Tanks

Tank information has been gathered from Addis Ababa Water Supply Project III A (TAHAL, 2015) and from AAWSA (Unaccounted for water and System Control and Monitor Performer Team). Information about the tanks diameter, base elevation, minimum elevation, initial elevation and maximum (over flow) elevation, use Table 3.2.

Table 3.2 Tank information of the system

S.no	Level	Base Elevation (m)	Tank Diameter (m)	Minimum Elevation (m)	Initial HGL (m)	Maximum Elevation (m)
1	BBR1	2272.00	27.50	2272.60	2274	2276.00

3.5.1.3 Population Projection

Census record of population size of Addis Ababa city for different years has been collected from the Central Statistical Agency. Geometric Increase method of population forecasting has been adopted for this research. Because this, method is mostly applicable for growing towns and cities having vast scope of expansion, like Addis Ababa city. Moreover, it is based on the assumption that the percentage increase in population remains constant. The following formula has been adopted for the population projection.

$$P_n = P_o * (1 + K)^n \quad (3.9)$$

Where;

P_o = initial population

P_n = population at n decades or years

n = Decade or year

K = percentage (geometric) increase

1961	- 443,728	
1967	- 683,53	6 years at 7.60% growth
1978	- 1,167,315	11 years at 4.99% growth
1984	- 1,423,111	6 years at 3.63% growth
1994	- 2,112,737	10 years at 3.57% growth
2030	-6,236,000	36 years at 3.05% growth

For this study 3.05 % growth rate from 1994 up to 2030 is adopted as the coming year increase the population increase rate decrease as the result shown above (TAHAL, 2015).

3.5.1.4 Peak Factors

For some consumption condition, specially predicted consumption, demands can be determined by applying a multiplication factor or a peaking factor. For example, a modeler might determine that future maximum day demands will be double the average-day demands for a particular system. The peaking factor is calculated as the ratio of discharges for the various conditions. For example, the peaking factor applied to average-day demands to obtain maximum day demands can be found by using Equation (3.10).

$$PF = \frac{Q_{\max}}{Q_{\text{avg}}} \quad (3.10)$$

Where

PF = peaking factor between maximum and average day demands

Q_{\max} = maximum day demands (m^3/s)

Q_{avg} = average day demands (m^3/s)

Determining system-wide peaking factors is fairly easy because most utilities keep good records on production and tank levels. However, peaking factors for different types of demands applied at individual nodes are more difficult to determine, because individual nodes do not necessarily follow the same demand pattern as the system as a whole.

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 they must be determined based on the demand characteristics of the system at hand (Walski et al 2003).

Peak factor for a water distribution designing can also estimated from the ratio of peak hourly demand on a maximum demand day during the year over the average hourly demand over the same period (Swamee, 1940).

Table 3.3 Peak day and peak hour factors

Peak day factor

1.5 For population over 10,000

2 for population below 2000

Peak hour factor /peak factor

2 for population over 10,000

5 for population below 2000

Water demand in a distribution system fluctuates over time. This variation in demand over time can be modeled using demand patterns. Demand patterns are multipliers that vary with time and are applied to a given base demand, most typically the average daily demand. The variation in water consumption over a 24-hour period was adopted which had been investigated. Use Table 3.4.

Table 3.4 Demand multiplier of Addis Ababa water supply in 24 hour

Time from start (hour)(0:00)	3	6	9	12	15	18	21	24
Multiplier	0.3	0.4	1.3	1.2	1.0	1.2	0.5	0.4

Sources: (TAHAL, 2015)

3.6 Data Entering

All the data have been entered into the skeletonized water distribution network using dialog box type of data entering. These data are the following.

- ❖ The gathered data have been entered in to the sketched water CAD model.
- ❖ The ground elevations of reservoirs, tanks, nodes, pumps, valves and other locations have been interpolated and entered by superimposing a topographic map on a map of the network model throughout the system. The 1m contour interval has been used for the interpolation of ground elevation of different locations or DEM elevation extraction method.
- ❖ Average-day demands have been allocated to nodes using a simple unit loading
- ❖ Method, the number of customers that contribute to the demand at every node and

multiplying it by the unit demand. By careful examination of the distribution system, the entire demand was allocated to a node or combination of nodes, as appropriate. Peaking factor for each nodal demand have been entered.

Hence, the distribution system has been configured for each updated pipe network with local technicians, who are currently works as a supervising and controlling the system as whole, by carefully identifying the location of high elevation and low elevation zone of the system.

3.7 Model Representation

All the existing water distribution Bole Bulbula subsystem components model skeletonization is sketched using the following considerations and steps.

Steps followed are:

- ❖ Selection of pipelines for modeling has been based on the primary line, all pipelines of the system having a diameter greater than or equal to 40mm.
- ❖ Bole Bulbula water distribution Subsystem will delineate from the existing Auto CAD Addis Ababa city water distribution system.
- ❖ The network of the system is sketched out by over laying on the AutoCAD's distribution components using Water CAD tools in Water CAD for AutoCAD software, like reservoirs, tanks, pumps, valves, pipes and so on.
- ❖ In accordance with the requirements of the model, a node will be located at all points where the pipeline diameter changed or where three or more pipelines joined.

3.8 Model Calibration and Validation

For model calibration and validation effort data were collected from field selected sample locations. The required collected data include: pressure and residual chlorine. For each node record was taken five times at different times in single days. Model calibration and validation were undertaken based on the different calibration standard criteria for hydraulic network and water quality modeling.

3.9 Data Analysis and Presentation

The physical characteristics of the system were represented in the model by nodes and pipes (or elements). The nodes, joined together by pipes, pipe junctions, changes in pipe diameter and the locations of system attributes such as valves and of large demands. The node and pipe data sets contain geographic co-ordinates, ground levels, basic demand data, internal diameter and friction

coefficient, service reservoir geometry, valve performance characteristics.

Water demand was allocated to the node nearest to its draw off point. Nodal demands were distributed based on population estimates served by the nodes; with considerations of patterns.

The analysis applied operational conditions to the network data such as diurnal demand patterns when valves were opened and closed. The analysis for sequence of time steps, known as extended period or quasi dynamic simulation; each step representing a unique set of demand and operational conditions. An extended period simulation analysis used the initial set of demand profiles, reservoir levels and network operational conditions to calculate demands, pressures and flows in the network over the first time period to determine the operational status of automated pumps and control valves and the net reservoir inflows/outflows and thereby, using the reservoir geometry, changes in reservoir levels. The results were displayed both graphically and in tabular form for a single time (steady states analysis) or a sequence of time steps to illustrate the changing performance of the network and individual elements of the system over the period of the analysis.

Subsequent to hydraulic and water quality simulation was undertaken. In doing so, initial water quality was assigned to reservoir and tank nodes. Later Bulk and wall reaction coefficients were assigned to pipes globally. Similar to the hydraulic simulation, the results for water quality simulation were displayed both graphically and in tabular form to illustrate the changing performance of the network and individual elements of the system over the period of the analysis.



Figure 3.2 Bole Bulbula water supply distribution model representation aerial view

4. RESULTS AND DISCUSSION

4.1 Existing Water Supply Evaluation

Introduction

Problems in provision of adequate water supply to the rapidly growing urban population are increasing dramatically. Water demand in the domestic sector of developing cities including Addis Ababa increases through time that as a result demands for additional water sources and infrastructure. Despite to these, the financial capacity of the city is low to satisfy the growing demand. Financial constraint is one of the major factors for the low water coverage of the water supply but poor management of the existing water supply system also has a great impact for the low coverage. Beside to the overall low supply coverage, supply disparity exists among different localities. Therefore evaluating the entire distribution of the water supply system is important in order to identify the problematic areas and intervene accordingly.

4.1.1 Domestic Water Supply Coverage

Water supply coverage is usually evaluated based on the quantity, quality, paying capacity of the people, distance, etc., but the intention of this research is not to evaluate all these but related to the quantity of supply and level of connection that are related to the water loss. In this part of the analysis, the number of domestic connections per family and the average daily per capita consumption is used to analyze the domestic water supply coverage for the entire study area. Access to water supply may be evaluated using the amount of water consumed and the level of connection. For evaluating the amount of water consumption, the annual water consumption is converted to average daily per capita consumption using the population data of Bole Bulbula subsystem. The number of domestic connections per family has been also used for analyzing the level of connection as elaborated below.

4.1.1.1 Average Daily Per Capita Consumption

The volume of water consumed for domestic purpose has been aggregated to all customers' of the system so as to analyze the distribution of the water coverage in the study area. Evaluating the domestic water supply coverage using volume of consumption may not allow realizing the distribution comparison among the study area (Desalegn, 2005). Per capita consumption in the study area is estimated by using the Equation (3.1) is about 58 liters/capita/day.

4.1.1.2 Level of Connection per Family

Level of water connection is an important element on the one hand for evaluating the level of water coverage that will be the focus of this section and on the other hand it has a direct impact on the

water loss that will be dealt separately. According to AAWSA ,Megenagna branch office billed data ,the total numbers of connections or water meters with in the study area are about 4109 among those, 3681 are domestic customers , 413 non-domestic customers and 15 standing pipe or public taps.

According to Socio Economic Profile of Addis Ababa, Policy Study and Analysis, 2013, 3.8 average house hold family size for Bole sub city is used for calculating the average number of connection per family in Bole sub city was estimated below. Water supply coverage in the study area with regard to connection per family is about 57% by using Equation (3.2).

4.1.2 Water Balance

Practically ahead of assigning nodal water demand, it is very common to quantify water loss in the water distribution system. The amount of water lost across the network is estimated by doing water balance analysis. The difference between production and water consumption is quantified as total water loss. Water loss in the system is frequently due to either leakage in the system or apparent loss which include; meter inaccuracy, illegal use of water by unauthorized person etc .Table 4.1 below depicts water produced from June 2014 to December 2015 based on available data on hand.

Table 4.1 Monthly water production

Water meter reading date	Water meter reading volume (Production m ³)	Monthly water production (m ³)
June first 2014	658723	91123.00
June end 2014	749846	
July first 2014	821365	109131.00
July end 2014	930496	
August first 2014	940523	101478.00
August end 2014	1042001	
September first 2015	105338	110032.00
September end 2015	215370	
October first 2015	215540	111023.00
October end 2015	326563	
November first 2015	327823	130023.00
November end 2015	457846	
December first 2015	460101	98012.00
December end 2015	558113	
Monthly average		107260.29 m ³ /month
Daily		3575.34 m ³ /day
Yearly		1305000.14 m ³ /year

Water consumption data at Bole Bulbula system level was accessible in AWSSA's data base in the structure of customers billing data which was organized and controlled by Megenagna branch office. Under this branch currently there are over 4109 registered customers at Bole Bulbula subsystem. To obtain the exact figure of water consumption, it was required to compile customer's bill data. According

water consumption from June 2014 to December 2015 was extracted from compiled customer's billing data and presented in Table 4.2.

Table 4.2 Monthly billed water consumption data

Month	Billed consumption volume (m ³)		
	Domestic consumption(m ³)	Non-domestic consumption(m ³)	Total monthly consumption(m ³)
June 2014	54281.00	7879.00	62160.00
July 2014	53762.00	10170.00	63932.00
August 2014	57480.00	8275.00	65755.00
September 2015	56548.00	9391.00	65939.00
October 2015	59180.00	15168.00	74348.00
November 2015	63639.00	15269.00	78908.00
December 2015	57392.00	19435.00	76827.00
Average	57468.86	12226.71	69695.57
Daily	1915.63	407.56	2323.19
yearly	699204.43	148758.36	847962.79

Using water production and consumption data from June to December water balance is done presented in Table 4.3.

Table 4.3 Monthly water balance and losses in the subsystem based on average value

Month	Production (m ³)	Billed consumption (m ³)	Water balance (m ³)	Water loss in (%)
June 2014	91123.00	62160.00	28963.00	31.78
July 2014	109131.00	63932.00	45199.00	41.42
August 2014	101478.00	65755.00	35723.00	35.20
September 2015	110032.00	65939.00	44093.00	40.07
October 2015	111023.00	74348.00	36675.00	33.03
November 2015	130023.00	78908.00	51115.00	39.31
December 2015	98012.00	76827.00	21185.00	21.61
Average	107260.29	69695.57	37564.71	34.63

As depicted in Table 4.3 the water loss across the system was 34.63%.

4.1.3 Water Loss in the Subsystem

Leakage is frequently the largest component of UFW and includes distribution losses from supply pipes, distribution and trunk mains, services up to the meter, and tanks. The amount of leakage varies from system to system, but there is a general correlation between the age of a system and the amount of UFW. New systems may have as little as 5 percent leakage, while older systems may have 40 percent leakage or higher. Leakage tends to increase over time unless a leak detection and repair program is in place.

Other factors affecting leakage include system pressure (the higher the pressure, the more leakage), burst frequencies of mains and service pipes, and leakage detection and control policies. These factors make

leakage very difficult to estimate, even with-out the complexity of approximating other UFW causes. If better information is not available, UFW is usually assigned uniformly around the system (Walski, 2003).

Table 4.4 Monthly water balance and losses in the subsystem based on cumulative value

Months	Production (m3)	Consumption (m3)	Water loss (%)	Com_Prod (m3)	Com_Consm (m3)	Com_loss (%)
June	91123	62160	31.78	91123	62160	31.78
July	109131	63932	41.42	200254	126092	37.03
August	101478	65755	35.2	301732	191847	36.42
September	110032	65939	40.07	411764	257786	37.39
October	111023	74348	33.03	522787	332134	36.47
November	130023	78908	39.31	652810	411042	37.03
December	98012	76827	21.61	750822	487869	35.02

The cumulative average water loss of the system is shown in the Table 4.4 above. Water loss is usually expressed in terms of percentage (UFW), loss per kilometer length of main pipes and loss per properties or number of connections. In this study calculate the water loss in using above as percentage of (UFW).

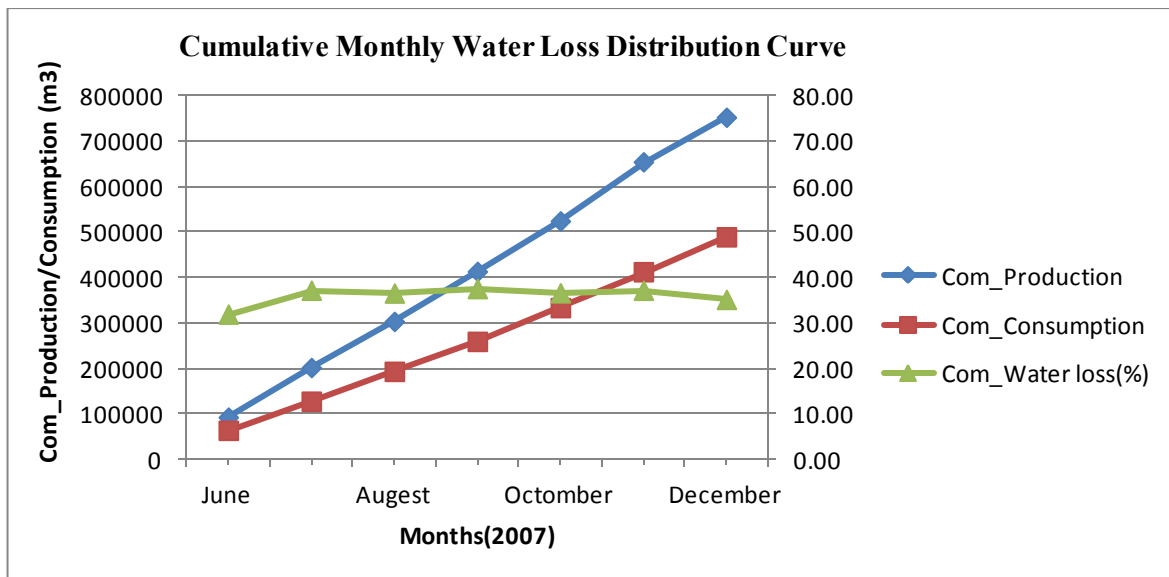


Figure 4.1 Monthly water loss distribution curve based on cumulative values

The seven month water produced and distributed to the distribution and the water billed that was aggregated from the individual customer meter readings were used to quantify the total water loss for the study area. As the authorized non metered consumption are insignificant while compared with the water production, the unaccounted for water (UFW) has been as a synonymy of the water loss in this analysis. The seven months water production and consumption that the water loss calculation was based on average is shown in Table 4.3 and Table 4.4 while the corresponding curve of the total monthly loss is also shown in Figure 4.1 above.

4.1.4 Population Forecasting

In order to forecast the current(2015) population of the study area based on last population census report (2007)-population and housing census report of 2007 which was prepared by Ethiopian Central Statistical Agency (CSA) was accessed mainly to establish base population. For this study 3.05 % growth rate from 1994 up to 2030 is adopted as the coming year increase the population increase rate decrease.

Table 4.5 past, present and projected population estimation in the study area

year	1994	2002	2007	2015	2040	2050
Population	2540	3181	21623	27498	58277	78701

Source: (CSA, 2007) census

4.1.5 Diurnal Curves of the Addis Ababa Water Supply System for Domestic Demand

Each city has its own unique level of usage that is a function of recent climatic conditions and the time of day. Economic growth also influences demands, but its effect occurs over periods longer than the typical modeling time horizon, and it is accounted for using future demand projections. Figure 4.2 illustrates a typical diurnal curve for a residential area. There is relatively low usage at night when most people sleep, increased usage during the early morning hours as people wake up and prepare for the day, decreased usage during the middle of the day, and finally, increased usage again in the early evening as people return home.

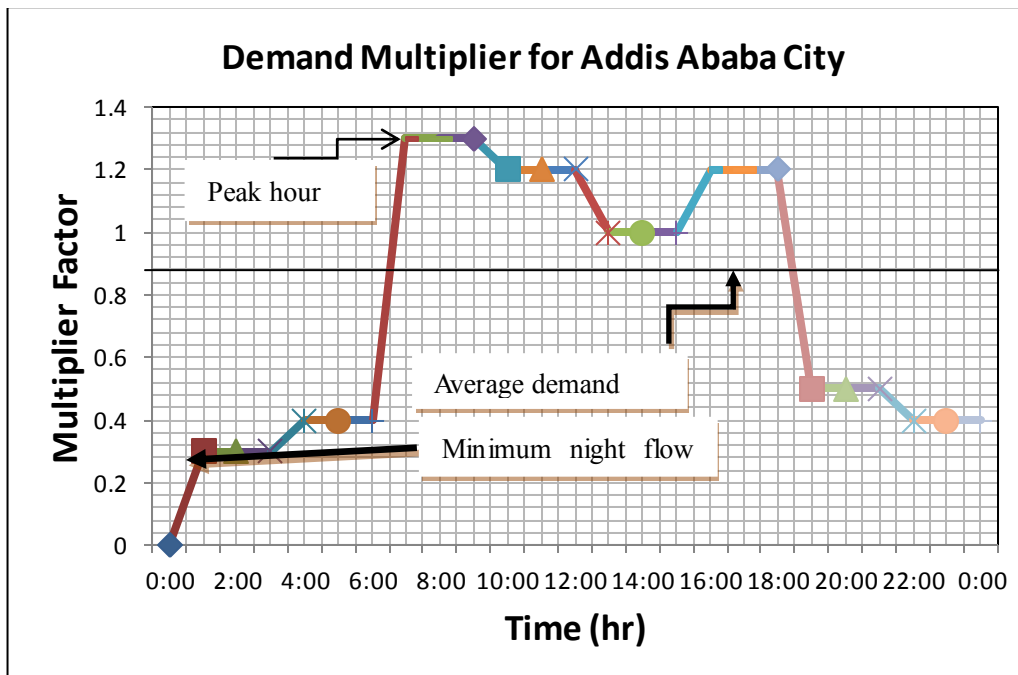


Figure 4.2 Variation of domestic water demand during the day

4.1.6 Current and Future Water Demand in the Study Area

The consumption or use of water, also known as water demand, is the driving force behind the hydraulic dynamics occurring in water distribution systems. Anywhere that water can leave the system represents a point of consumption, including a customer's faucet, a leaky main, or an open fire hydrant (Jeffrey .A). Water demand estimation is one of the basic inputs to select source of water supply and to find the amount of water required to fill the gap between supply and demand of the subsystem. Three questions related to water consumption must be answered when building a hydraulic model:

- (1) How much water is being used: peak and daily average?
- (2) Where are the points of consumption located?
- (3) How does the usage change as a function of time? This chapter addresses these questions for each of the three basic demand types described below.

- ❖ Customer demand is the water required to meet the non-emergency needs of users in the system. This demand type typically represents the metered portion of the total water consumption.
- ❖ Unaccounted-for water (UFW) is the portion of total consumption that is “lost” due to system leakage, theft, unmetered services, or other causes.
- ❖ Fire flow demand is a computed system capacity requirement for ensuring adequate protection is provided during fire emergencies.

Overestimating the water demand it is a cause for uneconomic investments and operational costs. In spite of uncertainties, planners have developed methods, which are used in forecast. But must be clear that forecast is not a prediction. Inappropriate or unintended assumptions may be made. For projection of water demand many factors may intervene. Inexactness in population projection or changes in the mix of house hold types, for example, forecast is made for various horizons: short, medium or long term, time extrapolation, coefficient method for unit use and per capita demand method. Hence for this particular study because of the shortage of data available per capital demand is adopted. The per capita water use rate can be assumed constant or projected to change over time based on historical water use data. Per capita water use rates can be estimated based on water use records for a particular city, or alternatively, regional or national use rates can be obtained from the literature (Walski, 2003).

Water distribution models are created not only to solve the problems of today, but also to prevent problems in the future. With almost any endeavor, the future holds a lot of uncertainty, and demand projection is no exception. Long-range planning may include the analysis of a system for 5- 10 and 20-35 year time frames. When performing long term planning analyses, estimating future demands is an important factor influencing the quality of information provided by the model (Walski, 2003).

Table 4.6 Summarizing current and projected water demand in the study area

Item	Description	Unit	Year		
			2015	2040	2050
1	Population to be Served	No.	27498	58277	78701
2	Per capita demand	l/c/d	58	135	150
3	Average Domestic Demand (ADD)	m ³ /d	1594.88	7867.44	11805.14
3.1	Average Public Water Demand (5-7% of ADD)	m ³ /d	111.64	550.72	826.36
3.2	Average Industrial Water Demand (30% of ADD)	m ³ /d	478.46	2360.23	3541.54
3.3	Average Demand (TAD)	m ³ /d	2184.99	10778.40	16173.04
4	UFW (34.63%,20%,15% of TAD)	m ³ /d	756.66	2155.68	2425.96
5	Fire Fight Water Demand	m ³ /d	5703.00	5703.00	5703.00
6	Total Average Day Water Demand (TADD)	m ³ /d	8644.65	12934.08	18598.99
6.1	Total Average Day Water Demand (TADD)	l/s	250.13	374.25	538.17
6.2	Max Day Factor		1.5	1.5	1.5
6.3	Max Day Demand	m ³ /d	12966.97	19401.11	27898.49
6.4	Max Day Demand	l/s	150.08	224.55	322.90
6.5	Peak Hour Factor		2.00	2.00	2.00
6.6	Peak Hour Demand	m ³ /d	17289.29	25868.15	37197.99
6.7	Peak Hour Demand	l/s	500.27	748.50	1076.33

Water supply and demand gap between production and demand=**Supply–Demand= (3575.34-8644.65)m³/day= (-5069.3) m³/day**. Negative sign indicates that additional water quantity required in the system per day to meet the subsystem supply and demand gap.

4.1.7 Existing Water Supply System Gap Identified

The existing water supply to Bole Bulbula subsystem was 3575.34m³/day. This water is supplying in the study area at both 24hrs and 12hrs at lower and higher elevation area respectively. Hence the total demand including the UFW in the system is 8644.65m³/day for supplying water 24hrs. To fill the gap additional 5069.3m³/day amount of water is required to fulfill the supply shortage and demand the Bole Bulbula water supply system.

Table 4.7 Water supply gaps and service level benchmark in the study area

S.no	Indicators	Benchmark	Current status	Gaps identified
1	Water supply coverage	100%	57%	43%
2	Per capita water supply demand	110(l/c/d)	58(l/c/d)	52(l/c/d)
3	Currently demand and supply condition	8644.65 m ³ /day	3575.34m ³ /day	-5069.3m ³ /day
4	Continuity of water supply	24hrs	24-12hrs	12hrs
5	Extent of non revenue water (UFW)	5-20%	34.63%	-14.63%
6	Updating of water line network	100%	90%	10%
7	Fire hydrant (based on calculation)	2	1	-1

4.2 Model Analysis

Analysis of the model of existing system has been made by running the model at current year daily average, at peaking and temporal variations of demand with different scenarios.

4.2.1 Steady-state Analysis

The model has been performed in steady state run for the average daily demand, which is the demand at every node not changing throughout 24 hours of a day. The software simulates Steady-State hydraulic calculation based on mass and energy conservation equations principle. Use appendix-C, E, F for the results.

4.2.2 Extended Period Simulation

The system conditions have been computed over twenty-four hours with a specified time increment of three hour and starting model run time at 12:00 PM. The software simulates non-steady-State hydraulic calculation based on mass and energy conservation principle.

The model can be simulated for every three-hour time setup in the twenty- four hour duration. However, for the analysis the peak and minimum hours, demand has been simulated to identify the current problems of the system and then to redesign the model based on the design criteria of the water distribution system, parameters like pressure and velocity.

Use Table 4.10 and Table 4.11, the attached results of the system performed run from:

- ❖ 12:00 PM – 3:00 AM for the minimum hour consumption.
- ❖ 6:00 AM – 9:00 AM for the peak hour consumption.

Note: Minimum hour model run has been made at 1:00 hour from starting time. Peak hour model has been made at 7:00 hour from the starting. The water distribution main model has a total length of 55747.69m, which integrates. The water distribution main model inventory also consists of 492-pressure pipe, 1-reservoir, 363-junctions, and 1-tank.

4.2.3 Model Calibration and Validation

The credibility of a model is merely evident if a model result precisely reflects observed field values. Thus, to have a confidence on model result it needs to calibrate a model. An effort to perform hydraulic network and water quality model calibration and validation for this case study is presented as follows.

Calibration is the process of comparing the model results to field observations and, if necessary, adjusting the data describing the system until model predicted performance reasonably agrees with measured system performance over a wide range of operating conditions.

Even though the required data have been collected and entered into a hydraulic simulation software package, the modeler cannot assume that the model is an accurate mathematical representation of the system. The hydraulic simulation software simply solves the equations of continuity and energy using the supplied data; thus, the quality of the data will dictate the quality of the results. The accuracy of a hydraulic model depends on how well it has been calibrated, so a calibration analysis should always be performed before a model is used for decision making purposes.

4.2.4 Calibration Standards

The following issues are raised frequently in the field of distribution system modeling:

- ❖ Extent of calibration needed for various applications, and
- ❖ Standards for calibration.

Though these are very reasonable questions, straight forward answers are usually not readily available.

There is general agreement in the modeling profession that the amount and degree of calibration required for a model should depend upon the intended use of the model (Engineering Computer Applications Committee, ECAC. 1999, cited by USEPA, 2005). Some applications such as design and water quality analysis typically require a high degree of calibration, while other uses, such as master planning, can be performed with a model that has not been calibrated to such a high standard. However, there are no universally accepted standards.

In 1999, the AWWA Engineering Computer Applications Committee developed and published a set of draft criteria for modeling. These were not intended as true calibration standards, but rather as a starting

point for discussion on modeling needs. These criteria are summarized in the following Table 4.8.

Table 4.8 ECAC calibration guidelines

Intended Use	Level of Detail	Type of Time Simulation	Number of Pressure Reading	Accuracy of Pressure Reading	Number of Flow Reading	Accuracy of Flow Reading
Long Range Planning	Low	Steady State or EPS	10% of Nodes	±5 psi (3.5m) for 100% Reading	1% of Pipes	±10%
Design	Moderate to High	Steady State or EPS	5%-2% of Nodes	±2 psi (1.4m) for 90% of Reading	3% of Pipes	±5%
Operations	Low to High	Steady State or EPS	10%- 2% of Nodes	±2 psi (1.4m) for 90% of Reading	2% of Pipes	±5%
Water Quality	High	EPS	2% of Nodes	±3 psi (2.07m) for 70% of Reading	5% of Pipes	±2%

The number of pressure readings is related to the level of detail as illustrated in the table below.

Level of Detail	Number of Pressure Readings
Low	10% of Nodes
Moderate	5% of Nodes
High	2% of Nodes

Sampling location

Five representative samples have taken; according to (USEPA, calibration Guidelines) see Table 4.8 measurements to the water main spread throughout the study area have been selected for the calibration. It was difficult to take measurement at a direct connection to the water main nodes, due to size of pressure gauge available in AAWSA, which is 25mm.

The measurements were taken at a location other than the direct connection to the water mains, nearer to the supply main nodes at homes faucet. The locations of the representative samples of a supply main nodes and the corresponding home faucet (field test) are shown in Table 4.9 and Figure 4.3. As a result, 100% of the field test measurements were within ± 2 m, showing an acceptable level of pressure calibration criteria show Table 4.8 above. The comparison of model simulated and field test are shown Table 4.9 and Figure 4.4.

This is carried out to examine the levels of accuracy between the model and the actual physical network. Field test locations for this exercise are identified through a process known as the sampling design problem which essentially defines the limiting calibration criteria that delineate the test location sample space (Walski, 2003). Test location sampling is done randomly and the following limiting criteria often used (AWWA, 1999).

1. Sampling points should be at the extremities of the network, a considerable distance from the boundary nodes in the network (reservoirs and tanks).
2. Selected points should also have relatively high discharges and pressures.
3. The actual values of the minimum distance from boundary nodes, minimum discharge, and minimum pressure are relative and unique to a given model. They are therefore selected having considered the system hydraulics and constraints of the modeling environment (Kapelan, 2003).

However, prior to testing reconnaissance must be carried out to assess the suitability of the selected test sites. Reconnaissance is done by physically examining the network to establish which mains and junctions in the network are actually accessible for testing purposes. Accessible mains and junctions then define the sample space from which field measurements can be taken.

Additionally, during reconnaissance the modeler should establish under what conditions pump operators turn on a pump, and under what conditions valves are opened or closed. There is also need to establish which facilities represented in the model are actually operational. It is necessary to establish whether some facilities are off-line for maintenance or repair.



Figure 4.3 Sample locations in the subsystem

Sampling size

In general, international proposed guide lines stipulate that for a medium to highly detailed network model (medium to low skeletonization), the following limits should be adopted modeling based on ECAS,1999 Sample calibration criteria for modeling pressure and flow criteria as mentioned below :

To use the Table 4.8 first select the aim or intended use list then fix the sample nodes to be observed. For this thesis the study area water supply network is already existed in this case prefer intended use would be operational. According to operational case criteria the sample size consideration has been taken:

Pressure:

1. Number of pressure reading 10%-2% of nodes and accuracy of pressure readings ± 2 psi (1.4m)
2. Number of flow reading in the pipe 2% of pipes and accuracy of flow readings $\pm 5\%$.
3. Water quality number of pressure reading nodes 2% of nodes and accuracy of pressure reading 5%.

Junctions:

- ❖ Total number of junctions in the network = 363 junctions
- ❖ However, the minimum acceptable sample = 2% of all the junctions in the network.
- ❖ Hence, sample size = $0.02 \times 363 = 7.26$ which is approximately 7 junctions
- ❖ So 5 junction points were tested in the network due to material, resources and time constraints to measure 7 junction five times each at the same time is so difficult by only a single pressure gage (15mm) on hand and those junction sample location is also located at upstream, middle and downstream of the system to meet the sample location criteria. Due to above constraints 5 nodes have been observed for calibration and validation process.

4.2.5 Calibrating Hydraulic Network

Pressure Measurement

Pressures are measured throughout the water distribution system to monitor the level of service and to collect data for use in model calibration. Pressure readings are commonly taken at fire hydrants also at hose bibs, and home faucets (Bentley, 2008).

If the measurements are taken at a location other than, a direct connection to a water main (for example, at a house hose bib), the head loss between the supply main and the site where pressure is measured must be considered. Models can be calibrated using one steady-state simulation, but the more steady-state simulations for which calibration is achieved, the more closely the model will represent the behavior of the real system.

4.2.6. Model Performance Evaluation

In order to calibrate and validate the models and for comparison purposes, some quantitative information is required to measure model performance. In this study, the pressure data measured at the near to node home faucet of the system was used to assess the model performance. The performance assessment was based on the water measured and simulated data by model, the agreement of the overall the time series of

pressure the value of the statistical performance indices (Vanlewi, 2003., Nash, 1970., Legates, 1999) such as the degree of accuracy (error of difference) and the goodness of fit tests (R^2) are two techniques to be considered for calibration model test as mentioned below.

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

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

Coefficient of determination (R^2) describes the degree of co linearity between simulated and measured data. The coefficient of determination, R^2 , Equation (4.1), which ranges between 0 and 1, describes the proportion of the variance in the measured data, which is explained by the model, with higher values indicating less error variance. Typically, $R^2 > 0.5$ is considered acceptable (Singh, 2004, Santhi, 2001).

$$R^2 = \left[\frac{\sum_{i=1}^n (O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^n (O_i - \bar{O})^2} \sqrt{\sum_{i=1}^n (P_i - \bar{P})^2}} \right]^2, \quad 0 \leq R^2 \leq 1 \quad (4.1)$$

Where,

n- the number of observations in the period under consideration

O_i , the i-th observed value

\bar{O}_i , - the mean observed value

P_i , - the i-th model-predicted value and \bar{P}_i , -the mean model-predicted value.

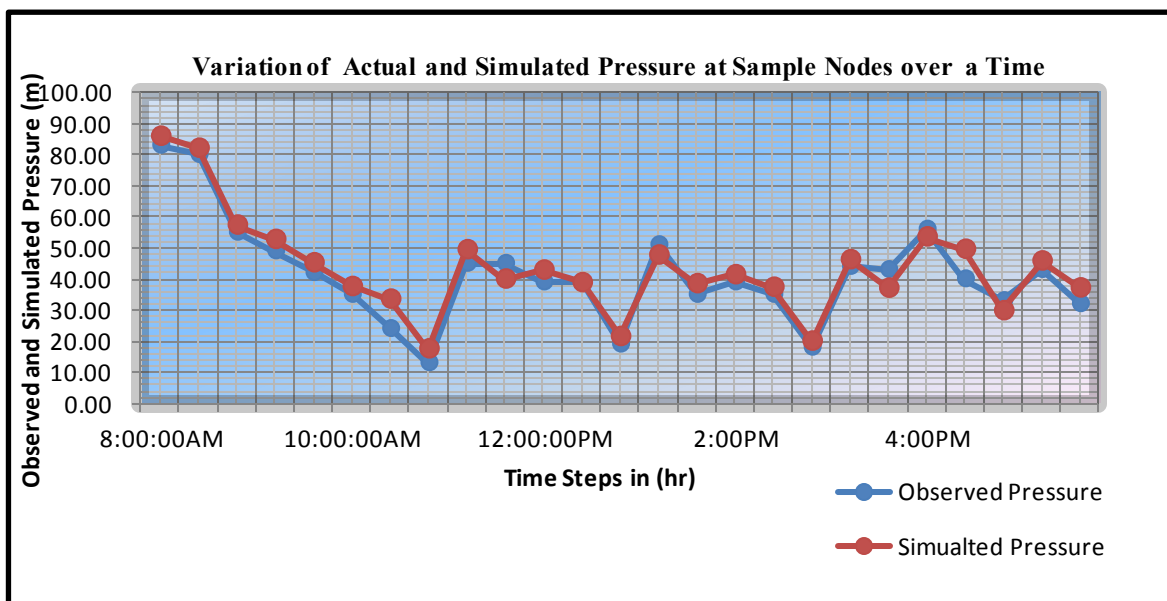


Figure 4.4 Actual and simulated pressure at samples node.

Pressures were measured in the field in order to compare with the results of the distribution model. The measurements covered a wide range of subsystems and branch to get a representative sample. Figure 4.4 and detailed in appendix B, is a comparison plot of observed pressures versus calculated pressures at various taps throughout the system. The diagonal line on the plot represents the line of perfect correlation in Figure 4.5 below here. Ideally all the points should align themselves on this line; meaning that all observed pressures would be equal to the computed pressures, giving a correlation coefficient of 1 that is the best correlation between observed and simulated. The linear correlation coefficient (R) of observed versus computed pressures is calculated by Equation 4.1 value is at 0.96. The coefficient of determination (R^2) value was 0.96, it indicates that observed and simulated relation is strongly as values tend to 1.

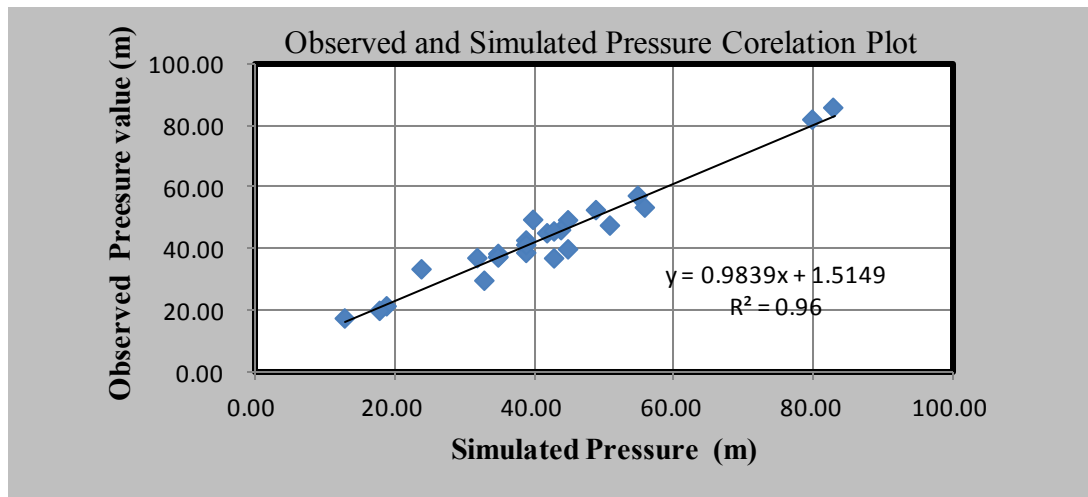


Figure 4.5 Correlation between observed and simulated pressure parameters

One reassuring fact with respect to Figure 4.4 is that the discrepancy between observed and computed pressures seems to be random rather than systematic. Indeed, one can observe both over-estimates and under-estimates of calculated pressures, at all ranges, and there is no particular tendency by subsystem either. If anything, one might observe a tendency to under-estimate pressures, but considering that minor head-losses have been ignored, this fact is most likely due to the small sample size.

2. Model Calibration Based on Difference Error

The degree of accuracy varies depending on the size of the system and the amount of field data and testing available to the modeler. (Bhave, 1998 cited by James G. 2002) states that the average difference of $\pm 1.5\text{m}$ to a maximum of $\pm 5.0\text{m}$ for a good data set and ± 3.0 to $\pm 10\text{m}$ for a bad data set would be a reasonable target. This is in terms of comparing the observed versus the calculated pressure and heads in the system.

Table 4.9 Junction pressure calibration based on degree of accuracy criteria

Time (hr)	Pressure Junction id	x	y	Elevation (m)	Observed Pressure (m)	Simulated Pressure (m)	Difference Pressure Error (m)
8:00:00AM	J-289	475553	988471	2186	83.00	85.91	(2.91)
	J-330	475746	988488	2190	80.00	82.05	(2.05)
	J-299	475958	989490	2216	55.00	57.32	(2.32)
	J-152	476177	990011	2225	49.00	52.69	(3.69)
	J-364	476363	990499	2234	42.00	45.18	(3.18)
10:00:00AM	J-289	475553	988471	2186	35.00	37.54	(2.54)
	J-330	475746	988488	2190	24.00	33.47	(9.47)
	J-299	475958	989490	2216	13.00	17.50	(4.50)
	J-152	476177	990011	2225	45.00	49.39	(4.39)
	J-364	476363	990499	2234	45.00	39.94	5.06
12:00:00PM	J-289	475553	988471	2186	39.00	42.82	(3.82)
	J-330	475746	988488	2190	39.00	38.79	0.21
	J-299	475958	989490	2216	19.00	21.45	(2.45)
	J-152	476177	990011	2225	51.00	47.67	3.33
	J-364	476363	990499	2234	35.00	38.47	(3.47)
2:00PM	J-289	475553	988471	2186	39.00	41.34	(2.34)
	J-330	475746	988488	2190	35.00	37.31	(2.31)
	J-299	475958	989490	2216	18.00	19.98	(1.98)
	J-152	476177	990011	2225	44.00	46.18	(2.18)
	J-364	476363	990499	2234	43.00	37.01	5.99
4:00PM	J-289	475553	988471	2186	56.00	53.51	2.49
	J-330	475746	988488	2190	40.00	49.53	(9.53)
	J-299	475958	989490	2216	33.00	29.76	3.24
	J-152	476177	990011	2225	43.00	45.77	(2.77)
	J-364	476363	990499	2234	32.00	37.10	(5.10)
						Average	(2.03)

As shown in Table 4.9, computed values are within an average error of -2.03m pressure simulated to observed values. Hence, the model is acceptable calibrated which is satisfied the setting pressure calibration and validation criteria under average level (*average* $\pm 1.5m$ to the maximum $\pm 5m$).

4.2.7 Calibrating Water Quality Modeling

Just subsequent to hydraulic model calibration and validation, water quality model calibration has to be performed separately. To this effort data sets were collected from different part of water distribution system. Table 4.10 depicts an attempt to water quality model calibration as guide line recommended: average error of roughly 0.1mg/l to 0.2mg/l (Walski, 2003).

Table 4.10 Water quality model calibration for the time series (Extended Period Simulation)

Time (hr)	Pressure Junction	x	y	Elevation (m)	Observed Chlorine Residual (mg/L)	Computed Chlorine Residual (mg/L)	Difference Error (mg/L)
8:00:00AM	J-289	475553	988471	2186	0.65	0.89	0.24
	J-330	475746	988488	2190	0.55	0.64	0.09
	J-299	475958	989490	2216	0.6	0.83	0.23
	J-152	476177	990011	2225	0.85	0.90	0.05
	J-364	476363	990499	2234	0.6	0.83	0.23
10:00:00AM	J-289	475553	988471	2186	0.4	0.72	0.32
	J-330	475746	988488	2190	0.3	0.52	0.22
	J-299	475958	989490	2216	0.35	0.40	0.05
	J-152	476177	990011	2225	0.2	0.44	0.24
	J-364	476363	990499	2234	0.55	0.81	0.26
12:00:00PM	J-289	475553	988471	2186	0.45	0.72	0.27
	J-330	475746	988488	2190	0.2	0.54	0.34
	J-299	475958	989490	2216	0.35	0.40	0.05
	J-152	476177	990011	2225	0.2	0.44	0.24
	J-364	476363	990499	2234	0.3	0.41	0.11
2:00:00PM	J-289	475553	988471	2186	0.6	0.72	0.12
	J-330	475746	988488	2190	0.3	0.52	0.22
	J-299	475958	989490	2216	0.2	0.40	0.2
	J-152	476177	990011	2225	0.3	0.44	0.14
	J-364	476363	990499	2234	0.3	0.4	0.1
4:00:00PM	J-289	475553	988471	2186	0.5	0.72	0.22
	J-330	475746	988488	2190	0.35	0.54	0.19
	J-299	475958	989490	2216	0.1	0.40	0.3
	J-152	476177	990011	2225	0.2	0.44	0.24
	J-364	476363	990499	2234	0.25	0.41	0.16
						Average	0.1932

As shown in Table 4.10, computed values are within an average error of 0.1932mg/l to observed values. Hence, the model is well calibrated.

4.2.8 Validation

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

4.3 Identified Problems and System Design Improvements

4.3.1 Pressure

Pressure in water distribution system has to be maintained optimum; as to efficiently make water available to each demand category including at instances of fire fighting (high withdrawal period) and as to reduce leakage as well as pipe breakage across the system. The former one is frequently achieved in setting minimum pressure to be maintained at each junction. The later one is achieved differently in setting allowable pressure to be maintained in the system.

According to (Swamee et al 2008) the minimum design nodal pressures are prescribed to discharge flows onto the properties. The general consideration is that the water should reach up to the stories of low rise buildings in sufficient quality and pressure, considering fire fighting requirement. In the case of high rise building, booster pumps are installed in the water supply system to cater for the pressure head requirements. With these considerations, various codes recommended minimum ranging from 8m to 20m for residential areas.

Similarly, (Johnson et al 2009) recommend;

1. Minimum pressures at peak hour demand: sufficient to serve the highest supply point in the network. Typically mains pressures of not less than 15m to 20m would be required to serve buildings up to three storeys high. Higher pressures may be necessary in some areas where there are significant numbers of dwellings exceeding three-storey height; but high rise buildings are normally required to have their own booster supply.
2. Maximum static pressure during low demand periods: typically at night should be as low as practicable to minimize leakage. For flat areas a maximum static pressure in the ranges 30m to 45m is desirable. The maximum pressure in mains is considered not to exceed 80m to limit leakage and stresses on pipes (Mosissa, 2008).

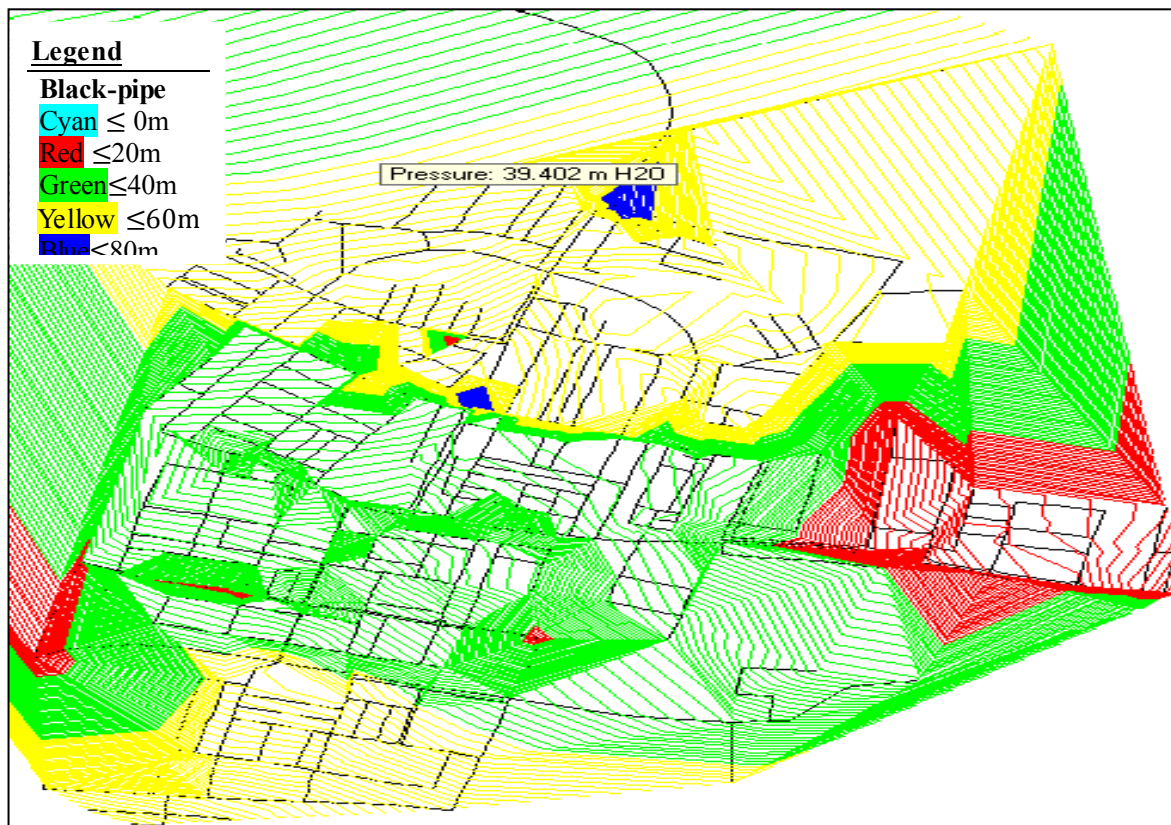
For city of Addis Ababa, AWWSA is using operating pressures which ranges from 60m to 80m: However, there was no defined maximum and minimum pressure ranges set by the office. Therefore, literature based recommendation for optimum operating pressure was used to assess system hydraulic performance.

With regard to current simulation, result for pressure at average day demand is summarized in Table 4.11 and Fig.4.6 shown in detail.

Table 4.11 Distribution of actual node pressure at average day demand

Pressure (m)	Nodes (number)	Percentage (%)
>80	0	0.00
70-80	1	0.28
60-70	1	0.28
50-60	49	13.50
40-50	100	27.55
30-40	131	36.09
20-30	48	13.22
<20	33	9.09
Total	363	100

As depicted in Table 4.11, shows that 9.09% of nodes are failed to satisfy desirable minimum pressure during the average day demand situation. There is no node exceed maximum allowable pressure of 80m. While 90.91% of nodes are in the permissible pressure ranges of minimum 20m and maximum 80m. From the above table results 9.09% should be improved to be under the minimum pressure criteria in the water supply system.

**Figure 4.6 Shows actual node pressure contour at average day demand consumption hour**

With regard to current simulation of actual water distribution condition at peak hour demands as shown below in both tabular and figure and the results for pressure at peak flow is summarized in

Table 4.12 and Figure 4.7 and detailed in Appendix D, pressure on this peak hour is the most important for design and improving and expansion of existing system, updating and installation of new water supply distribution schemes.

Table 4.12 Distribution of actual node pressure at peak hour flow

Pressure (m)	Nodes (number)	Percentage (%)
>80	0	0.00
70-80	1	0.28
60-70	1	0.28
50-60	5	1.38
40-50	76	20.94
30-40	26	7.16
20-30	0	0.00
<20	254	69.97
Total	363	100

As depicted in Table 4.12, 69.97% of nodes are below the minimum desirable pressures (20m) during peak hour demand. There are no nodes exceeded to maximum allowable pressures of 80m. While 30.04% of nodes are in the permissible pressure ranges of minimum 20m and maximum 80m pressure. Estimating pressure distribution at the peak hour demand is the governing parameters for the purposes of design and improving the existing water distribution network next to minimum consumption hour demand type. At this peak hour level the water consumption demand expected to more over all the hour demands. Demand is peak especially at morning and early evening for domestic water consumption or residential use. Therefore from the above Table 4.12 pressure which less than the minimum pressure must be improved for the purpose of to demand and water quality problems in the study area.

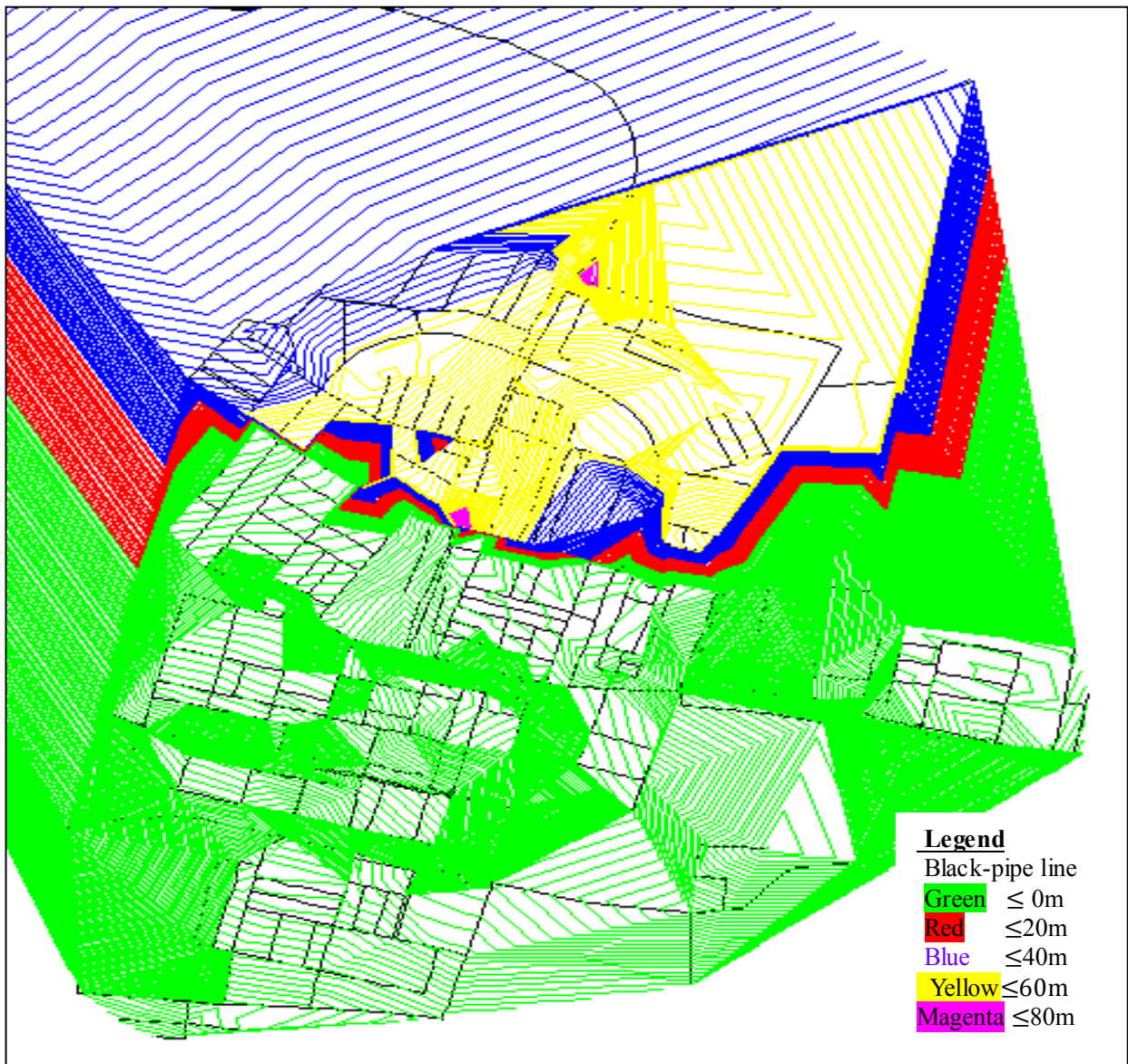


Figure 4.7 Shows actual node pressure contour map at peak hour demand consumption

Figure 4.7 shows pressure distribution contour map during peak hour flow. As shown in the figure above, nodes located at the green color marked area which is more covered the downstream part of the system with lower elevation, are susceptible to lower pressure (negative pressure) due to under pipe diameter size. There are some reasons that are why the negative pressure is occurred in the water supply distribution system might be as result of the following:

- ❖ Properties on high ground; elevations difference
- ❖ remote properties at the end of long lengths of pipe; downstream side
- ❖ demands that are greater than the design demand; negative Q demand
- ❖ pipes of inadequate capacity (too small diameter); pipe size
- ❖ rough pipes (e.g. corroding iron pipes or pipes with a build-up of sediment);
- ❖ Equipment failures (e.g. pumps and valves).

In contrary minimum pressures are also observed mainly nodes situated near to tanks. In few instances nodes positioned in middle of network are susceptible to low pressure. Whereas majority of nodes located in relative perfect loop receive optimum pressure which does not violet minimum or maximum allowable pressure range. On the other hand, at night time maximum pressure, maximum water residence time (water age in the pipe) and minimum velocity and leakage rate are expected to be high because at this time no water flow occurred at the distribution. The actual node pressure simulation distribution as shown below Table 4.13 and Figure 4.8 in detail.

Table 4.13 Distribution of actual node pressure at minimum consumption hour

Pressure (m)	Nodes (number)	Percentage (%)
>80	10	2.75
70-80	38	10.47
60-70	75	20.66
50-60	211	58.13
40-50	29	7.99
30-40	0	0.00
20-30	0	0.00
<20	0	0.00
Total	363	100

During low flow typically at mid-night distribution system of case study is marked by excessive pressure. As portrayed in Table 4.13, Figure 4.8 and detailed in appendix C, 2.75% of nodes are liable to extremely high pressure. This figure is relatively high. Minimum pressure is also observed during low consumption period. Only 97.25% of nodes are received water of optimum pressure at low consumption hour. As compared to at peak hour Table 4.12, shows only 30.04% nodes with permissible pressure due to excessive demand.

Node pressure at the minimum consumption hour, is very important rather than others two peak and average water demand because, leakage and water quality is deter rioted very high in the system during this low consumption hour. Due to above reasons new and existing water supply distribution systems often time are designed by taking considerations it as the base parameters. For this study, improving the existing water supply system has been done at both peak and low consumption hour level because minimum and maximum pressures are found than average demand.

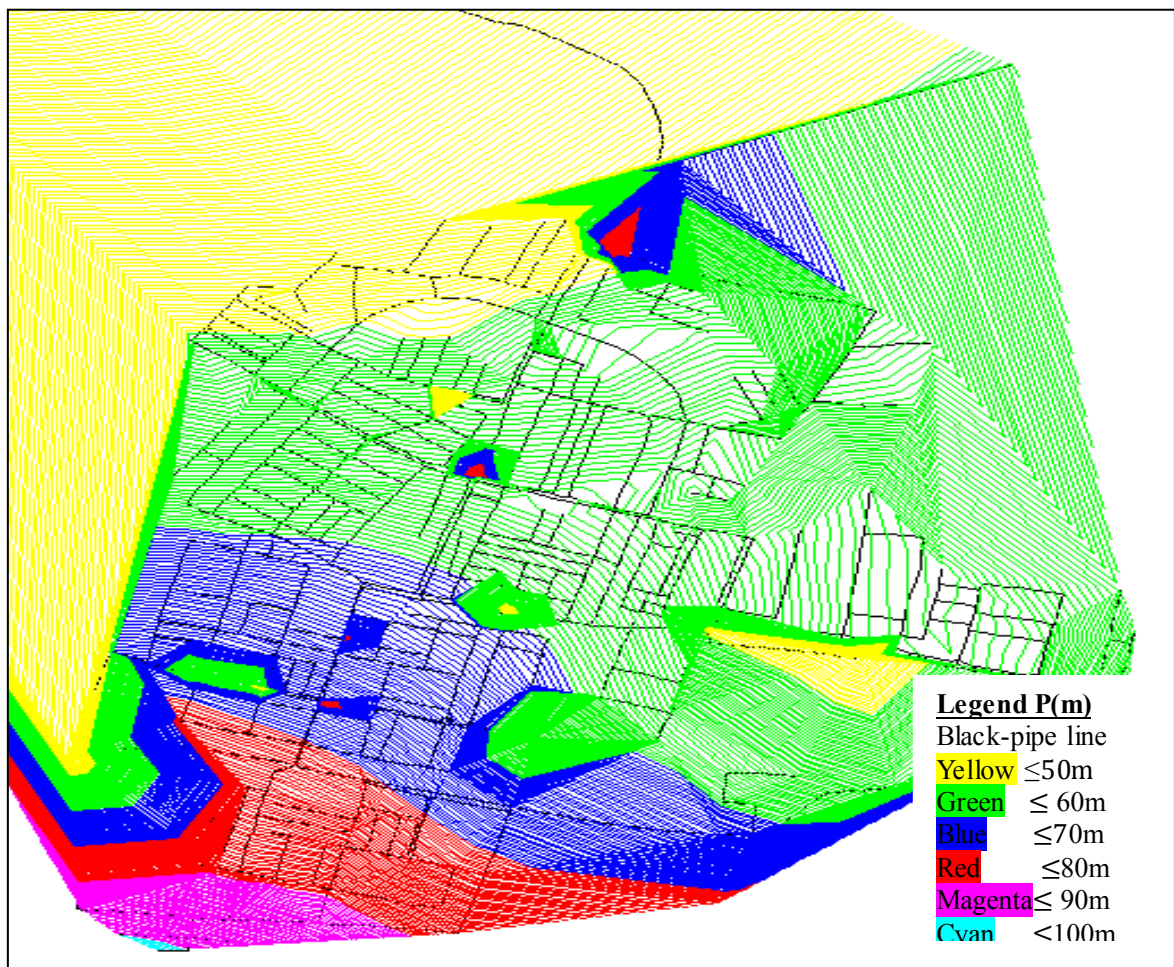


Figure 4.8 Shows actual node pressure contour map at minimum consumption hour

4.3.2. Velocity Distribution in Actual Pipe

Velocity of water flow in a pipe is also one of the important parameters in hydraulic modeling performance evaluation of the efficiency of water supply distribution and transmission line. Velocity distribution is also varying with demand pattern changes. At the peak hour demand the values are different as compare to minimum consumption hour. The water supply system network velocity during peak hour demand is summarized in the Table 4.14 below.

Table 4.14 Distribution of actual pipe velocity at peak hour demand

Velocity (m/s)	Pipe (number)	Percentage (%)
≥ 2.5	22	4.47
2-2.5	9	1.83
1.5-2	25	5.08
1-1.5	55	11.18
0.3-1	189	38.41
0.1-0.3	103	20.93
0.05-0.1	34	6.91
≤ 0.05	55	11.18
Total	492	100

As depicted in Table 4.14, during the peak hour demand situations about 4.47% of pipes are failed to satisfy the permissible velocity or maximum velocity in distribution and transmission line ($>2.5\text{m/s}$), in addition to that, 11.18% of pipes also below the minimum velocity at residential tap 0.05 m/s . While, only 84.34% of pipes are in the permissible velocity ranges. Improving or upgrading the existing water supply distribution is also considering and checking the velocity minimum and maximum limit based criteria. For this study velocity is considered as criteria during resizing the pipe diameter. Velocity has also a great impact on water quality as turbidity and the like. Carried out Modeling is helpful in pinpointing the cause of hydraulic efficiency problems. In general the study area of water distribution system has the following major problems with respect to hydraulic network modeling as mentioned below:

- ❖ Undersized service pipe diameter
- ❖ Oversized service pipe diameter
- ❖ Low pressure
- ❖ High pressure
- ❖ High velocity
- ❖ Low velocity

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

No fixed rule exists regarding the maximum velocity in a main (although some utilities do have guidelines). The optimal velocity in pumped lines can range from 1 to 3 m/s, depending on the relative size of the peak and average flow rates (Desalegn,2005). When checking designs for permissible velocities some engineers use 1.5 m/s as a maximum, other use 2.4m/s, and yet still others use 3.1m/s. Consistent low pressure problem is due to trying to serve customers at too high an elevation for that pressure zone. High pressures are usually caused by serving by serving customers at too low an elevation for the pressure zone. Usually, high pressures are easiest to evaluate with model runs at low demands. This range corresponds to minimum night time demands for a typical system. If the engineer feels that pressures are too high, the usual solution is to establish a new pressure zone for the lower elevation using PRVs.

4.3.3 Water Quality in the System

Water quality simulation requires a series of runs to understand the movement of water and water quality transformation in the system. Specific simulations included in this study are: water age and residual chlorine modeling are investigated in this study.

This is a variation of water quality in distribution system from hour to hour of a particular day. This hourly variation of water quality is mainly related to demand patterns. Water quality variation is also

observe as system sizes are subjected changes.

To obtain the dominant factors currently contributing to water deterioration specifically loss of residual chlorine in distribution system of Addis Ababa city the following two possible scenarios were assessed.

Scenario1. Demand pattern

- a. Water age at peak and low hour flow
- b. Residual chlorine at peak and low hour flow

Scenario2. Pipe geometry

- a. Water age for existing and modified pipe sizes
- b. Residual chlorine for existing and modified pipe sizes.

Scenario1. Demand Pattern

Hourly water use in a given day is subjected to changes due to many factors. Frequently there is high water consumption at early morning 8:00am and 12:00pm and low water consumption at mid-night. These variations lead use of large pipes and storage tanks. However their benefits, large pipes and storage tanks have negative impacts on water quality.

Scenario1 is about assessing water quality conditions in the distribution system of Bole Bulbula water supply system under the influence of water demand variations. Water quality situation at peak hour flow and low hour flow was assessed taking water age and residual as water quality parameters.

4.3.3.1 Water Age at Peak and Low Hour Flow

Analysis of water age was based on assumption that the distribution system was loaded with continuous flow. Thus, any findings for this parameter are limited to this assumption. Table 4.15 and Table 4.16 depict water age distribution at peak and low hour flow.

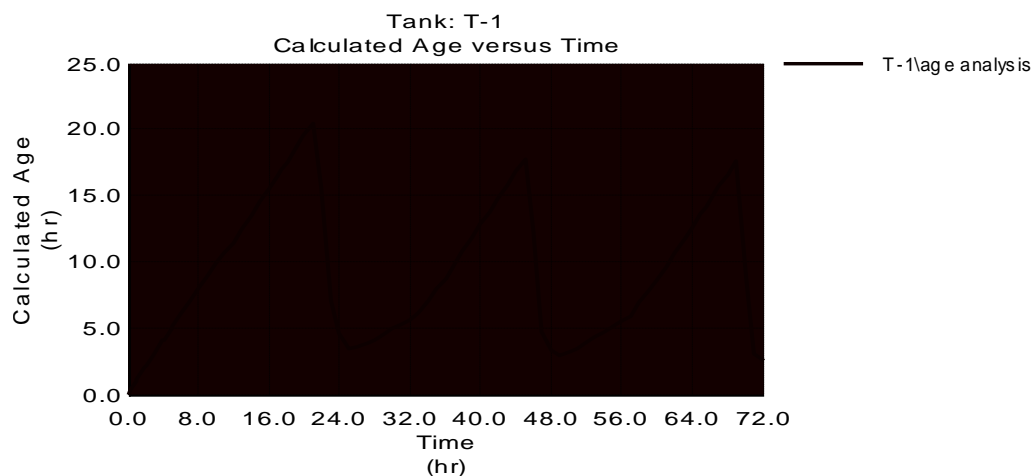


Figure 4.9 water age curve at tank-1

From the Figure 4.9, you can see that once a repeating pattern is reached, the age of the water fluctuates between approximately 21hr and 4.8 hours in 7-hour periods. Looking at these equilibrium ranges for various nodes can help guide you in setting up initial water age values in subsequent runs. In addition to that from the graph the maximum water age or water residence in the distribution network is also estimated in the subsystem. From Figure 4.9, the maximum water age or water residence in the pipe line in the system is approximately 21 hour this parameter is very important for bottle test time boundary.

Table 4.15 Water age at low hour flow

Age (hr)	Node(number)	Percentage (%)
<6	346	95.32
6-12	5	1.38
12-15	0	0.00
15-18	1	0.28
18-21	3	0.83
≥21	8	2.20
Total	363	100

Table 4.16 Water age at peak hour flow

Age (hr)	Node (number)	Percentage (%)
<6	179	49.31
6-12	19	5.23
12-15	37	10.19
15-18	120	33.06
18-21	8	2.20
≥21	0	0.00
Total	363	100

As it is illustrated in Table 4.15 and Figure 4.10, at low hour flow majority nodes 95.32% receive water age lower than 6hrs. Only 2.20% receive water with age greater than 21hrs. While at peak hour flow nodes receiving water with age less than 6hrs is reduced to 49.31%. There is significant difference between water age reaching nodes at high water consumption time and low water consumption time.

As also shown Figure 4.10, water age increases for the areas far from reservoir and tank; and those located at the downstream section or lower elevation of the system. Areas where tanks concentrate, average water age significantly decreases and nodes at downstream receives water of high residence time.

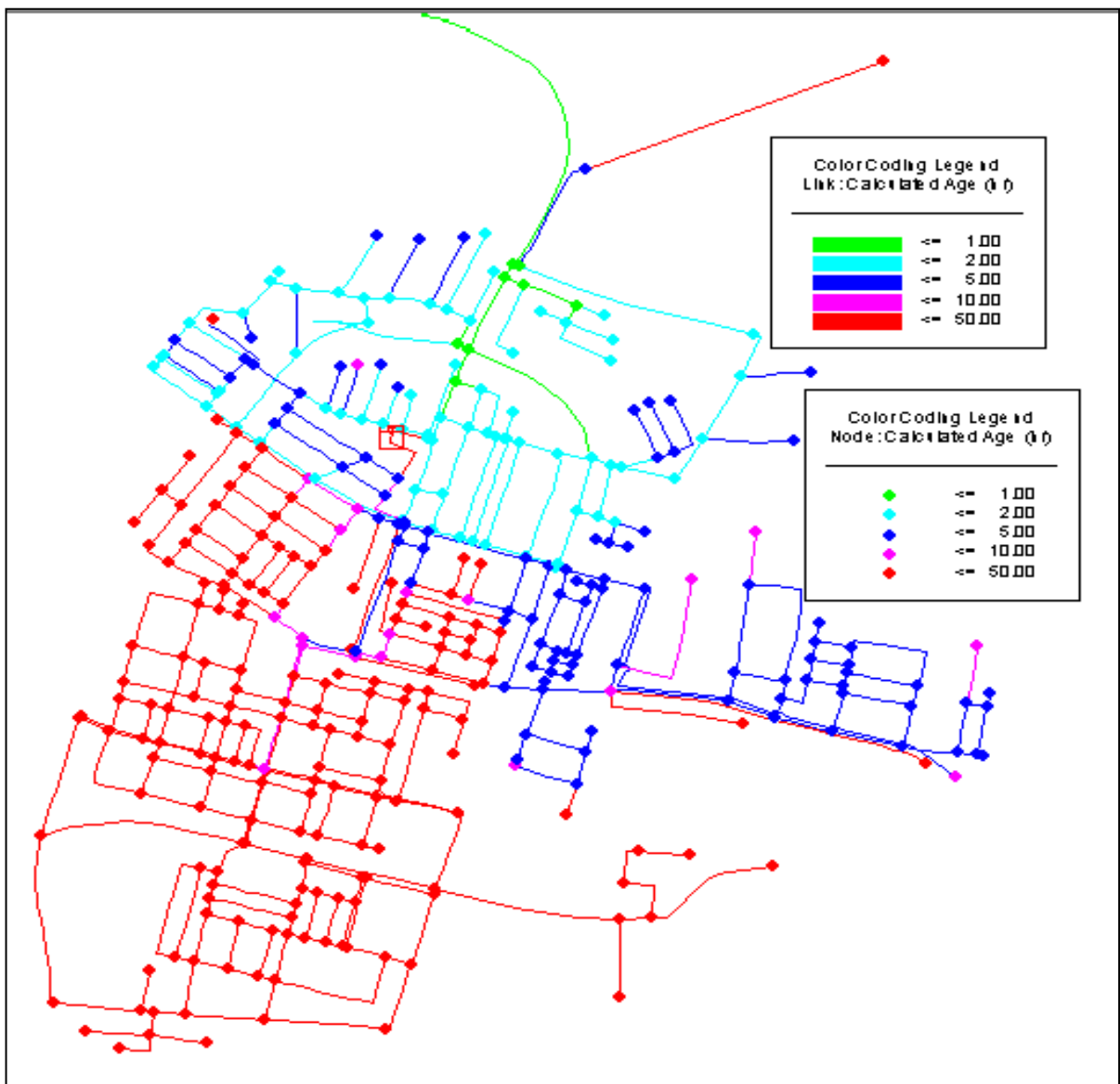


Figure 4.10 Water age map at low consumption hour flow

4.3.3.2. Residual Chlorine at Peak and Low Hour Flow

It had been so long since it was proved that microbiologically safe water would be supplied only while continuous disinfection prior to water distribution is possible along with letting distributed water with optimum residual chlorine as to control recontamination in distribution system.

Recontamination of water in a distribution system occurs due to various factors and their outcomes also different. No matter what the reason is microbiologically unsafe water shall not be tolerated since its consequence is very appalling. The widespread strategy to tackle the probable recontamination is ensuring residual chlorine in water distribution system. Recommended residual chlorine at the taps of the users usually lies between 0.2mg/l to 0.5mg/l (WHO, 2011; WHO, 1997). Table 4.17 and Table 4.18 depict residual chlorine concentration at low and peak hour flow for more analysis.

Table 4.17 Residual chlorine distribution at low hour flow

Residual chlorine (mg/l)	Node (number)	Percentage (%)
0	0	0.00
0.01-0.1	0	0.00
0.1-0.2	0	0.00
0.2-0.5	323	88.98
>0.5	40	11.02
Total	363	100

Table 4.18 Residual chlorine distribution at peak hour flow

Residual chlorine (mg/l)	Node (number)	Percentage (%)
0	0	0.00
0.01-0.1	0	0.00
0.1-0.2	0	0.00
0.2-0.5	355	97.80
>0.5	8	2.20
Total	363	100

As depicted in Table 4.18 and Figure 4.11, shows residual chlorine in the water supply system at low hour flow only. From the above table about only 88.98% of nodes receive water with residual chlorine between (0.2mg/l - 0.5mg/l). While as it was shown in (Table 4.18 and Figure 4.11) at peak hour flow 97.8 % of nodes obtain water with residual chlorine between (0.2mg/l - 0.5mg/l). This figure indicates the quality of water in distribution system of Bole Bulbula network is much better at peak hour flow than low hour flow.

From the above (Table 4.17 and 4.18) the results as shows that residual chlorine concentration at both minimum and peak flow there is excessive residual chlorine concentration ,which is more than 0.5mg/l in the system 40% and 2.2% during low and peak hour demand respectively. Therefore, residual chlorine concentration dosage at the source and tank should be adjusted until minimum and maximum concentration of residual chlorine in the distribution line become under the minimum and maximum ranges based on WHO criteria standards in water for drinking water.

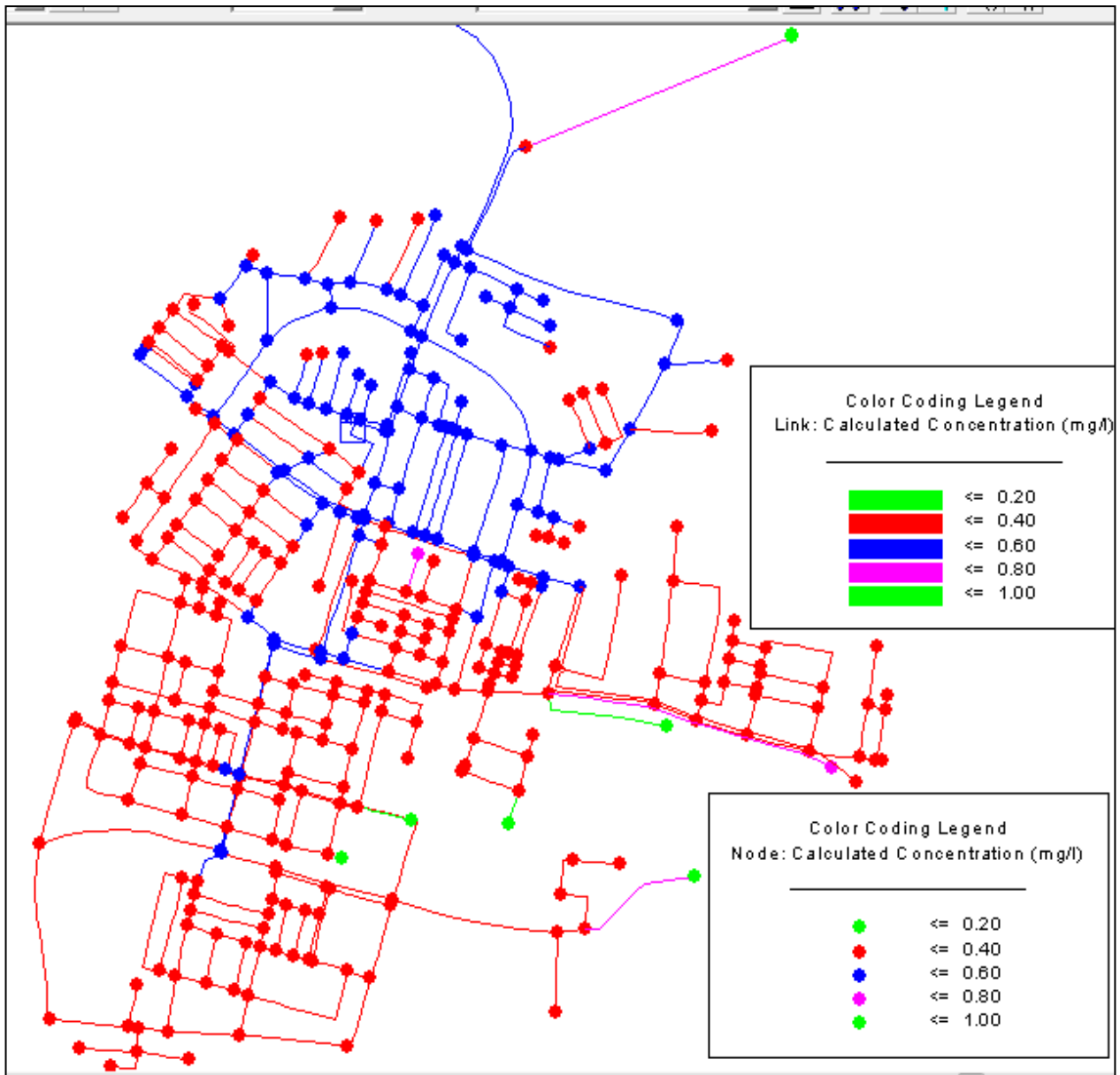


Figure 4.11 Residual chlorine plots at low hour flow

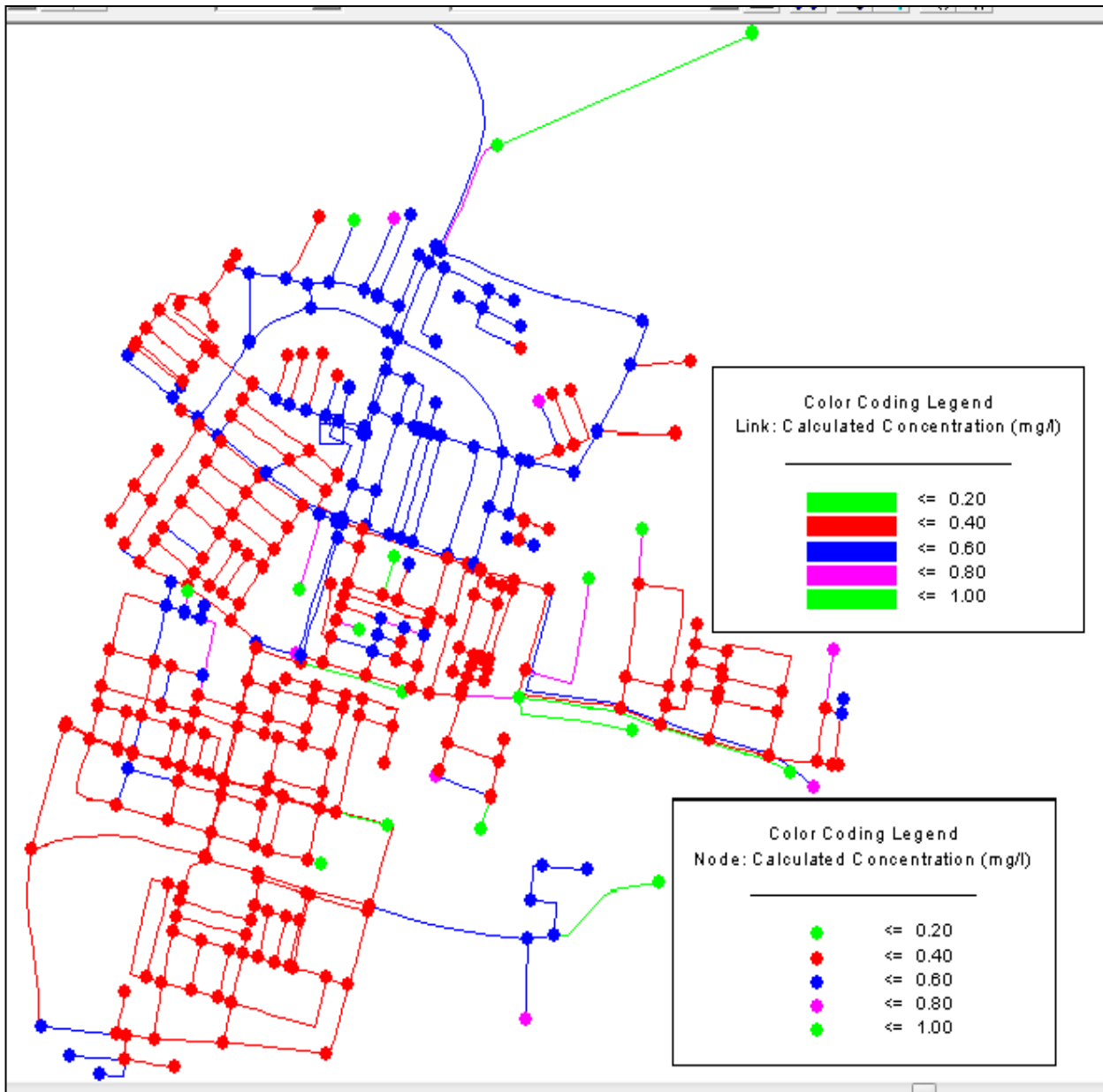


Figure 4.12 Residual chlorine plots at peak hour flow

4.4 Relationship between Pressure, Leakage and Water Quality for Water Supply System

4.4.1 Relationship between Pressure and Leakage

Pressure can affect system losses in a number of ways. The rate of leakage from leaking pipes or faulty joints will increase with a rise in pressure. In a similar way, especially in older systems, an increase in pressure even by a few meters can result in large leakage frequencies. Conversely, pressure reduction can reduce the rate at which bursts occur.

Pressure surge can happen when a pump is switched on too quickly, or a valve is opened or closed too quickly. The sudden surge in pressure can cause the pipe to fracture, or can move thrust blocks, or damage the socket. There is also some evidence that surge can cause pipes to flex and move against rocks, resulting in local stress concentrations, and sometimes pipe failure especially in PVC pipes. The relationship between leakage and pressure can be given by orifice equation for individual leaks:

In the past the conventional view was that leakage from water distribution systems is relatively insensitive to pressure, as described by the orifice Equation 2.6 and Equation 2.7 in literature review chapter 2.

Table 4.19 Evaluation of pressure effects on leakage in the study area

Nodes	Pressure (Improved) (m) (1)	Pressure (Actual) (m) (2)	Difference Pressure (m) (2)-(1)	α	c	Actual System Leakage (L/s)	Improved system leakage (L/s)	Saved Leakage amount (L/s)
J-344	50	90.11	39.63	0.5	0.074	0.70	0.53	0.47
J-362	76	87.96	11.71	0.5	0.074	0.69	0.65	0.25
J-57	58	86.36	27.87	0.5	0.074	0.69	0.57	0.39
J-58	58	86.16	27.88	0.5	0.074	0.69	0.56	0.39
J-352	38	82.76	44.65	0.5	0.074	0.67	0.46	0.49
J-250	49	88.61	39.63	0.5	0.074	0.70	0.52	0.47
J-289	52	91.19	39.63	0.5	0.074	0.71	0.53	0.47
J-330	48	87.35	39.65	0.5	0.074	0.69	0.51	0.47
J-292	57	85.18	27.89	0.5	0.074	0.68	0.56	0.39
J-316	53	81.57	28.85	0.5	0.074	0.67	0.54	0.40
							Total	4.18

A statistical measurement of correlation can be calculated using the least squares method to quantify the strength of the relationship between two variables. The output of that calculation is the Correlation Coefficient, or (r), which ranges between -1 and 1. A value of 1 indicates perfect positive correlation as one variable increases, the second increases in a linear fashion. Likewise, a value of -1 indicates perfect negative correlation as one variable increases, the second decreases. A value of zero indicates zero

correlation (George, 1978). Analysis of Figure 4.13 and Figure 4.14 below based on this discussion point of view.

From the Table 4.19 above 4.18l/s (361.15m³/day) of water is saved by reducing high pressure which is occurred at minimum or night flow in the system with a pressure reducer valve. It is the value which is only aspects to by control maximum pressure level. You can see Fig. 4.13 that the data is clustered closely around the line, and that the line has an upward slope. There is strong positive correlation expressed by two related pressure and leakage parameters.

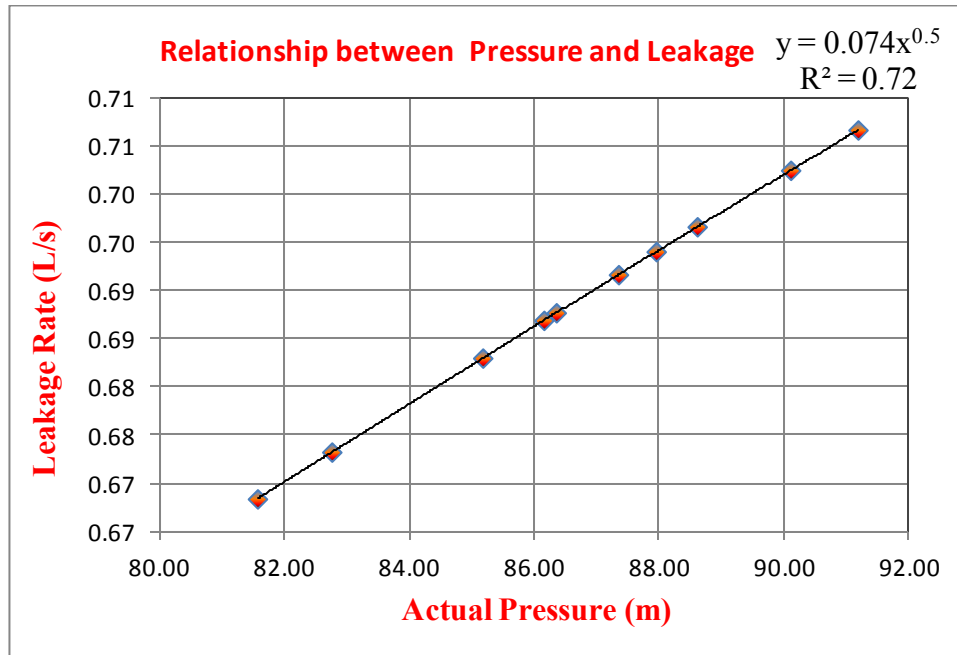


Figure 4.13 Pressure and leakage relation in the water supply distribution lines

The relationship of water loss (leakage) and pressure as you can see from the above graph, the graph is linear function.

Y: - is from the graph represent the leakage (L/s).

X: - is represent Pressure (m).

From this expression the above graph function is $Y=0.074 X^{0.5}$ and the factor $R^2= 0.72$ that means leakage and pressure positively correlated. $q=0.074 (P)^{0.5}$ which is the pressure and the water loss (leakage) are directly proportional when the pressure in distribution system is high the water loss is also high.

4.4.2 Relationship between Pressure, Velocity and Water Quality

In the big distribution systems, water needs to travel a large distance with a long water residence time. The problem could affect water quality. This may be due to low pressure (negative pressure), big and multiple

reservoir storages, insufficient disinfection in the system, leaking, fracture and loosening of joints, and so on. As a result, the problems of quantity are basic agents in the decay of water quality in distribution systems. One of the parameter that could reason to decrease water quality in distribution system is pressure change in network. Many researchers have been carried out about affects pressure change in the water quality in distribution systems. Some of the result is described as follows (Shamsaei et al 2012).

Pressures lower (negative pressure) than that of the atmosphere may cause increased bacteria growth because bacteria from outside the system are then allowed to enter in to the distribution systems. In addition leaking and fractures in the systems permit the entrance of pollutants from outside to the systems. So, water quality which concluded that change of pressure, joints and problems with hydraulics allow pollution to enter the systems, the effects of hydraulics and bacteria growth on biofilm haven't been easily related and that many parameters involve pipe design, high velocity flow rates and conditions of terminal demands. Improved maintenance management of the distribution system with positive pressures, flushing of pipes, coating of pipes to control the entrance of contaminated material, and maintaining disinfection are required (Shamsaei et al 2012).

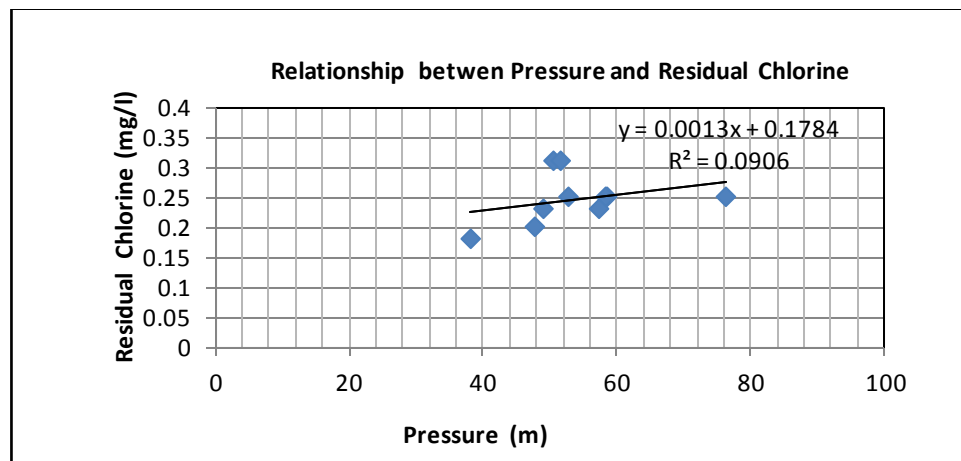


Figure 4.14 Correlation between pressure and residual chlorine

High residence time, high pressure and low pressure systems and distribution network will cause a decline in the water quality in the distribution system and the distance travelled and residence times have been causing to increase bacterial growth, chlorine consumption and hydraulic change (pressure) in water distribution system. Hydraulic changes were causing others for chlorine consumption effectively. Figures 4.14 shows pressure has a direct relationship with residual chlorine. Hydraulic change (pressure) has been causing to increase chlorine consumption more (Shamsaei et al 2012). From the Figure 4.11 correlation between pressure and water quality or R^2 (0.1), which is greater than 0, hence their relationship is positively poor correlated.

4.5 System Model Improvements

4.5.1. Hydraulic Network Improvement

In designing or improving a system there are sets of design criterion to be considered these are: pressure, residual chlorine and velocity. The design criteria used in the design of water supply distribution system components, nodal pressure during the period of peak demand, and optimum velocities of the transfer and distribution mains are as follows (TAHAL, 2015):

- ❖ Minimum static head is 20 m, which can supply a 4-storey building from the distribution system.
- ❖ Maximum static head within a pressure zone was limited to 80 m.
- ❖ Maximum velocities of major transfer mains ≤ 2.5 m/s.
- ❖ Maximum velocities of distribution mains ≤ 2 m/s.
- ❖ Head loss gradient (m/km) ≤ 15 .
- ❖ The absolute minimum velocity of flow in a pipeline is in the range 0.1m/s-0.3m/se, in order to avoid stagnation and water quality problems in the water system (Vairavamoorthy et al 2000).

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

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

The system is redesigned at peak hour flow. So before improving the distribution system the following problems have been identified:

- ❖ Nodes at minimum consumption hour, showing high pressures is shown in tabular report in appendix C and in Figure. 4.8
- ❖ Nodes at scenario with peak flow showing low-pressure problems are in tabular report appendix D and in Figure. 4.7.

A water distribution system is designed at peak hour and minimum hour demand flow. By examine what is going on the system as result of peak hour, solutions have been given to the problems faced (pressures and velocities out of the design limit) within the network. Modification to the problems is made by creating new alternatives and scenario, trial and error procedure until a solution appeared to meet the design criteria.

The procedures were:

- ❖ At peak hour, 8:00 AM the velocities out of the design range are modified by resizing pipe diameters and the pressure is drop in different nodes.
- ❖ At minimum hour demand, 1:00 AM pressures were high at lower elevation area.

This type of pressure has a great effect on leakage and water quality degradation; reduction of excessive pressure to the desired allowable value, feasible suggestions has been made by installing pressure reducer valves (PRVs) at links which has maximum pressure, see the Table 4.20. During this minimum consumption hour there is excess pressure which is greater than the permissible pressure (80m),

Table 4.20 Excess pressure in the improved system at minimum consumption hour

S.no	Label	X	Y	Elevation (m)	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
1	J-344	475477	988516	2188	2277.79	90
2	J-362	475404	988583	2190	2277.79	88
3	J-57	475597	988566	2191	2277.79	86
4	J-58	475624	988563	2191	2277.79	86
5	J-352	475873	988544	2195	2277.81	83
6	J-250	475619	988505	2189	2277.79	89
7	J-289	475553	988471	2186	2277.79	91
8	J-330	475746	988488	2190	2277.79	87
9	J-292	475697	988556	2192	2277.80	85
10	J-316	475619	988667	2196	2277.71	82

According to the above methods criteria procedures, the distribution mains are modified and Pressure reducer valves are added. As a result, 8.33% of the total distribution mains have been resized. Use Table 4.21 and Table 4.22.

Table 4.21 Improved distribution main lines

S.no	Label	Existing Pipe Size (mm)		Modified Pipe Size (mm)		Length (m)
		Diameter (mm)	Velocity (m/s)	Diameter (mm)	Velocity (m/s)	
1	P-4	40	0.72	63	0.34	97.23
2	P-14	63	1.77	110	0.64	131.98
3	P-20	40	0.02	63	0.12	15.85
4	P-23	63	1.47	110	0.53	158.5
5	P-62	40	1.19	150	0.09	39.93
6	P-103	110	0.31	150	0.15	110.34
7	P-105	110	0.15	150	0.16	44.81
8	P-111	110	0.23	150	0.15	99.67
9	P-113	110	0.13	150	0.06	43.59
10	P-218	63	1.26	150	0.63	73.15
11	P-219	63	0.64	110	0.2	32.31
12	P-220	63	1.81	110	0.62	74.68
13	P-221	63	1.11	110	0.31	99.97
14	P-222	63	0.25	110	0.44	39.01
15	P-224	63	0.66	110	0.36	35.66
16	P-225	63	3.32	150	1.5	118.26
17	P-226	110	1.09	150	1.5	78.33
18	P-301	75	1.9	150	0.42	199.34
19	P-302	63	1.9	110	0.68	110.64
20	P-319	63	3.43	150	1.52	14.94
21	P-321	63	0.42	110	0.14	78.64
22	P-323	63	0.49	110	0.14	44.2
23	P-324	40	0.83	150	0.05	236.22
24	P-326	63	1.37	110	0.24	64.62
25	P-327	40	1.5	150	0.08	94.18
26	P-329	63	1.08	110	0.03	74.37
27	P-444	63	0.17	110	0.05	80.77
28	P-445	63	0.55	110	0.11	71.02
29	P-446	63	0.52	110	0.06	79.25
30	P-447	63	1.18	110	0.54	101.8
31	P-448	110	0.66	150	0.86	69.19
32	P-449	110	0.22	150	0.59	41.15
33	P-451	63	1.12	110	0.22	73.15
34	P-452	63	0.24	110	0.54	70.71
35	P-453	63	0.47	110	0.4	38.4
36	P-474	110	0.12	150	0.51	136.86
37	P-475	63	2.45	150	0.36	16.46
38	P-478	63	2.64	110	0.77	324
39	P-480	63	2.88	110	0.68	10.36

40	P-483	63	27.85	250	1.91	8.53
41	P-484	63	4.56	150	1.05	5.79

Table 4.22 Pressure reducer valves in the improved system

S.no	Label	X	Y	Elevation (m)	Diameter (mm)
1	PRV-1	475,383.55	988,743.70	2,228.00	110
2	PRV-2	475,706.44	988,635.84	2,194.00	63
3	PRV-3	475,885.90	988,604.08	2,195.00	50
4	PRV-4	475,622.76	988,549.05	2,188.00	40
5	PRV-5	476,019.83	988,534.65	2,200.00	50
6	PRV-6	475,773.66	988,551.48	2,193.00	50
7	PRV-7	475,528.77	988,572.82	2,190.00	63
8	PRV-8	475,383.07	989,023.68	2,233.00	110
9	PRV-9	475,396.36	988,659.67	2,226.00	110
10	PRV-10	475,557.47	989,036.79	2,232.00	75

The results of the improved systems are illustrated with appendix E, and appendix F:

- ❖ Pressure at junctions (Appendix -F Nodes with improved system) in the tabular report and Figure 4.16 at peak hour condition.
- ❖ Pressure at junctions (Appendix E-Nodes with improved system) in the tabular report and Figure 4.15 at minimum hour.

Table 4.23 Improved system nodes with pressure at minimum consumption hour.

Pressure (m)	Node (number)	Percentage (%)
≥80	0	0.00
70-80	35	9.64
60-70	71	19.56
50-60	212	58.40
40-50	44	12.12
30-40	1	0.28
20-30	0	0.00
≤20	0	0.00
Total	363	100

Table 4.24 Improved system nodes at peak hour

Pressure (m)	Node (number)	Percentage (%)
≥80	0	0.00
70-80	1	0.28
60-70	7	1.93
50-60	78	21.49
40-50	223	61.43
30-40	52	14.33
20-30	2	0.55
≤20	0	0.00
Total	363	100

Table 4.25 Distribution of actual pipe velocity at peak hour demand

Velocity (m/s)	Pipe (number)	Percentage (%)
≥ 2.5	22	4.47
2-2.5	9	1.83
1.5-2	25	5.08
1-1.5	55	11.18
0.3-1	189	38.41
0.1-0.3	103	20.93
0.05-0.1	34	6.91
≤ 0.05	55	11.18
Total	492	100

Table 4.26 Improved system velocity distribution at peak hour

Velocity (m/s)	Pipe (number)	Percentage (%)
≥ 2.5	0	0.00
2-2.5	8	1.59
1.5-2	10	1.99
1-1.5	35	6.97
0.3-1	186	37.05
0.1-0.3	136	27.09
0.05-0.1	62	12.35
0-0.05	65	12.95
0	0	0.00
Total	502	100

The results of the improved systems are summarized above from Table 4.21 up to Table 4.26 and appendix C in detail:

As depicted in Table 4.23 and Table 4.24 all nodes percent of pressure are found under desirable allowable minimum and maximum pressure (20m-80m) in the system respectively during peak hour and minimum consumption hour demand.

As depicted in Table 4.25 and Table 4.26 summarized shows that compare and evaluation of distribution of velocity of water flow in both actual and improved links of the system. Improved system velocity distribution in both peak day demand and minimum day demand all percents of pipes are under allowable with both maximum and minimum velocity ranges of criteria at transmission, distribution and service line or customers tap sides (0.05m/s-2.5m/s). The above result shows that our trial and testing pipe size diameter changing with modeling was satisfactory results.

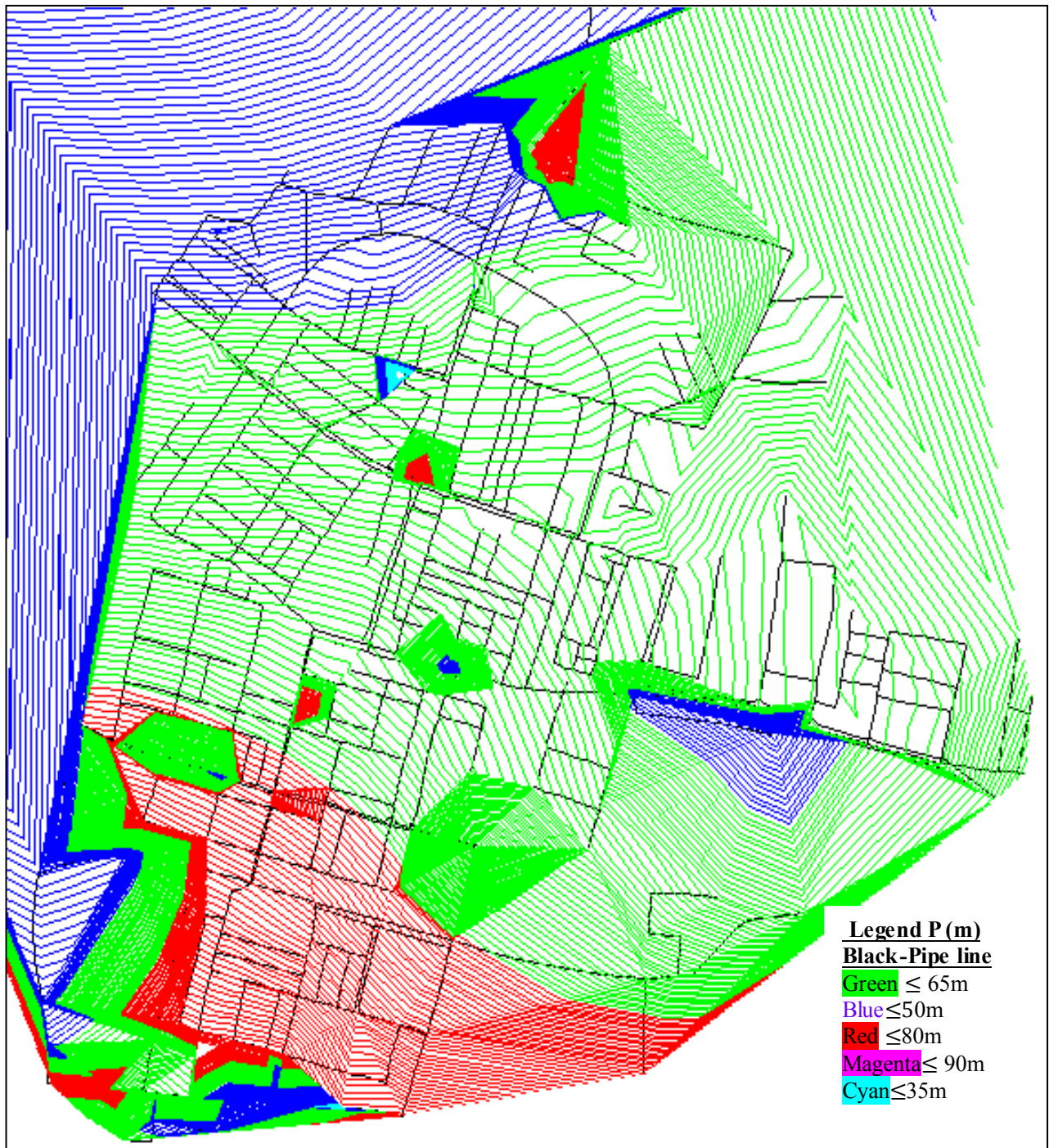


Figure 4.15 Shows improved pressure contour map at minimum hour consumption

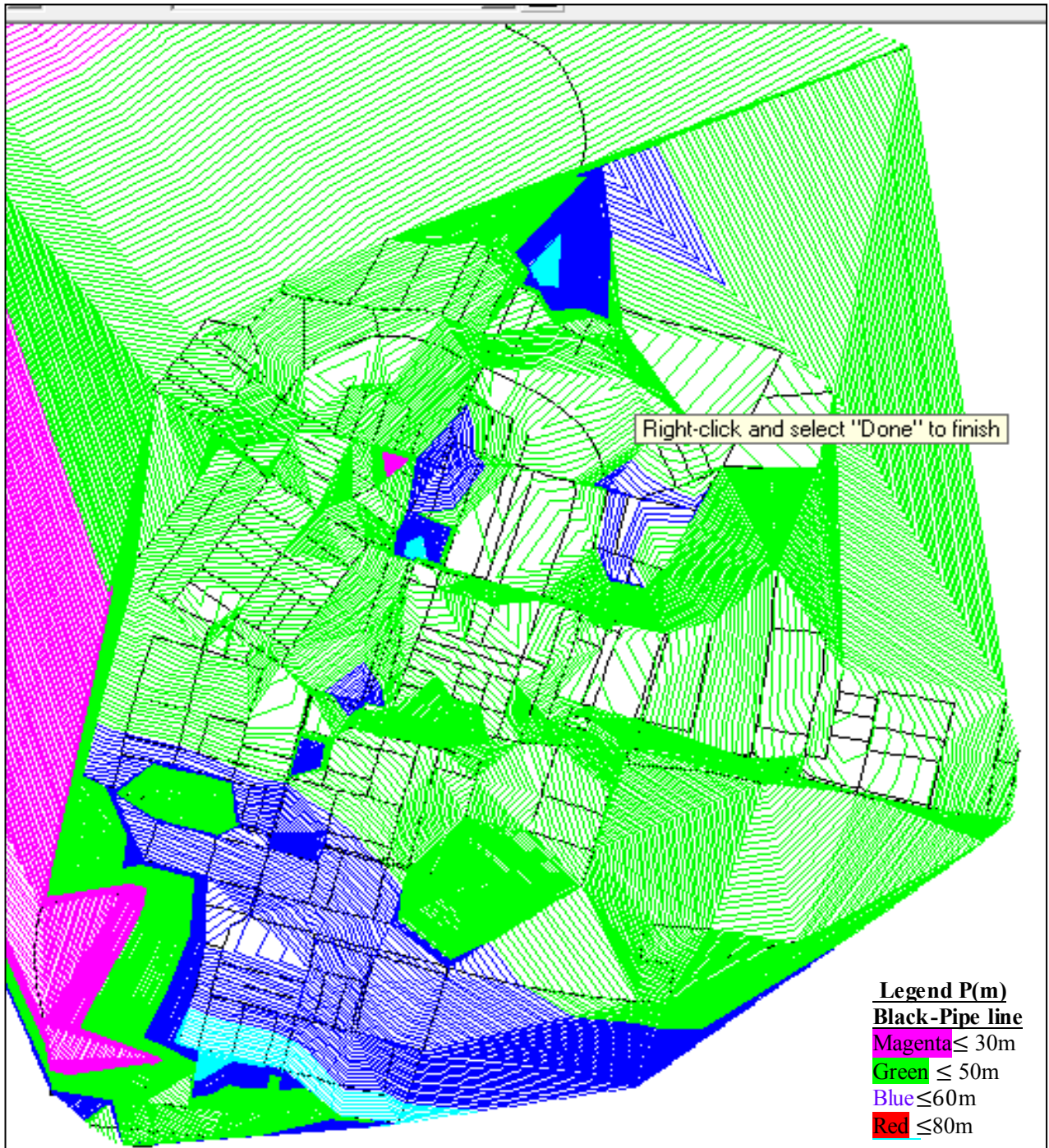


Figure 4.16 Shows improved pressure contour map at peak hour consumption

4.5.2. Water Quality Improvement

Establishing booster disinfection stations is an intervention required to improve water quality deterioration in distribution system of Bole Bulbula water supply system. Table 4.27 depicts possible booster disinfection sites and concentration of chlorine dosage at each station.

Table 4.27 Chlorine dosage concentration for proposed booster disinfection stations

Selected Nodes	Actual chlorine Dosage(mg/l)	Improved Chlorine Dosage(mg/l)
R-1	0.5	0.4
Tank 1	0.4	0.3

Table 4.28 illustrates the distribution of residual chlorine during low hour flow for actual system and corresponding residual chlorine concentration for proposed system with intervention (with establishment of booster disinfection stations).

Table 4.28 Distribution of residual chlorine at low hour flow for actual and improved system

Residual chlorine (mg/l)	Actual system		Improved system	
	Nodes	Percentage (%)	Nodes	Percentage (%)
0	0	0.00	0	0.00
0.01-0.1	0	0.00	0	0.00
0.1-0.2	0	0.00	8	2.20
0.2-0.5	323	88.98	345	96.97
>0.5	40	11.02	3	0.83
Total	363	100	363	100

As depicted in Table 4.27 and Table 4.28 establishment of booster disinfection sites significantly improves residual chlorine concentration. From the Table 4.28, 11.02% of actual nodes received more than 0.5mg/l residual chlorine concentration during low consumption hour flow. But the improved nodes at the same time of low flow hour received 0.83% residual chlorine concentration only. Therefore, the excessive residual chlorine can be maintained, that minimum and maximum (WHO, 0.2-0.5mg/l), by decreasing the initial concentration dosage at both sources and storage tank (R-1 and tank-1).

Figure 4.17 and Figure 4.18 illustrates distribution of residual chlorine during low hour flow for actual system and proposed system. In actual system case nodes obtain water with residual chlorine exceeding 0.5mg/l which is microbiologically unsafe to use. In proposed system with establishment of booster disinfection sites, only few nodes obtain water with residual chlorine exceeding 0.5mg/l which is microbiologically safe to use. The above results shows as pipe diameter size, pressure, velocity demand and velocity has a great impact on water quality degradation.

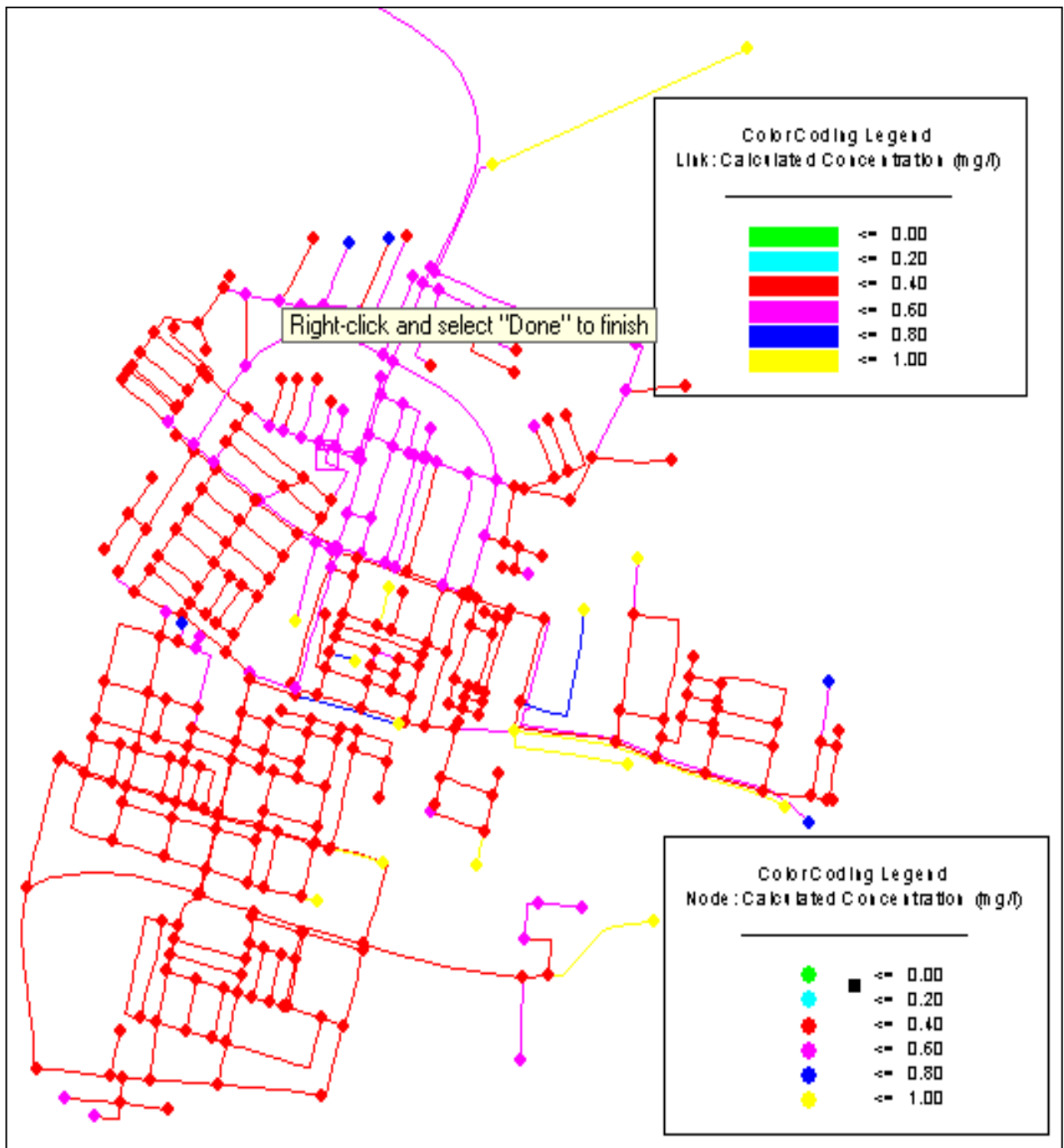


Figure 4.17 Existing system residual chlorine distribution plot at low flow hour

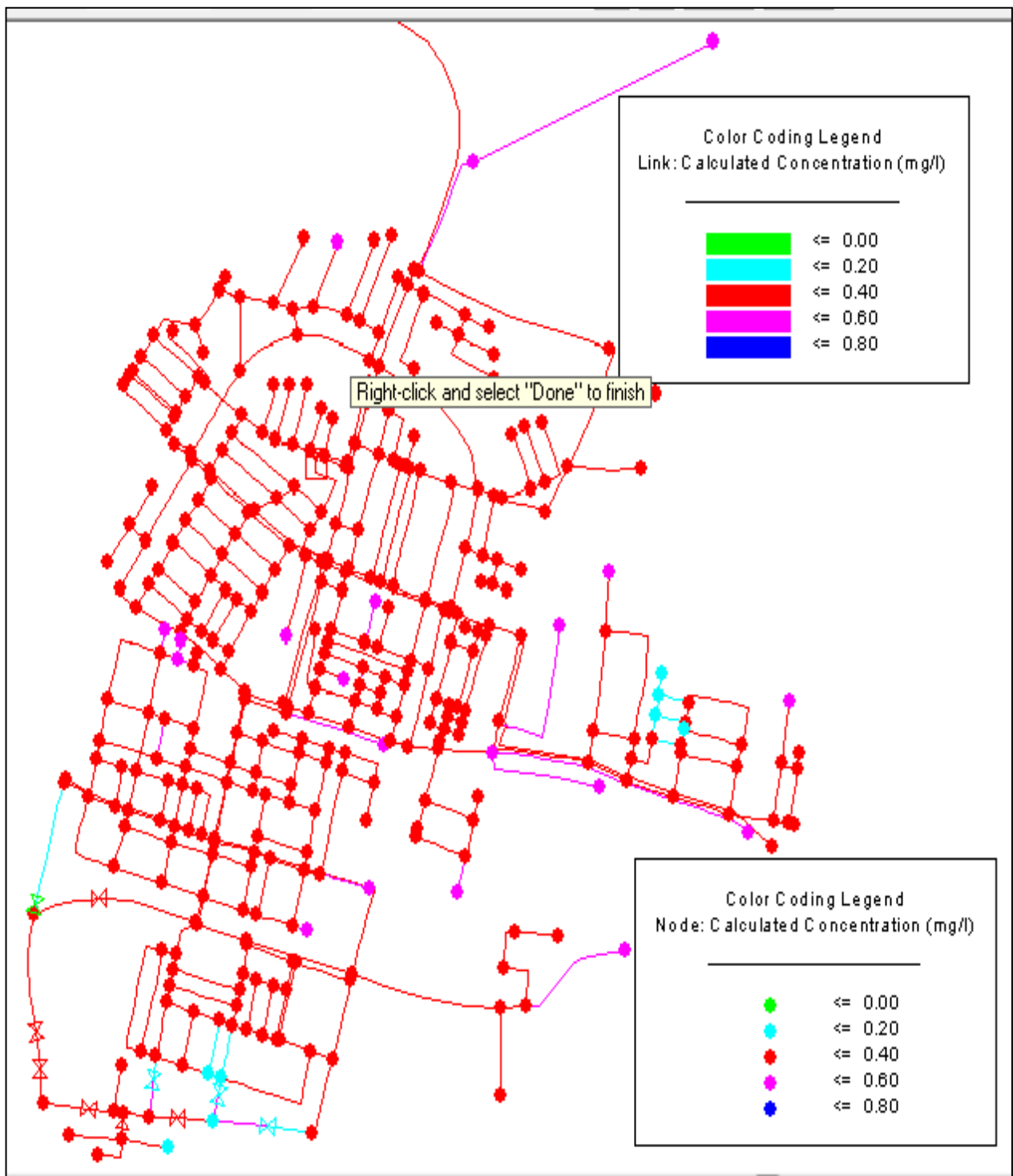


Figure 4.18 Proposed system residual chlorine distribution plot at low flow hour

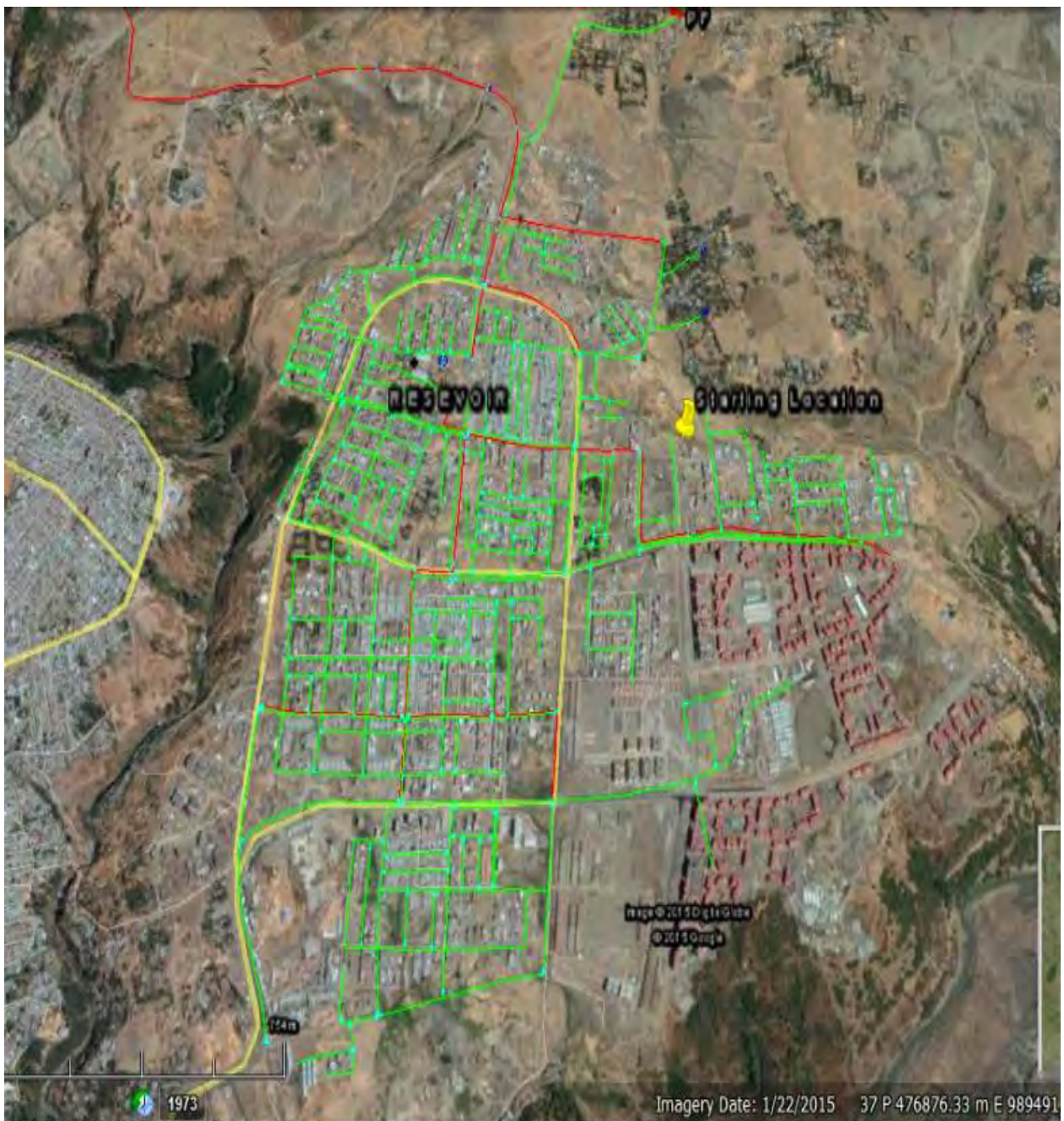


Figure 4.19 3D Bole Bulbula improved water supply system model aerial view image.

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

To assess the current situation of Addis Ababa water supply network system modeling was found appropriate technique and accordingly modeling efforts were carried out for case study of Bole Bulbula supply system. The base of the assessment was evaluating hydraulic performance of the distribution system as well as analyzing issues of supply network and water quality in the distribution system based on results of calibrated and validated model. With intended objectives the study was undertaken and it has come with significant outcomes. The research project focused to model hydraulic, and to upgrade Bole Bulbul water supply subsystem, and the research results are in the following key achievements:

- ❖ Development of Bole Bulbula water supply distribution model created.
- ❖ 8.33% of the system's total distribution hydraulic performance improved by resizing existing distribution mains pipes with respect to low pressure.
- ❖ Water quality residual chlorine improved from 11.02% excess of residual chlorine in the distribution system lowered by 0.83% from existing supply to proposed supply.
- ❖ Excessive service pressure area and pressure zone with respect to pressures criteria are identified.
- ❖ Water supply network line is updated.
- ❖ Excessive rate of unaccounted for water is estimated (34.46%).
- ❖ Pressure Reducer Valve (PRV) is added in the system to overcoming the problems of high pressure effects on water supply line.
- ❖ 0.4% galvanized steel pipe to be replaced by new corrosion resistance pipe material.
- ❖ Domestic water supply coverage was assessed in both way of coverage that by family connection (57%) and average base line demands (58 l/c/d).
- ❖ 715.068 m³/day water losses are saved in the whole system.
- ❖ Water demand current and future are also estimated.

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

existence of operational problems.

In general, the simulated hydraulic result indicated that the currently hydraulic performance of Bole Bulbula supply is not satisfactory. But it doesn't mean that the subsystem is not functional. Rather the frequency of service interruption is relatively high. This interruption is partly contributing for the current water shortage in the city of Addis Ababa. Variation of water use (water demand pattern) is the dominant factor currently contributing to water quality deterioration in distribution system of Addis Ababa city.

Disinfection modeling result showed that the distribution system lacks the ability to fully distribute microbiologically safe water due to absence of minimum allowable residual chlorine at least once per day. Based on simulation result, part of distribution system is liable to risk of health problem because of the absence or excess of residual chlorine in water at least once per day.

In general, from hydraulic and water quality point of view modeling results showed that Bole Bulbula supply system is currently performing in a poor situation. Particularly, the subsystem is not maintaining the minimum and maximum pressure, velocity and residual chlorine which guard the probable recontamination of water during distribution.

5.2 Recommendation

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

- ❖ To permanently modify the hydraulic performance of the sub system, the design needs to be reviewed and pressure zones which serve customers situated in nearly equivalent elevation has to be established. If the elevation difference is significantly greater, more pressure zones are needed.
- ❖ Adjustment or implementation of pressure reducing valve or break pressure tanks; devices which decrease pressure are recommended as solution to control occurrences of maximum pressures for isolated parts of network.
- ❖ Uses of pressure sustaining valves are recommended as to control the occurrences of minimum pressures. These valves start closing if the upstream pressure falls below the present value as to guarantee allowable minimum pressure for isolated parts of networks.
- ❖ Modification in current flushing program which program which only targets storage tank cleaning per year is necessary. But periodic flushing of pipe system elements associated with long water age may also minimize water quality degradation by removal of pipes scales and sediment

associated with disinfectant consumption.

- ❖ Installing new pipes as to eliminating dead ends and letting water to route in the system is essential. Such an effort contributes reduction in water age. An attempt to eliminating dead ends of case study by installing new pipes showed significant reduction of water age.
- ❖ Booster disinfection station has to be established to maintain life guarantee minimum residual chlorine across the distribution system. If implementation of booster disinfection is not possible, local disinfection mechanisms at home level such as use of household chemicals prior to consumption has to be promoted particularly in the rainy season.
- ❖ Hydraulic pressure zones should be mapped out to give guidance on the number and nature of consumers that can be connected to the respective mains.
- ❖ Updating of the network which is undergoing by the GIS unit of AAWSA is appreciated, but this need to be integrated with the land information system of the city as well as information on hydraulic flow of the water network. Operation and maintenance data including pressure records need also be integrated spatially with the network. Therefore, introducing geographic information system (GIS) is timely as it may facilitate the updating of the networks and support to perform related spatial analysis. The recently prepared digital elevation model (DEM) of the city may support to divide the network in to manageable smaller hydraulic zones or district meter areas.
- ❖ The city water supply system is characterized by un functional meters and valves. It is essential to repair or replace all meters and valves so that night flow measurement at different levels would be possible. Night Flow Measurement is the first and simplest method that can assist in estimating locating and evaluating losses within a zone or district once the system is divided into DMAs. As most of the valves and meters are not functional in the systems nowadays, night flow measurement is not being conducted in the city.
- ❖ Establishing District Meter Areas (DMA) The principle of zoning and DMA is a hierarchical way of evaluating and managing losses that covers a number of levels beginning with measurement at the supply and ends at the customers meter for an estimate of consumption. The network system of the entire city has to be sub-divided into different zones and sub-zones. Implementation of a zoning scheme whereby the complete water distribution network is broken down into manageable segments enables easy metering, monitoring and analyzing; it also creates better ground for further operations related to loss analysis and control. In establishing zoning and district meter areas, the areas have to be investigated based on the ground elevation difference and distance

from the respective service reservoirs. Literatures recommend metering at each hierarchy and permanent disconnection of zones and districts from one another. Besides the following are recommended:

- Zones to include from 10,000 to 50,000 properties
- District meter areas (DMA) to incorporate around 3,000 properties
- Sub-district meter areas shall include about 1,000 properties
- ❖ Most of flow control gate valves are not found under a protected condition, so to increase their functions all gate valves must be covered with standard manholes.
- ❖ Currently water pipe network installation method carried out traditionally, especially at branch level. Therefore, AAWSA has to be prepared the working guideline manuals for the purpose of new pipe installation, age pipe replacement and upgrading existing pipe size, extending the pipe to new expansion area and installation of new pipe size based on demand calculation.

This research has generated several significant results. Pressure, water age and residual chlorine were modeled to provide deeper understanding of the current situation of water distribution network system. Subsequently valuable suggestions were drawn based on finding to improve the situation. However, more comprehensive and detailed understanding, future works are suggested to focus on:

- ❖ More local studies are recommended. This is to understand how the water systems perform under the local conditions of operation and management.
- ❖ Impacts of various development activities on performance of water distribution system.

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APPENDIX

APPENDIX A: Checklist for Discussion with Local Experts

Checklist for discussion with local experts	
1	What are the main sources of water in the Bole Bulbula subsystem? Are there any water sources that are not included to the distribution system? Where and how much?
2	Is there any difference in level of water distribution among different localities? If yes, how do you manage to balance the supply?
3	Is there any seasonal difference in amount (volume) of water supplied particularly in rainy season and dry season? If yes to what extent?
4	Are there any non-metered water consumptions? If so for what purpose and how do you estimate the volume of water consumed?
5	How do you estimate the residential water demand? Do you have any standard?
6	How do you identify leakage or breakage of water pipes? How do the residents/communities support in reporting leakage or breakage of pipes?
7	From your experience, does leakage and breakage of pipes have significant relation with age of pipes?
8	From your experience does the ground elevation difference of the subsystem have a significant impact on pressure and distribution of water? How do you manage the pressure with the big elevation difference of the city?
9	Do you have a plan to replace aged pipes and water meters? What major criteria do you use for prioritization of replacement?
10	Do you use GIS and water cad in your operational management of the water supply network? If yes, which GIS and water cad software do you use?

APPENDIX B: Pressure Calibration Fitness Test

Time steps	Pressure junction	O _i	\bar{O}_i	P _i	\bar{P}_i	$(O_i - \bar{O}_i)^2$	$(P_i - \bar{P}_i)^2$
8:00:00AM	J-289	84.00	42.84	85.91	43.51	1694.15	1797.91
	J-330	80.00	42.84	82.05	43.51	1380.87	1485.54
	J-299	55.00	42.84	57.32	43.51	147.87	190.68
	J-152	49.00	42.84	52.69	43.51	37.95	84.41
	J-364	42.00	42.84	45.18	43.51	0.71	2.79
10:00:00AM	J-289	35.00	42.84	37.54	43.51	61.47	35.63
	J-330	24.00	42.84	33.47	43.51	354.95	100.77
	J-299	13.00	42.84	17.50	43.51	890.43	676.48
	J-152	45.00	42.84	49.39	43.51	4.67	34.64
	J-364	45.00	42.84	39.94	43.51	4.67	12.70
12:00:00PM	J-289	39.00	42.84	42.82	43.51	14.75	0.47
	J-330	42.00	42.84	38.79	43.51	0.71	22.28
	J-299	27.00	42.84	21.45	43.51	250.91	486.30
	J-152	51.00	42.84	47.67	43.51	66.59	17.35
	J-364	35.00	42.84	38.47	43.51	61.47	25.40
2:00PM	J-289	39.00	42.84	41.34	43.51	14.75	4.68
	J-330	35.00	42.84	37.31	43.51	61.47	38.44
	J-299	26.00	42.84	19.98	43.51	283.59	553.72
	J-152	48.00	42.84	46.18	43.51	26.63	7.17
	J-364	43.00	42.84	37.01	43.51	0.03	42.21
4:00PM	J-289	57.00	42.84	53.51	43.51	200.51	100.06
	J-330	40.00	42.84	49.53	43.51	8.07	36.30
	J-299	33.00	42.84	29.76	43.51	96.83	188.99
	J-152	44.00	42.84	45.77	43.51	1.35	5.10
	J-364	36.00	42.84	37.10	43.51	46.79	41.08

$$R^2 = \left[\frac{\sum_{i=1}^n (O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^n (O_i - \bar{O})^2} \sqrt{\sum_{i=1}^n (P_i - \bar{P})^2}} \right]^2$$

$$R^2=0.960571553$$

APPENDIX C

Steady State Simulation Analysis Results

Actual Nodes at Minimum Consumption Hour

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
1	J-138	476131	989136	2213	0.01	Fixed	2277.77	64.54
2	J-156	475749	989295	2211	0.01	Fixed	2277.78	66.26
3	J-195	477096	989483	2226	0	Fixed	2277.53	51.45
4	J-375	477343	989182	2223	0	Fixed	2277.89	54.70
5	J-299	475958	989490	2216	0.01	Fixed	2277.88	61.59
6	J-208	476089	990035	2226	0	Fixed	2278.52	52.71
7	J-102	475756	989160	2209	0.09	Fixed	2277.78	68.88
8	J-254	475970	989888	2223	0.04	Fixed	2277.87	54.99
9	J-239	476133	989443	2217	0	Fixed	2277.89	61.00
10	J-234	477077	989388	2226	0	Fixed	2277.54	51.55
11	J-28	475650	990197	2229	0	Fixed	2278.86	49.81
12	J-328	476081	990170	2228	0	Fixed	2278.51	50.01
13	J-266	476295	990131	2227	0.01	Fixed	2279.68	52.12
14	J-108	475924	988757	2202	0.01	Fixed	2277.82	75.64
15	J-121	475602	989240	2225	0.01	Fixed	2277.78	52.59
16	J-233	475897	989793	2221	0.01	Fixed	2277.87	56.75
17	J-231	476007	989711	2220	0	Fixed	2277.87	58.03
18	J-97	475994	989172	2212	0	Fixed	2277.77	65.97
19	J-331	476693	990060	2227	0.01	Fixed	2280.98	54.28
20	J-374	477246	990928	2237	0	Fixed	2288.95	51.53
21	J-344	475477	988516	2188	0	Fixed	2277.79	90.11
22	J-13	476089	988897	2209	0.02	Fixed	2277.83	68.98
23	J-339	476300	989056	2226	0	Fixed	2277.78	51.34
24	J-279	476524	989952	2225	0.12	Fixed	2279.37	54.40
25	J-162	476485	989476	2221	0.04	Fixed	2277.91	57.07
26	J-106	475938	989696	2219	0.04	Fixed	2277.87	58.64
27	J-281	476731	988797	2216	0	Fixed	2277.84	61.41
28	J-357	477047	989984	2227	0.02	Fixed	2284.30	57.45
29	J-77	476334	989734	2222	0.03	Fixed	2278.52	56.76
30	J-74	475876	989161	2206	0.06	Fixed	2277.78	71.86
31	J-284	476426	990055	2226	0.02	Fixed	2279.07	52.63
32	J-188	475823	989689	2219	0.02	Fixed	2277.87	58.84
33	J-82	476396	989506	2220	0.06	Fixed	2277.89	57.76
34	J-308	475733	989070	2207	0.03	Fixed	2277.78	70.92
35	J-226	476150	990339	2231	0.02	Fixed	2279.74	48.26

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Steady State Simulation Analysis Results

Actual Nodes at Minimum Consumption Hour

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
36	J-212	475727	989577	2217	0.01	Fixed	2277.78	61.00
37	J-323	476040	990167	2228	0.02	Fixed	2278.51	50.07
38	J-183	477028	989387	2226	0.01	Fixed	2277.60	51.86
39	J-201	477178	989468	2226	0.02	Fixed	2277.53	51.82
40	J-351	476142	988519	2200	0.02	Fixed	2277.82	78.01
41	J-95	475807	989187	2210	0.03	Fixed	2277.80	67.85
42	J-348	476215	990484	2234	0	Fixed	2279.74	45.94
43	J-123	475991	988857	2206	0.01	Fixed	2277.83	71.75
44	J-190	476165	989088	2213	0.01	Fixed	2277.78	64.52
45	J-290	475817	988787	2202	0	Fixed	2277.81	76.07
46	J-174	476653	989780	2224	0	Fixed	2280.47	56.32
47	J-170	475915	989578	2217	0	Fixed	2277.87	60.51
48	J-144	476165	989540	2218	0	Fixed	2277.88	59.58
49	J-186	476236	989357	2217	0.02	Fixed	2277.76	60.69
50	J-114	475894	988641	2198	0.01	Fixed	2277.81	79.46
51	J-222	476140	989846	2222	0.01	Fixed	2278.03	55.53
52	J-325	476844	989989	2226	0.04	Fixed	2284.30	57.89
53	J-88	475889	990378	2233	0.01	Fixed	2279.25	46.61
54	J-345	476427	989173	2218	0.01	Fixed	2277.88	59.48
55	J-184	475674	988698	2198	0	Fixed	2277.81	79.25
56	J-83	475818	989547	2216	0.02	Fixed	2277.78	61.26
57	J-135	475744	990068	2226	0.01	Fixed	2278.88	52.43
58	J-283	476629	990294	2229	0.01	Fixed	2280.93	51.54
59	J-24	476183	989773	2222	0.01	Fixed	2277.90	56.28
60	J-160	475729	988921	2204	0.1	Fixed	2277.81	73.96
61	J-229	476376	989434	2219	0.01	Fixed	2277.89	58.58
62	J-101	475764	989195	2231	0.01	Fixed	2277.78	46.52
63	J-253	475933	989841	2222	0.04	Fixed	2277.87	55.76
64	J-60	476623	989615	2223	0	Fixed	2277.92	55.01
65	J-70	476611	989736	2223	0	Fixed	2280.47	56.99
66	J-139	476123	989097	2212	0.01	Fixed	2277.78	65.23
67	J-206	476565	990321	2230	0.01	Fixed	2280.93	50.85
68	J-175	475797	990141	2228	0.08	Fixed	2278.79	50.89
69	J-262	475844	989041	2207	0.01	Fixed	2277.79	70.39
70	J-294	476669	988881	2218	0.01	Fixed	2277.84	59.76
71	J-257	476042	989761	2221	0.01	Fixed	2277.87	57.05
72	J-241	475764	989822	2221	0.01	Fixed	2277.87	56.38

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Steady State Simulation Analysis Results

Actual Nodes at Minimum Consumption Hour

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
73	J-215	476093	990336	2232	0	Fixed	2279.66	48.03
74	J-310	476317	989690	2221	0	Fixed	2277.89	56.78
75	J-23	475466	989299	2210	0	Fixed	2277.80	67.68
76	J-341	476130	990170	2228	0.02	Fixed	2278.52	50.08
77	J-244	475813	990004	2225	0.01	Fixed	2277.87	52.69
78	J-80	476365	989725	2222	0	Fixed	2278.52	56.75
79	J-109	477476	989322	2221	0	Fixed	2277.49	56.60
80	J-280	476661	988793	2215	0.01	Fixed	2277.84	62.52
81	J-64	476516	989435	2221	0.01	Fixed	2277.90	56.92
82	J-291	476152	989228	2215	0.49	Fixed	2277.74	62.99
83	J-307	475599	989106	2206	0.18	Fixed	2277.78	71.51
84	J-169	475894	989542	2217	0.01	Fixed	2277.87	61.14
85	J-145	476170	989734	2221	0.03	Fixed	2277.90	56.92
86	J-127	475782	989625	2218	0	Fixed	2277.87	60.10
87	J-271	476716	989759	2224	0.05	Fixed	2280.46	55.97
88	J-129	476289	989600	2220	0	Fixed	2277.89	57.84
89	J-314	475582	989779	2221	0	Fixed	2277.86	57.18
90	J-87	475907	990403	2233	0.01	Fixed	2279.25	46.12
91	J-3	475964	988933	2207	0.01	Fixed	2277.83	70.80
92	J-373	477406	989149	2221	0.13	Fixed	2277.91	56.99
93	J-297	476542	989051	2219	0	Fixed	2277.88	58.88
94	J-8	476180	989783	2198	0.18	Fixed	2278.22	79.89
95	J-11	476521	989669	2222	0.01	Fixed	2277.92	55.75
96	J-128	475800	989652	2218	0	Fixed	2277.87	59.59
97	J-171	475558	989384	2212	0	Fixed	2277.78	65.69
98	J-320	476928	990144	2228	0.01	Fixed	2286.84	59.14
99	J-120	475871	989606	2218	0	Fixed	2277.87	60.22
100	J-191	476125	989790	2221	0.03	Fixed	2277.89	56.30
101	J-32	475965	988944	2207	0.01	Fixed	2277.83	70.58
102	J-130	476324	989588	2220	0.01	Fixed	2277.89	57.71
103	J-321	476958	990248	2229	0.01	Fixed	2288.62	59.73
104	J-96	475840	989178	2210	0.01	Fixed	2277.82	67.72
105	J-306	475581	989473	2214	0	Fixed	2277.78	63.78
106	J-237	475688	989825	2221	0	Fixed	2277.86	56.26
107	J-125	476344	989524	2220	0	Fixed	2277.88	58.11
108	J-124	475955	988869	2205	0.01	Fixed	2277.83	72.33
109	J-293	475958	989475	2216	0	Fixed	2277.78	61.70

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Steady State Simulation Analysis Results

Actual Nodes at Minimum Consumption Hour

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
110	J-277	475938	989400	2215	0.01	Fixed	2277.78	62.87
111	J-240	475797	989868	2222	0	Fixed	2277.87	55.44
112	J-245	475767	990037	2226	0.01	Fixed	2277.87	52.01
113	J-66	476406	989536	2220	0.18	Fixed	2277.89	57.45
114	J-126	476333	989487	2219	0	Fixed	2277.88	58.56
115	J-361	476659	988601	2206	0	Fixed	2277.84	71.91
116	J-71	476639	989729	2224	0	Fixed	2280.47	56.77
117	J-272	476454	989253	2219	0	Fixed	2277.88	58.70
118	J-22	475463	989293	2227	0	Fixed	2277.79	50.23
119	J-172	475550	989342	2211	0	Fixed	2277.78	66.54
120	J-285	476904	989334	2225	0	Fixed	2277.63	52.50
121	J-274	476229	989520	2219	0	Fixed	2277.88	59.24
122	J-39	476438	990417	2212	0.2	Fixed	2288.95	76.41
123	J-227	476455	989688	2222	0	Fixed	2277.92	56.10
124	J-18	476045	988725	2204	0	Fixed	2277.82	73.51
125	J-207	476545	990278	2229	0	Fixed	2280.92	51.35
126	J-168	476679	989718	2224	0	Fixed	2280.47	56.46
127	J-134	476009	988735	2204	0	Fixed	2277.82	74.15
128	J-51	476543	989456	2221	0	Fixed	2277.91	56.54
129	J-75	476508	989408	2221	0.21	Fixed	2277.89	57.15
130	J-205	475977	989670	2219	0	Fixed	2277.87	58.88
131	J-161	476406	990388	2232	0.04	Fixed	2280.94	49.32
132	J-362	475404	988583	2190	0	Fixed	2277.79	87.96
133	J-187	476226	989316	2216	0.06	Fixed	2277.75	61.21
134	J-164	475911	989293	2213	0.02	Fixed	2277.78	64.69
135	J-10	476523	989677	2222	0.01	Fixed	2278.07	55.85
136	J-243	476097	989943	2224	0	Fixed	2278.18	54.22
137	J-335	476382	990405	2232	0.07	Fixed	2280.05	48.06
138	J-43	476496	989382	2220	0.02	Fixed	2277.89	57.41
139	J-44	476489	989365	2220	0.03	Fixed	2277.89	57.59
140	J-131	476323	989451	2219	0	Fixed	2277.88	59.00
141	J-327	476091	988976	2210	0.01	Fixed	2277.78	67.65
142	J-35	476074	989443	2216	0.02	Fixed	2277.87	61.49
143	J-276	475984	989890	2223	0.02	Fixed	2278.25	55.33
144	J-81	476549	989397	2221	0.01	Fixed	2277.90	56.68
145	J-30	476248	988854	2211	0.01	Fixed	2277.84	66.82
146	J-159	475675	990231	2230	0	Fixed	2278.85	49.13

APPENDIX C**Steady State Simulation Analysis Results****Actual Nodes at Minimum Consumption Hour**

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
147	J-111	476273	989506	2219	0.02	Fixed	2277.88	58.98
148	J-90	475770	988911	2204	0.02	Fixed	2277.82	73.75
149	J-115	475729	989206	2226	0.01	Fixed	2277.78	52.00
150	J-62	476188	989603	2219	0.01	Fixed	2277.89	58.55
151	J-199	475773	989563	2217	0	Fixed	2277.78	61.13
152	J-94	475984	989138	2211	0.01	Fixed	2277.78	66.69
153	J-251	476329	990283	2230	0.02	Fixed	2280.05	50.21
154	J-132	476073	988835	2207	0.02	Fixed	2277.83	70.55
155	J-38	477169	989424	2226	0.01	Fixed	2277.53	51.77
156	J-53	476564	989449	2221	0.01	Fixed	2277.91	56.35
157	J-315	476123	990494	2234	0.01	Fixed	2279.54	45.54
158	J-247	476104	990277	2231	0	Fixed	2279.66	49.04
159	J-211	477310	989324	2225	0.01	Fixed	2277.52	52.63
160	J-342	476129	988966	2211	0	Fixed	2277.78	67.06
161	J-5	475825	988983	2206	0.01	Fixed	2277.84	71.79
162	J-137	476080	989249	2214	0.01	Fixed	2277.76	63.63
163	J-278	476455	989696	2222	0.02	Fixed	2278.48	56.60
164	J-219	476602	989260	2221	0.02	Fixed	2277.88	56.45
165	J-150	475628	989193	2208	0.01	Fixed	2277.78	69.33
166	J-216	476081	989814	2222	0.02	Fixed	2277.88	56.10
167	J-133	476037	988844	2207	0.01	Fixed	2277.83	71.16
168	J-230	475741	989631	2218	0.01	Fixed	2277.78	59.98
169	J-50	475848	990173	2228	0	Fixed	2278.67	50.10
170	J-232	476465	989541	2221	0	Fixed	2277.89	56.89
171	J-197	475695	989445	2214	0.02	Fixed	2277.78	63.87
172	J-275	476484	990305	2230	0.01	Fixed	2280.92	50.74
173	J-34	476077	989458	2216	0.01	Fixed	2277.89	61.32
174	J-141	476746	989941	2226	0.01	Fixed	2280.98	55.27
175	J-228	476598	989938	2225	0.01	Fixed	2280.26	55.23
176	J-329	476777	990083	2227	0.01	Fixed	2280.98	54.01
177	J-155	475964	988746	2203	0	Fixed	2277.82	74.99
178	J-142	476783	989955	2226	0	Fixed	2280.98	55.02
179	J-263	476527	989603	2222	0.02	Fixed	2277.91	56.02
180	J-67	476598	989624	2223	0.02	Fixed	2277.91	55.20
181	J-148	475788	989285	2212	0.01	Fixed	2277.78	66.07
182	J-182	477021	989343	2226	0.01	Fixed	2277.58	51.88
183	J-312	476170	990117	2227	0.01	Fixed	2278.53	51.12

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Steady State Simulation Analysis Results

Actual Nodes at Minimum Consumption Hour

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
184	J-224	476359	989381	2219	0	Fixed	2277.89	59.19
185	J-269	475825	990299	2231	0	Fixed	2279.08	48.01
186	J-48	476368	990000	2226	0.01	Fixed	2279.07	53.44
187	J-68	476302	990223	2229	0	Fixed	2280.11	51.17
188	J-270	475846	990237	2230	0.01	Fixed	2279.08	49.24
189	J-238	475645	989861	2222	0.01	Fixed	2277.86	55.58
190	J-122	475639	989231	2225	0	Fixed	2277.78	53.15
191	J-313	477134	989260	2226	0	Fixed	2277.54	51.63
192	J-84	475827	989577	2217	0.01	Fixed	2277.78	60.73
193	J-189	477433	989333	2222	0	Fixed	2277.49	55.47
194	J-93	475975	989106	2210	0	Fixed	2277.78	67.42
195	J-14	475766	990099	2227	0.02	Fixed	2278.85	51.76
196	J-202	475923	990061	2226	0.01	Fixed	2278.42	52.10
197	J-309	476355	989677	2221	0.01	Fixed	2277.89	56.69
198	J-152	476177	990011	2225	0	Fixed	2278.54	53.04
199	J-296	476566	989127	2220	0.01	Fixed	2277.88	57.64
200	J-286	476917	989406	2225	0	Fixed	2277.62	52.43
201	J-173	476613	989793	2224	0	Fixed	2280.47	56.56
202	J-225	476408	989371	2219	0.01	Fixed	2277.89	58.63
203	J-105	475907	989717	2219	0.01	Fixed	2277.87	58.41
204	J-209	475821	989411	2214	0.01	Fixed	2277.78	63.62
205	J-363	476656	989425	2223	0	Fixed	2277.85	55.24
206	J-6	475830	988981	2206	0.01	Fixed	2277.84	71.78
207	J-336	476729	990078	2227	0.07	Fixed	2280.98	54.08
208	J-116	475751	988844	2202	0.01	Fixed	2277.82	75.34
209	J-372	476065	989465	2216	0.01	Fixed	2277.90	61.33
210	J-192	476326	990015	2226	0	Fixed	2279.05	53.21
211	J-347	476640	989358	2228	0.01	Fixed	2277.89	49.64
212	J-151	476139	990024	2226	0.01	Fixed	2278.53	52.91
213	J-167	475810	989363	2213	0	Fixed	2277.78	64.46
214	J-295	476702	988962	2220	0.01	Fixed	2277.84	57.76
215	J-218	475951	990101	2227	0	Fixed	2278.50	51.32
216	J-86	476184	989336	2216	0	Fixed	2277.76	61.42
217	J-143	476152	989503	2218	0	Fixed	2277.88	60.19
218	J-27	476246	989984	2225	0.4	Fixed	2278.64	53.44
219	J-371	476935	989280	2231	0	Fixed	2277.89	46.39
220	J-358	476073	989613	2219	0	Fixed	2277.89	59.21

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Steady State Simulation Analysis Results

Actual Nodes at Minimum Consumption Hour

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
221	J-110	477482	989357	2221	0.01	Fixed	2277.49	56.41
222	J-203	475896	990024	2225	0.01	Fixed	2278.41	52.83
223	J-103	475935	988797	2203	0.02	Fixed	2277.82	74.43
224	J-214	476036	990349	2232	0	Fixed	2279.54	47.62
225	J-49	475832	990186	2229	0.18	Fixed	2278.69	49.87
226	J-12	476097	988895	2209	0	Fixed	2277.83	68.84
227	J-217	475865	989748	2220	0.26	Fixed	2277.87	57.82
228	J-178	475698	989729	2220	0	Fixed	2277.87	58.16
229	J-346	477455	989472	2222	0	Fixed	2277.49	54.92
230	J-223	477007	989295	2226	0	Fixed	2277.58	51.95
231	J-200	475784	989608	2217	0	Fixed	2277.78	60.31
232	J-350	476426	990201	2229	0.01	Fixed	2280.93	52.31
233	J-37	477166	989409	2226	0.01	Fixed	2277.53	51.76
234	J-154	475661	989317	2211	0.01	Fixed	2277.78	66.50
235	J-210	477322	989372	2225	0.01	Fixed	2277.53	52.90
236	J-332	475991	988999	2209	0.02	Fixed	2277.78	69.06
237	J-98	476567	989633	2222	0.01	Fixed	2277.91	55.47
238	J-319	475707	989943	2224	0.02	Fixed	2277.86	53.89
239	J-158	476277	990309	2230	0.01	Fixed	2279.94	49.52
240	J-181	476237	989755	2222	0	Fixed	2277.90	56.28
241	J-146	475991	989312	2214	0	Fixed	2277.77	63.57
242	J-117	476009	990062	2226	0.01	Fixed	2278.51	52.16
243	J-57	475597	988566	2191	0.06	Fixed	2277.79	86.36
244	J-261	476244	989764	2222	0.01	Fixed	2278.38	56.59
245	J-366	476341	989372	2218	0	Fixed	2277.87	59.49
246	J-119	475841	989625	2218	0.01	Fixed	2277.87	59.96
247	J-33	476168	989777	2222	0.01	Fixed	2277.90	56.28
248	J-26	476238	989997	2225	0.11	Fixed	2278.56	53.17
249	J-46	477155	989354	2226	0	Fixed	2277.53	51.71
250	J-113	475860	988651	2198	0.21	Fixed	2277.81	79.48
251	J-45	476387	989994	2225	0	Fixed	2279.06	53.55
252	J-58	475624	988563	2191	0.02	Fixed	2277.79	86.16
253	J-65	476414	989559	2221	0.02	Fixed	2277.89	57.20
254	J-273	476434	989189	2218	0.01	Fixed	2277.88	59.32
255	J-221	476169	989887	2223	0.02	Fixed	2278.02	54.76
256	J-52	476523	989461	2221	0.01	Fixed	2277.90	56.74
257	J-165	476470	989421	2220	0.01	Fixed	2277.90	57.54

APPENDIX C**Steady State Simulation Analysis Results****Actual Nodes at Minimum Consumption Hour**

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
258	J-55	476666	989917	2225	0	Fixed	2280.98	55.86
259	J-301	475716	989345	2212	0.05	Fixed	2277.78	65.61
260	J-282	476008	989381	2215	0.05	Fixed	2277.77	62.58
261	J-19	476054	988723	2204	0.08	Fixed	2277.82	73.34
262	J-147	475798	989324	2212	0.05	Fixed	2277.78	65.24
263	J-149	476284	989544	2219	0	Fixed	2277.88	58.45
264	J-343	477084	990152	2228	0.01	Fixed	2286.84	58.28
265	J-185	475715	988688	2199	0.02	Fixed	2277.81	79.09
266	J-163	475921	989333	2206	0.05	Fixed	2277.78	71.70
267	J-360	475874	989167	2210	0.45	Fixed	2277.85	67.64
268	J-246	475944	990362	2232	0.01	Fixed	2279.35	47.09
269	J-56	476643	989922	2225	0.01	Fixed	2280.68	55.60
270	J-340	475761	990286	2231	0.02	Fixed	2278.67	47.86
271	J-89	475761	988880	2203	0.02	Fixed	2277.82	74.48
272	J-264	476270	989849	2223	0.02	Fixed	2278.46	55.26
273	J-7	476186	989781	2222	0.02	Fixed	2278.04	56.29
274	J-177	475720	989761	2220	0.01	Fixed	2277.87	57.50
275	J-153	475623	989328	2211	0.01	Fixed	2277.78	66.48
276	J-140	475743	988807	2201	0.02	Fixed	2277.81	76.20
277	J-265	476210	989861	2217	0.09	Fixed	2278.41	61.68
278	J-242	476046	989919	2223	0.04	Fixed	2278.20	54.67
279	J-100	475983	989274	2213	0.03	Fixed	2277.77	64.28
280	J-260	476198	988681	2206	0.01	Fixed	2277.83	71.91
281	J-17	476404	989989	2225	0.04	Fixed	2279.07	53.65
282	J-352	475873	988544	2195	0.02	Fixed	2277.81	82.76
283	J-166	475828	989275	2212	0.04	Fixed	2277.78	65.86
284	J-85	476193	989366	2217	0.01	Fixed	2277.76	61.04
285	J-250	475619	988505	2189	0	Fixed	2277.79	88.61
286	J-326	476154	989628	2219	0.1	Fixed	2277.88	58.47
287	J-249	475659	989679	2219	0.15	Fixed	2277.86	59.20
288	J-337	476818	988954	2222	0.04	Fixed	2277.83	56.13
289	J-359	476299	990173	2228	0.11	Fixed	2278.56	50.31
290	J-255	475867	989964	2224	0	Fixed	2277.87	53.49
291	J-287	475530	989261	2209	0	Fixed	2277.79	68.45
292	J-213	476565	989809	2224	0.02	Fixed	2279.83	56.15
293	J-104	475945	988833	2204	0.01	Fixed	2277.82	73.37
294	J-289	475553	988471	2186	0	Fixed	2277.79	91.19

APPENDIX C

Steady State Simulation Analysis Results

Actual Nodes at Minimum Consumption Hour

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
295	J-256	476246	989412	2230	0.01	Fixed	2277.89	48.04
296	J-179	477411	989207	2221	0	Fixed	2277.49	56.15
297	J-311	475953	989010	2208	0.02	Fixed	2277.78	69.51
298	J-204	477103	989531	2226	0.01	Fixed	2277.53	51.44
299	J-252	475832	989915	2223	0.1	Fixed	2277.87	54.54
300	J-258	476264	990041	2226	0.01	Fixed	2279.05	52.87
301	J-268	475810	990018	2225	0	Fixed	2278.95	53.48
302	J-59	476557	989424	2221	0.03	Fixed	2277.90	56.50
303	J-180	476227	989714	2221	0.01	Fixed	2277.90	56.96
304	J-99	476017	989264	2214	0.01	Fixed	2277.77	64.08
305	J-36	476507	989673	2222	0	Fixed	2277.92	55.87
306	J-236	475862	989978	2225	0.1	Fixed	2278.46	53.78
307	J-349	475944	990200	2229	0.04	Fixed	2279.35	50.25
308	J-305	476313	989289	2217	0	Fixed	2277.75	60.49
309	J-322	476645	990234	2229	0.07	Fixed	2280.91	52.28
310	J-330	475746	988488	2190	0.02	Fixed	2277.79	87.35
311	J-157	476239	990323	2231	0	Fixed	2279.88	49.04
312	J-193	476027	989125	2211	0	Fixed	2277.78	66.31
313	J-118	476044	990048	2226	0.14	Fixed	2278.51	52.43
314	J-369	477002	988923	2223	0	Fixed	2277.84	54.87
315	J-318	477288	989222	2225	0.3	Fixed	2277.50	52.69
316	J-259	476140	988699	2206	0	Fixed	2277.82	72.12
317	J-292	475697	988556	2192	0.02	Fixed	2277.80	85.18
318	J-235	475708	990276	2231	0.1	Fixed	2278.86	48.24
319	J-107	475890	988767	2202	0	Fixed	2277.81	76.05
320	J-15	475771	990106	2227	0.02	Fixed	2278.85	51.61
321	J-92	476107	989355	2216	0.1	Fixed	2277.76	62.01
322	J-136	476088	989286	2215	0.02	Fixed	2277.76	62.96
323	J-303	476718	989614	2224	0.03	Fixed	2277.92	54.11
324	J-367	476823	989639	2225	0.01	Fixed	2277.85	53.25
325	J-72	476440	989977	2225	0.02	Fixed	2279.12	53.85
326	J-316	475619	988667	2196	0.18	Fixed	2277.71	81.57
327	J-334	476961	989756	2226	0	Fixed	2277.62	52.02
328	J-196	476448	990371	2231	0.01	Fixed	2280.93	49.67
329	J-198	475739	989433	2214	0.02	Fixed	2277.78	63.76
330	J-16	476413	989986	2225	0.01	Fixed	2279.08	53.68
331	J-25	476235	989987	2225	0.33	Fixed	2278.57	53.34

APPENDIX C**Steady State Simulation Analysis Results****Actual Nodes at Minimum Consumption Hour**

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
332	J-333	476951	989626	2225	0.02	Fixed	2277.62	52.26
333	J-194	477088	989440	2226	0	Fixed	2277.53	51.49
334	J-324	476785	989889	2225	0.05	Fixed	2282.67	57.18
335	J-302	476200	990094	2227	0.01	Fixed	2278.54	51.54
336	J-31	476252	988868	2211	0	Fixed	2277.84	66.43
337	J-61	476630	989636	2223	0	Fixed	2277.92	54.83
338	J-364	476363	990499	2234	0.1	Fixed	2279.93	46.17
339	J-69	476326	990209	2229	0.12	Fixed	2280.26	51.53
340	J-73	475870	989134	2209	0.11	Fixed	2277.78	68.27
341	J-338	476643	990182	2228	0.01	Fixed	2280.92	52.87
342	J-29	475644	990189	2229	0.01	Fixed	2278.86	49.97
343	J-370	475378	989001	2232	0.1	Fixed	2277.79	45.81
344	J-176	476585	989582	2222	0	Fixed	2277.91	55.54
345	J-365	476316	990490	2234	0	Fixed	2279.88	46.06
346	J-220	476588	989209	2221	0.01	Fixed	2277.88	56.91
347	J-40	476423	990424	2232	10.5	Fixed	2289.53	57.32
348	J-78	476306	989743	2222	0.07	Fixed	2278.52	56.74
349	J-54	476543	989662	2222	0.12	Fixed	2277.92	55.57
350	J-288	475790	988668	2198	0.02	Fixed	2277.81	79.35
351	J-91	476117	989386	2216	0.01	Fixed	2277.76	61.62
352	J-298	476038	989405	2216	0.03	Fixed	2277.76	62.04
353	J-112	476263	989470	2218	0.01	Fixed	2277.88	59.46
354	J-63	476197	989628	2220	0	Fixed	2277.89	58.18
355	J-267	476354	990110	2227	0	Fixed	2279.27	52.02
356	J-304	476292	989206	2216	0.07	Fixed	2277.74	61.21
357	J-76	476178	989578	2219	0	Fixed	2277.88	58.98
358	J-79	475625	990166	2228	0.01	Fixed	2278.86	50.43
359	J-248	475618	989723	2219	0.05	Fixed	2277.86	58.30
360	J-368	476584	990660	2225	0.02	Fixed	2288.95	63.45
361	J-47	477159	989374	2226	0.02	Fixed	2277.53	51.72
362	J-42	477468	989200	2219	0.11	Fixed	2277.49	57.90
363	J-41	477453	989202	2220	0	Fixed	2277.49	57.37

APPENDIX D

Steady State Simulation Analysis Results
Actual Nodes at Peak Hour

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
1	J-138	476131	989136	2213	0.22	Fixed	2,176.31	(36.72)
2	J-156	475749	989295	2211	0.2	Fixed	2,178.35	(32.97)
3	J-195	477096	989483	2226	0.07	Fixed	2,147.17	(78.65)
4	J-375	477343	989182	2223	0.02	Fixed	2,200.55	(22.49)
5	J-299	475958	989490	2216	0.22	Fixed	2,198.58	(17.54)
6	J-208	476089	990035	2226	0.02	Fixed	2,270.53	44.74
7	J-102	475756	989160	2209	1.67	Fixed	2,178.28	(30.42)
8	J-254	475970	989888	2223	0.65	Fixed	2,198.41	(24.31)
9	J-239	476133	989443	2217	0	Fixed	2,200.64	(16.08)
10	J-234	477077	989388	2226	0	Fixed	2,148.37	(77.36)
11	J-28	475650	990197	2229	0.07	Fixed	2,266.34	37.32
12	J-328	476081	990170	2228	0.07	Fixed	2,269.18	40.69
13	J-266	476295	990131	2227	0.22	Fixed	2,277.06	49.50
14	J-108	475924	988757	2202	0.18	Fixed	2,186.33	(15.66)
15	J-121	475602	989240	2225	0.16	Fixed	2,179.01	(45.98)
16	J-233	475897	989793	2221	0.14	Fixed	2,197.26	(23.69)
17	J-231	476007	989711	2220	0	Fixed	2,197.47	(22.20)
18	J-97	475994	989172	2212	0	Fixed	2,177.36	(34.24)
19	J-331	476693	990060	2227	0.09	Fixed	2,271.82	45.14
20	J-374	477246	990928	2237	0.02	Fixed	2,275.45	38.06
21	J-344	475477	988516	2188	0.04	Fixed	2,180.94	(6.55)
22	J-13	476089	988897	2209	0.31	Fixed	2,188.78	(19.89)
23	J-339	476300	989056	2226	0	Fixed	2,177.91	(48.33)
24	J-279	476524	989952	2225	2.09	Fixed	2,266.35	41.40
25	J-162	476485	989476	2221	0.79	Fixed	2,200.25	(20.43)
26	J-106	475938	989696	2219	0.77	Fixed	2,196.98	(22.08)
27	J-281	476731	988797	2216	0.02	Fixed	2,191.61	(24.65)
28	J-357	477047	989984	2227	0.32	Fixed	2,272.73	45.91
29	J-77	476334	989734	2222	0.59	Fixed	2,260.61	38.88
30	J-74	475876	989161	2206	1.06	Fixed	2,178.10	(27.61)
31	J-284	476426	990055	2226	0.38	Fixed	2,267.74	41.32
32	J-188	475823	989689	2219	0.38	Fixed	2,196.74	(22.12)
33	J-82	476396	989506	2220	1.06	Fixed	2,200.33	(19.64)
34	J-308	475733	989070	2207	0.47	Fixed	2,178.69	(27.97)
35	J-226	476150	990339	2231	0.4	Fixed	2,271.70	40.24
36	J-212	475727	989577	2217	0.18	Fixed	2,178.18	(38.41)
37	J-323	476040	990167	2228	0.32	Fixed	2,268.76	40.34
38	J-183	477028	989387	2226	0.2	Fixed	2,157.03	(68.47)

APPENDIX D

Steady State Simulation Analysis Results
Actual Nodes at Peak Hour

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
39	J-201	477178	989468	2226	0.4	Fixed	2,146.98	(78.47)
40	J-351	476142	988519	2200	0.4	Fixed	2,187.17	(12.45)
41	J-95	475807	989187	2210	0.59	Fixed	2,182.62	(27.13)
42	J-348	476215	990484	2234	0.07	Fixed	2,271.70	37.91
43	J-123	475991	988857	2206	0.13	Fixed	2,188.18	(17.72)
44	J-190	476165	989088	2213	0.2	Fixed	2,177.91	(35.15)
45	J-290	475817	988787	2202	0.07	Fixed	2,185.69	(15.87)
46	J-174	476653	989780	2224	0.07	Fixed	2,266.25	42.13
47	J-170	475915	989578	2217	0.07	Fixed	2,197.23	(19.97)
48	J-144	476165	989540	2218	0.07	Fixed	2,200.34	(17.80)
49	J-186	476236	989357	2217	0.29	Fixed	2,173.40	(43.45)
50	J-114	475894	988641	2198	0.22	Fixed	2,185.34	(12.83)
51	J-222	476140	989846	2222	0.13	Fixed	2,271.65	49.16
52	J-325	476844	989989	2226	0.77	Fixed	2,272.78	46.39
53	J-88	475889	990378	2233	0.14	Fixed	2,269.06	36.44
54	J-345	476427	989173	2218	0.14	Fixed	2,200.20	(18.04)
55	J-184	475674	988698	2198	0.04	Fixed	2,185.41	(12.97)
56	J-83	475818	989547	2216	0.4	Fixed	2,178.13	(38.19)
57	J-135	475744	990068	2226	0.13	Fixed	2,267.20	40.77
58	J-283	476629	990294	2229	0.13	Fixed	2,275.73	46.34
59	J-24	476183	989773	2222	0.13	Fixed	2,203.59	(17.87)
60	J-160	475729	988921	2204	1.78	Fixed	2,185.74	(17.93)
61	J-229	476376	989434	2219	0.09	Fixed	2,200.40	(18.75)
62	J-101	475764	989195	2231	0.13	Fixed	2,178.27	(52.79)
63	J-253	475933	989841	2222	0.74	Fixed	2,197.71	(24.24)
64	J-60	476623	989615	2223	0.02	Fixed	2,202.44	(20.32)
65	J-70	476611	989736	2223	0.02	Fixed	2,266.25	42.80
66	J-139	476123	989097	2212	0.11	Fixed	2,177.92	(34.44)
67	J-206	476565	990321	2230	0.11	Fixed	2,275.73	45.66
68	J-175	475797	990141	2228	1.42	Fixed	2,265.94	38.07
69	J-262	475844	989041	2207	0.13	Fixed	2,180.67	(26.53)
70	J-294	476669	988881	2218	0.23	Fixed	2,191.17	(26.74)
71	J-257	476042	989761	2221	0.25	Fixed	2,198.16	(22.51)
72	J-241	475764	989822	2221	0.18	Fixed	2,196.80	(24.52)
73	J-215	476093	990336	2232	0.02	Fixed	2,271.53	39.92
74	J-310	476317	989690	2221	0	Fixed	2,200.72	(20.23)
75	J-23	475466	989299	2210	0	Fixed	2,182.04	(27.89)
76	J-341	476130	990170	2228	0.32	Fixed	2,270.19	41.77

APPENDIX D

Steady State Simulation Analysis Results
Actual Nodes at Peak Hour

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
77	J-244	475813	990004	2225	0.18	Fixed	2,196.69	(28.33)
78	J-80	476365	989725	2222	0	Fixed	2,256.65	34.92
79	J-109	477476	989322	2221	0	Fixed	2,143.10	(77.52)
80	J-280	476661	988793	2215	0.09	Fixed	2,191.63	(23.52)
81	J-64	476516	989435	2221	0.23	Fixed	2,198.71	(22.11)
82	J-291	476152	989228	2215	8.75	Fixed	2,170.53	(44.01)
83	J-307	475599	989106	2206	3.19	Fixed	2,178.38	(27.70)
84	J-169	475894	989542	2217	0.09	Fixed	2,197.48	(19.09)
85	J-145	476170	989734	2221	0.54	Fixed	2,203.23	(17.59)
86	J-127	475782	989625	2218	0.02	Fixed	2,196.84	(20.77)
87	J-271	476716	989759	2224	0.97	Fixed	2,265.04	40.58
88	J-129	476289	989600	2220	0.05	Fixed	2,200.72	(19.17)
89	J-314	475582	989779	2221	0.07	Fixed	2,196.28	(24.25)
90	J-87	475907	990403	2233	0.2	Fixed	2,269.06	35.95
91	J-3	475964	988933	2207	0.23	Fixed	2,189.42	(17.44)
92	J-373	477406	989149	2221	2.39	Fixed	2,202.40	(18.37)
93	J-297	476542	989051	2219	0	Fixed	2,200.21	(18.64)
94	J-8	476180	989783	2198	3.2	Fixed	2,269.87	71.55
95	J-11	476521	989669	2222	0.25	Fixed	2,203.61	(18.41)
96	J-128	475800	989652	2218	0.02	Fixed	2,196.81	(21.30)
97	J-171	475558	989384	2212	0.02	Fixed	2,178.52	(33.37)
98	J-320	476928	990144	2228	0.25	Fixed	2,274.08	46.40
99	J-120	475871	989606	2218	0.02	Fixed	2,197.00	(20.49)
100	J-191	476125	989790	2221	0.49	Fixed	2,201.54	(19.90)
101	J-32	475965	988944	2207	0.11	Fixed	2,189.88	(17.20)
102	J-130	476324	989588	2220	0.11	Fixed	2,200.72	(19.31)
103	J-321	476958	990248	2229	0.13	Fixed	2,275.23	46.36
104	J-96	475840	989178	2210	0.11	Fixed	2,187.11	(22.80)
105	J-306	475581	989473	2214	0.07	Fixed	2,178.30	(35.50)
106	J-237	475688	989825	2221	0.07	Fixed	2,196.52	(24.92)
107	J-125	476344	989524	2220	0.07	Fixed	2,200.34	(19.28)
108	J-124	475955	988869	2205	0.09	Fixed	2,188.24	(17.08)
109	J-293	475958	989475	2216	0.02	Fixed	2,179.20	(36.69)
110	J-277	475938	989400	2215	0.18	Fixed	2,178.38	(36.32)
111	J-240	475797	989868	2222	0.02	Fixed	2,197.21	(25.06)
112	J-245	475767	990037	2226	0.2	Fixed	2,196.69	(29.01)
113	J-66	476406	989536	2220	3.24	Fixed	2,200.33	(19.95)
114	J-126	476333	989487	2219	0.04	Fixed	2,200.35	(18.83)

APPENDIX D

Steady State Simulation Analysis Results
Actual Nodes at Peak Hour

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
115	J-361	476659	988601	2206	0.07	Fixed	2,191.60	(14.16)
116	J-71	476639	989729	2224	0	Fixed	2,266.25	42.58
117	J-272	476454	989253	2219	0.02	Fixed	2,200.37	(18.66)
118	J-22	475463	989293	2227	0.02	Fixed	2,181.47	(45.90)
119	J-172	475550	989342	2211	0.02	Fixed	2,178.90	(32.14)
120	J-285	476904	989334	2225	0	Fixed	2,160.99	(63.90)
121	J-274	476229	989520	2219	0.02	Fixed	2,200.34	(18.15)
122	J-39	476438	990417	2212	3.6	Fixed	2,275.46	62.94
123	J-227	476455	989688	2222	0	Fixed	2,203.59	(18.07)
124	J-18	476045	988725	2204	0	Fixed	2,187.75	(16.39)
125	J-207	476545	990278	2229	0.02	Fixed	2,273.54	43.98
126	J-168	476679	989718	2224	0.02	Fixed	2,266.25	42.27
127	J-134	476009	988735	2204	0	Fixed	2,187.50	(15.99)
128	J-51	476543	989456	2221	0.02	Fixed	2,200.36	(20.85)
129	J-75	476508	989408	2221	3.78	Fixed	2,197.40	(23.18)
130	J-205	475977	989670	2219	0.07	Fixed	2,197.22	(21.61)
131	J-161	476406	990388	2232	0.72	Fixed	2,276.93	45.32
132	J-362	475404	988583	2190	0.04	Fixed	2,181.55	(8.09)
133	J-187	476226	989316	2216	1.08	Fixed	2,173.05	(43.28)
134	J-164	475911	989293	2213	0.38	Fixed	2,178.08	(34.81)
135	J-10	476523	989677	2222	0.11	Fixed	2,210.95	(11.13)
136	J-243	476097	989943	2224	0.07	Fixed	2,271.09	47.14
137	J-335	476382	990405	2232	1.19	Fixed	2,273.71	41.74
138	J-43	476496	989382	2220	0.31	Fixed	2,200.55	(19.77)
139	J-44	476489	989365	2220	0.54	Fixed	2,200.55	(19.59)
140	J-131	476323	989451	2219	0.02	Fixed	2,200.36	(18.37)
141	J-327	476091	988976	2210	0.14	Fixed	2,178.03	(31.90)
142	J-35	476074	989443	2216	0.29	Fixed	2,198.12	(18.10)
143	J-276	475984	989890	2223	0.31	Fixed	2,269.88	46.97
144	J-81	476549	989397	2221	0.14	Fixed	2,198.14	(22.91)
145	J-30	476248	988854	2211	0.2	Fixed	2,190.92	(19.92)
146	J-159	475675	990231	2230	0.04	Fixed	2,266.33	36.62
147	J-111	476273	989506	2219	0.27	Fixed	2,200.34	(18.41)
148	J-90	475770	988911	2204	0.29	Fixed	2,186.48	(17.41)
149	J-115	475729	989206	2226	0.25	Fixed	2,178.30	(47.27)
150	J-62	476188	989603	2219	0.25	Fixed	2,200.39	(18.79)
151	J-199	475773	989563	2217	0.04	Fixed	2,178.15	(38.30)
152	J-94	475984	989138	2211	0.16	Fixed	2,177.99	(32.90)

APPENDIX D

Steady State Simulation Analysis Results
Actual Nodes at Peak Hour

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
153	J-251	476329	990283	2230	0.27	Fixed	2,273.87	44.04
154	J-132	476073	988835	2207	0.29	Fixed	2,188.20	(18.89)
155	J-38	477169	989424	2226	0.25	Fixed	2,147.04	(78.46)
156	J-53	476564	989449	2221	0.25	Fixed	2,200.42	(20.98)
157	J-315	476123	990494	2234	0.13	Fixed	2,270.81	36.82
158	J-247	476104	990277	2231	0	Fixed	2,271.71	41.10
159	J-211	477310	989324	2225	0.11	Fixed	2,146.15	(78.48)
160	J-342	476129	988966	2211	0	Fixed	2,178.03	(32.48)
161	J-5	475825	988983	2206	0.11	Fixed	2,191.08	(14.80)
162	J-137	476080	989249	2214	0.13	Fixed	2,174.34	(39.58)
163	J-278	476455	989696	2222	0.27	Fixed	2,241.59	19.79
164	J-219	476602	989260	2221	0.27	Fixed	2,200.22	(21.06)
165	J-150	475628	989193	2208	0.18	Fixed	2,178.37	(29.88)
166	J-216	476081	989814	2222	0.36	Fixed	2,200.00	(21.63)
167	J-133	476037	988844	2207	0.09	Fixed	2,188.17	(18.31)
168	J-230	475741	989631	2218	0.09	Fixed	2,178.17	(39.43)
169	J-50	475848	990173	2228	0.04	Fixed	2,266.49	37.94
170	J-232	476465	989541	2221	0.02	Fixed	2,201.33	(19.52)
171	J-197	475695	989445	2214	0.43	Fixed	2,178.21	(35.50)
172	J-275	476484	990305	2230	0.2	Fixed	2,273.47	43.31
173	J-34	476077	989458	2216	0.2	Fixed	2,200.71	(15.70)
174	J-141	476746	989941	2226	0.09	Fixed	2,271.83	46.13
175	J-228	476598	989938	2225	0.11	Fixed	2,273.37	48.35
176	J-329	476777	990083	2227	0.2	Fixed	2,271.64	44.69
177	J-155	475964	988746	2203	0.04	Fixed	2,187.01	(15.64)
178	J-142	476783	989955	2226	0.02	Fixed	2,271.65	45.71
179	J-263	476527	989603	2222	0.34	Fixed	2,202.09	(19.66)
180	J-67	476598	989624	2223	0.32	Fixed	2,202.02	(20.54)
181	J-148	475788	989285	2212	0.14	Fixed	2,178.35	(33.17)
182	J-182	477021	989343	2226	0.13	Fixed	2,154.81	(70.65)
183	J-312	476170	990117	2227	0.11	Fixed	2,272.15	44.75
184	J-224	476359	989381	2219	0.02	Fixed	2,200.59	(17.96)
185	J-269	475825	990299	2231	0	Fixed	2,267.85	36.79
186	J-48	476368	990000	2226	0.13	Fixed	2,271.07	45.46
187	J-68	476302	990223	2229	0	Fixed	2,275.14	46.21
188	J-270	475846	990237	2230	0.13	Fixed	2,267.83	38.02
189	J-238	475645	989861	2222	0.09	Fixed	2,196.29	(25.83)
190	J-122	475639	989231	2225	0.05	Fixed	2,178.39	(46.04)

APPENDIX D

Steady State Simulation Analysis Results
Actual Nodes at Peak Hour

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
191	J-313	477134	989260	2226	0.04	Fixed	2,148.58	(77.06)
192	J-84	475827	989577	2217	0.2	Fixed	2,178.13	(38.73)
193	J-189	477433	989333	2222	0.02	Fixed	2,143.11	(78.64)
194	J-93	475975	989106	2210	0.02	Fixed	2,178.17	(31.99)
195	J-14	475766	990099	2227	0.31	Fixed	2,266.32	39.26
196	J-202	475923	990061	2226	0.25	Fixed	2,269.34	43.05
197	J-309	476355	989677	2221	0.2	Fixed	2,200.63	(20.41)
198	J-152	476177	990011	2225	0.07	Fixed	2,273.65	48.15
199	J-296	476566	989127	2220	0.13	Fixed	2,200.21	(19.88)
200	J-286	476917	989406	2225	0.07	Fixed	2,160.28	(64.68)
201	J-173	476613	989793	2224	0.04	Fixed	2,267.16	43.27
202	J-225	476408	989371	2219	0.16	Fixed	2,200.59	(18.52)
203	J-105	475907	989717	2219	0.11	Fixed	2,196.88	(22.42)
204	J-209	475821	989411	2214	0.2	Fixed	2,178.13	(35.82)
205	J-363	476656	989425	2223	0.07	Fixed	2,193.68	(28.76)
206	J-6	475830	988981	2206	0.22	Fixed	2,190.52	(15.36)
207	J-336	476729	990078	2227	1.33	Fixed	2,271.18	44.30
208	J-116	475751	988844	2202	0.22	Fixed	2,186.02	(16.27)
209	J-372	476065	989465	2216	0.22	Fixed	2,203.02	(13.39)
210	J-192	476326	990015	2226	0.02	Fixed	2,273.30	47.48
211	J-347	476640	989358	2228	0.16	Fixed	2,200.55	(27.55)
212	J-151	476139	990024	2226	0.16	Fixed	2,272.18	46.57
213	J-167	475810	989363	2213	0.07	Fixed	2,178.13	(34.98)
214	J-295	476702	988962	2220	0.18	Fixed	2,190.52	(29.38)
215	J-218	475951	990101	2227	0.02	Fixed	2,268.87	41.71
216	J-86	476184	989336	2216	0.02	Fixed	2,173.69	(42.43)
217	J-143	476152	989503	2218	0.07	Fixed	2,200.34	(17.19)
218	J-27	476246	989984	2225	7.2	Fixed	2,277.35	52.16
219	J-371	476935	989280	2231	0.02	Fixed	2,200.55	(30.79)
220	J-358	476073	989613	2219	0.05	Fixed	2,201.54	(16.99)
221	J-110	477482	989357	2221	0.2	Fixed	2,143.07	(77.74)
222	J-203	475896	990024	2225	0.25	Fixed	2,269.37	43.80
223	J-103	475935	988797	2203	0.27	Fixed	2,186.59	(16.62)
224	J-214	476036	990349	2232	0.02	Fixed	2,270.88	38.98
225	J-49	475832	990186	2229	3.17	Fixed	2,266.19	37.39
226	J-12	476097	988895	2209	0.04	Fixed	2,188.80	(20.01)
227	J-217	475865	989748	2220	4.72	Fixed	2,196.71	(23.17)
228	J-178	475698	989729	2220	0.05	Fixed	2,196.72	(22.83)

APPENDIX D

Steady State Simulation Analysis Results
Actual Nodes at Peak Hour

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
229	J-346	477455	989472	2222	0.02	Fixed	2,143.11	(79.19)
230	J-223	477007	989295	2226	0.02	Fixed	2,154.95	(70.44)
231	J-200	475784	989608	2217	0.02	Fixed	2,178.15	(39.12)
232	J-350	476426	990201	2229	0.22	Fixed	2,276.33	47.71
233	J-37	477166	989409	2226	0.11	Fixed	2,147.04	(78.47)
234	J-154	475661	989317	2211	0.22	Fixed	2,178.39	(32.69)
235	J-210	477322	989372	2225	0.14	Fixed	2,146.82	(77.54)
236	J-332	475991	988999	2209	0.27	Fixed	2,178.17	(30.35)
237	J-98	476567	989633	2222	0.2	Fixed	2,201.99	(20.30)
238	J-319	475707	989943	2224	0.27	Fixed	2,196.12	(27.69)
239	J-158	476277	990309	2230	0.2	Fixed	2,272.43	42.02
240	J-181	476237	989755	2222	0.07	Fixed	2,203.59	(17.88)
241	J-146	475991	989312	2214	0.07	Fixed	2,176.56	(37.44)
242	J-117	476009	990062	2226	0.22	Fixed	2,269.02	42.69
243	J-57	475597	988566	2191	1.1	Fixed	2,180.86	(10.38)
244	J-261	476244	989764	2222	0.14	Fixed	2,267.97	46.20
245	J-366	476341	989372	2218	0.04	Fixed	2,198.12	(20.10)
246	J-119	475841	989625	2218	0.13	Fixed	2,196.89	(20.85)
247	J-33	476168	989777	2222	0.14	Fixed	2,203.06	(18.40)
248	J-26	476238	989997	2225	1.98	Fixed	2,276.23	50.83
249	J-46	477155	989354	2226	0.05	Fixed	2,147.04	(78.52)
250	J-113	475860	988651	2198	3.78	Fixed	2,185.19	(12.95)
251	J-45	476387	989994	2225	0.05	Fixed	2,268.72	43.23
252	J-58	475624	988563	2191	0.43	Fixed	2,181.29	(10.15)
253	J-65	476414	989559	2221	0.4	Fixed	2,200.72	(19.81)
254	J-273	476434	989189	2218	0.13	Fixed	2,200.37	(18.04)
255	J-221	476169	989887	2223	0.27	Fixed	2,273.10	49.85
256	J-52	476523	989461	2221	0.16	Fixed	2,199.90	(21.11)
257	J-165	476470	989421	2220	0.13	Fixed	2,198.45	(21.75)
258	J-55	476666	989917	2225	0.02	Fixed	2,272.28	47.17
259	J-301	475716	989345	2212	0.88	Fixed	2,178.16	(33.82)
260	J-282	476008	989381	2215	0.97	Fixed	2,176.47	(38.51)
261	J-19	476054	988723	2204	1.53	Fixed	2,187.75	(16.55)
262	J-147	475798	989324	2212	0.97	Fixed	2,178.14	(34.20)
263	J-149	476284	989544	2219	0.02	Fixed	2,200.34	(18.94)
264	J-343	477084	990152	2228	0.2	Fixed	2,274.06	45.53
265	J-185	475715	988688	2199	0.29	Fixed	2,185.23	(13.31)
266	J-163	475921	989333	2206	0.97	Fixed	2,178.10	(27.77)

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Steady State Simulation Analysis Results
Actual Nodes at Peak Hour

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
267	J-360	475874	989167	2210	8.1	Fixed	2,193.63	(16.42)
268	J-246	475944	990362	2232	0.2	Fixed	2,269.94	37.69
269	J-56	476643	989922	2225	0.16	Fixed	2,272.29	47.22
270	J-340	475761	990286	2231	0.27	Fixed	2,266.35	35.57
271	J-89	475761	988880	2203	0.29	Fixed	2,186.29	(16.87)
272	J-264	476270	989849	2223	0.32	Fixed	2,271.35	48.17
273	J-7	476186	989781	2222	0.41	Fixed	2,268.33	46.59
274	J-177	475720	989761	2220	0.16	Fixed	2,196.74	(23.46)
275	J-153	475623	989328	2211	0.2	Fixed	2,178.61	(32.50)
276	J-140	475743	988807	2201	0.38	Fixed	2,185.70	(15.72)
277	J-265	476210	989861	2217	1.6	Fixed	2,272.13	55.41
278	J-242	476046	989919	2223	0.81	Fixed	2,270.45	46.93
279	J-100	475983	989274	2213	0.56	Fixed	2,176.60	(36.68)
280	J-260	476198	988681	2206	0.11	Fixed	2,187.99	(17.74)
281	J-17	476404	989989	2225	0.72	Fixed	2,267.76	42.36
282	J-352	475873	988544	2195	0.43	Fixed	2,185.08	(9.78)
283	J-166	475828	989275	2212	0.81	Fixed	2,178.87	(32.85)
284	J-85	476193	989366	2217	0.18	Fixed	2,173.60	(42.91)
285	J-250	475619	988505	2189	0.07	Fixed	2,180.94	(8.04)
286	J-326	476154	989628	2219	1.78	Fixed	2,199.46	(19.80)
287	J-249	475659	989679	2219	2.68	Fixed	2,196.47	(22.03)
288	J-337	476818	988954	2222	0.81	Fixed	2,189.01	(32.51)
289	J-359	476299	990173	2228	2	Fixed	2,274.83	46.59
290	J-255	475867	989964	2224	0.05	Fixed	2,197.99	(26.22)
291	J-287	475530	989261	2209	0.04	Fixed	2,180.77	(28.37)
292	J-213	476565	989809	2224	0.4	Fixed	2,256.00	32.36
293	J-104	475945	988833	2204	0.2	Fixed	2,187.16	(17.11)
294	J-289	475553	988471	2186	0.04	Fixed	2,180.94	(5.47)
295	J-256	476246	989412	2230	0.09	Fixed	2,200.61	(29.09)
296	J-179	477411	989207	2221	0.02	Fixed	2,143.16	(77.92)
297	J-311	475953	989010	2208	0.36	Fixed	2,178.43	(29.64)
298	J-204	477103	989531	2226	0.11	Fixed	2,147.16	(78.67)
299	J-252	475832	989915	2223	1.78	Fixed	2,197.38	(25.79)
300	J-258	476264	990041	2226	0.2	Fixed	2,277.22	51.05
301	J-268	475810	990018	2225	0.02	Fixed	2,269.23	43.78
302	J-59	476557	989424	2221	0.54	Fixed	2,198.79	(22.45)
303	J-180	476227	989714	2221	0.16	Fixed	2,202.97	(17.81)
304	J-99	476017	989264	2214	0.2	Fixed	2,176.33	(37.16)

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Steady State Simulation Analysis Results
Actual Nodes at Peak Hour

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
305	J-36	476507	989673	2222	0.05	Fixed	2,203.60	(18.31)
306	J-236	475862	989978	2225	1.85	Fixed	2,269.23	44.57
307	J-349	475944	990200	2229	0.65	Fixed	2,270.03	40.95
308	J-305	476313	989289	2217	0.02	Fixed	2,172.40	(44.65)
309	J-322	476645	990234	2229	1.17	Fixed	2,270.75	42.15
310	J-330	475746	988488	2190	0.4	Fixed	2,180.50	(9.74)
311	J-157	476239	990323	2231	0.07	Fixed	2,272.20	41.37
312	J-193	476027	989125	2211	0.07	Fixed	2,177.98	(33.29)
313	J-118	476044	990048	2226	2.47	Fixed	2,269.19	43.14
314	J-369	477002	988923	2223	0.04	Fixed	2,191.61	(31.18)
315	J-318	477288	989222	2225	5.4	Fixed	2,143.20	(81.34)
316	J-259	476140	988699	2206	0	Fixed	2,187.77	(17.75)
317	J-292	475697	988556	2192	0.36	Fixed	2,183.25	(9.19)
318	J-235	475708	990276	2231	1.78	Fixed	2,266.33	35.73
319	J-107	475890	988767	2202	0.04	Fixed	2,185.86	(15.72)
320	J-15	475771	990106	2227	0.32	Fixed	2,266.30	39.10
321	J-92	476107	989355	2216	1.78	Fixed	2,174.10	(41.44)
322	J-136	476088	989286	2215	0.29	Fixed	2,174.49	(40.10)
323	J-303	476718	989614	2224	0.54	Fixed	2,202.60	(21.06)
324	J-367	476823	989639	2225	0.09	Fixed	2,193.67	(30.77)
325	J-72	476440	989977	2225	0.31	Fixed	2,266.85	41.61
326	J-316	475619	988667	2196	3.24	Fixed	2,163.50	(32.40)
327	J-334	476961	989756	2226	0.04	Fixed	2,159.83	(65.53)
328	J-196	476448	990371	2231	0.11	Fixed	2,276.56	45.31
329	J-198	475739	989433	2214	0.29	Fixed	2,178.16	(35.66)
330	J-16	476413	989986	2225	0.09	Fixed	2,267.42	42.05
331	J-25	476235	989987	2225	5.94	Fixed	2,277.41	52.18
332	J-333	476951	989626	2225	0.31	Fixed	2,159.84	(65.28)
333	J-194	477088	989440	2226	0.02	Fixed	2,147.40	(78.38)
334	J-324	476785	989889	2225	0.99	Fixed	2,272.39	46.93
335	J-302	476200	990094	2227	0.23	Fixed	2,273.54	46.54
336	J-31	476252	988868	2211	0.02	Fixed	2,191.74	(19.50)
337	J-61	476630	989636	2223	0.02	Fixed	2,202.90	(20.04)
338	J-364	476363	990499	2234	1.82	Fixed	2,271.12	37.37
339	J-69	476326	990209	2229	2.16	Fixed	2,276.95	48.22
340	J-73	475870	989134	2209	2	Fixed	2,178.25	(31.06)
341	J-338	476643	990182	2228	0.23	Fixed	2,273.31	45.28
342	J-29	475644	990189	2229	0.25	Fixed	2,266.34	37.49

APPENDIX D**Steady State Simulation Analysis Results****Actual Nodes at Peak Hour**

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H₂O)
343	J-370	475378	989001	2232	1.78	Fixed	2,181.66	(50.13)
344	J-176	476585	989582	2222	0.02	Fixed	2,201.88	(20.34)
345	J-365	476316	990490	2234	0.04	Fixed	2,272.19	38.39
346	J-220	476588	989209	2221	0.18	Fixed	2,200.22	(20.59)
347	J-40	476423	990424	2232	189	Fixed	2,276.85	44.67
348	J-78	476306	989743	2222	1.33	Fixed	2,263.74	41.99
349	J-54	476543	989662	2222	2.16	Fixed	2,203.39	(18.81)
350	J-288	475790	988668	2198	0.29	Fixed	2,185.26	(13.02)
351	J-91	476117	989386	2216	0.14	Fixed	2,173.87	(42.05)
352	J-298	476038	989405	2216	0.52	Fixed	2,173.82	(41.69)
353	J-112	476263	989470	2218	0.2	Fixed	2,200.36	(17.92)
354	J-63	476197	989628	2220	0.07	Fixed	2,200.74	(18.82)
355	J-267	476354	990110	2227	0.04	Fixed	2,274.02	46.78
356	J-304	476292	989206	2216	1.17	Fixed	2,170.20	(46.12)
357	J-76	476178	989578	2219	0.04	Fixed	2,200.35	(18.41)
358	J-79	475625	990166	2228	0.09	Fixed	2,266.38	37.98
359	J-248	475618	989723	2219	0.94	Fixed	2,196.47	(22.93)
360	J-368	476584	990660	2225	0.32	Fixed	2,275.45	49.98
361	J-47	477159	989374	2226	0.32	Fixed	2,147.04	(78.51)
362	J-42	477468	989200	2219	0.11	Fixed	2,143.15	(76.17)
363	J-41	477453	989202	2220	0	Fixed	2,143.15	(76.70)

APPENDIX E

Steady State Simulation Analysis Results

Improved Nodes at Minimum Consumption Hour

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
1	J-138	476131	989136	2213	0.05	Fixed	2,277.04	64
2	J-156	475749	989295	2211	0.04	Fixed	2,277.03	66
3	J-195	477096	989483	2226	0.02	Fixed	2,277.13	51
4	J-375	477343	989182	2223	0	Fixed	2,277.33	54
5	J-299	475958	989490	2216	0.05	Fixed	2,277.28	61
6	J-208	476089	990035	2226	0	Fixed	2,277.89	52
7	J-102	475756	989160	2209	0.37	Fixed	2,277.02	68
8	J-254	475970	989888	2223	0.14	Fixed	2,277.24	54
9	J-239	476133	989443	2217	0	Fixed	2,277.34	60
10	J-234	477077	989388	2226	0	Fixed	2,277.14	51
11	J-28	475650	990197	2229	0.02	Fixed	2,277.78	49
12	J-328	476081	990170	2228	0.02	Fixed	2,277.78	49
13	J-266	476295	990131	2227	0.05	Fixed	2,279.12	52
14	J-108	475924	988757	2202	0.04	Fixed	2,276.91	75
15	J-121	475602	989240	2225	0.04	Fixed	2,277.03	52
16	J-233	475897	989793	2221	0.03	Fixed	2,277.17	56
17	J-231	476007	989711	2220	0	Fixed	2,277.19	57
18	J-97	475994	989172	2212	0	Fixed	2,277.04	65
19	J-331	476693	990060	2227	0.02	Fixed	2,279.89	53
20	J-374	477246	990928	2237	0	Fixed	2,286.59	49
21	J-344	475477	988516	2188	0.01	Fixed	2,238.08	50
22	J-13	476089	988897	2209	0.07	Fixed	2,276.99	68
23	J-339	476300	989056	2226	0	Fixed	2,277.04	51
24	J-279	476524	989952	2225	0.46	Fixed	2,278.68	54
25	J-162	476485	989476	2221	0.18	Fixed	2,277.25	56
26	J-106	475938	989696	2219	0.17	Fixed	2,277.16	58
27	J-281	476731	988797	2216	0	Fixed	2,277.07	61
28	J-357	477047	989984	2227	0.07	Fixed	2,282.46	56
29	J-77	476334	989734	2222	0.13	Fixed	2,277.93	56
30	J-74	475876	989161	2206	0.24	Fixed	2,277.04	71
31	J-284	476426	990055	2226	0.08	Fixed	2,278.53	52
32	J-188	475823	989689	2219	0.08	Fixed	2,277.14	58
33	J-82	476396	989506	2220	0.24	Fixed	2,277.31	57
34	J-308	475733	989070	2207	0.1	Fixed	2,277.02	70
35	J-226	476150	990339	2231	0.09	Fixed	2,278.75	47
36	J-212	475727	989577	2217	0.04	Fixed	2,277.02	60

APPENDIX E**Steady State Simulation Analysis Results****Improved Nodes at Minimum Consumption Hour**

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H2O)
37	J-323	476040	990167	2228	0.07	Fixed	2,277.75	49
38	J-183	477028	989387	2226	0.04	Fixed	2,277.20	51
39	J-201	477178	989468	2226	0.09	Fixed	2,277.13	51
40	J-351	476142	988519	2200	0.09	Fixed	2,276.97	77
41	J-95	475807	989187	2210	0.13	Fixed	2,277.05	67
42	J-348	476215	990484	2234	0.02	Fixed	2,278.75	45
43	J-123	475991	988857	2206	0.03	Fixed	2,276.97	71
44	J-190	476165	989088	2213	0.04	Fixed	2,277.04	64
45	J-290	475817	988787	2202	0.02	Fixed	2,276.89	75
46	J-174	476653	989780	2224	0.02	Fixed	2,279.44	55
47	J-170	475915	989578	2217	0.02	Fixed	2,277.18	60
48	J-144	476165	989540	2218	0.02	Fixed	2,277.31	59
49	J-186	476236	989357	2217	0.06	Fixed	2,277.06	60
50	J-114	475894	988641	2198	0.05	Fixed	2,276.88	79
51	J-222	476140	989846	2222	0.03	Fixed	2,277.71	55
52	J-325	476844	989989	2226	0.17	Fixed	2,282.46	56
53	J-88	475889	990378	2233	0.03	Fixed	2,278.22	46
54	J-345	476427	989173	2218	0.03	Fixed	2,277.31	59
55	J-184	475674	988698	2198	0.01	Fixed	2,276.89	78
56	J-83	475818	989547	2216	0.09	Fixed	2,277.02	61
57	J-135	475744	990068	2226	0.03	Fixed	2,277.84	51
58	J-283	476629	990294	2229	0.03	Fixed	2,279.97	51
59	J-24	476183	989773	2222	0.03	Fixed	2,277.53	56
60	J-160	475729	988921	2204	0.4	Fixed	2,276.89	73
61	J-229	476376	989434	2219	0.02	Fixed	2,277.32	58
62	J-101	475764	989195	2231	0.03	Fixed	2,277.03	46
63	J-253	475933	989841	2222	0.16	Fixed	2,277.20	55
64	J-60	476623	989615	2223	0	Fixed	2,277.38	54
65	J-70	476611	989736	2223	0	Fixed	2,279.44	56
66	J-139	476123	989097	2212	0.02	Fixed	2,277.04	64
67	J-206	476565	990321	2230	0.02	Fixed	2,279.97	50
68	J-175	475797	990141	2228	0.32	Fixed	2,277.72	50
69	J-262	475844	989041	2207	0.03	Fixed	2,277.04	70
70	J-294	476669	988881	2218	0.05	Fixed	2,277.04	59
71	J-257	476042	989761	2221	0.06	Fixed	2,277.22	56
72	J-241	475764	989822	2221	0.04	Fixed	2,277.15	56
73	J-215	476093	990336	2232	0	Fixed	2,278.68	47
74	J-310	476317	989690	2221	0	Fixed	2,277.33	56

APPENDIX E**Steady State Simulation Analysis Results****Improved Nodes at Minimum Consumption Hour**

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H2O)
75	J-23	475466	989299	2210	0	Fixed	2,277.04	67
76	J-341	476130	990170	2228	0.07	Fixed	2,277.87	49
77	J-244	475813	990004	2225	0.04	Fixed	2,277.14	52
78	J-80	476365	989725	2222	0	Fixed	2,277.93	56
79	J-109	477476	989322	2221	0	Fixed	2,277.12	56
80	J-280	476661	988793	2215	0.02	Fixed	2,277.07	62
81	J-64	476516	989435	2221	0.05	Fixed	2,277.15	56
82	J-291	476152	989228	2215	1.94	Fixed	2,277.03	62
83	J-307	475599	989106	2206	0.71	Fixed	2,277.01	71
84	J-169	475894	989542	2217	0.02	Fixed	2,277.20	60
85	J-145	476170	989734	2221	0.12	Fixed	2,277.51	57
86	J-127	475782	989625	2218	0	Fixed	2,277.15	59
87	J-271	476716	989759	2224	0.22	Fixed	2,279.37	55
88	J-129	476289	989600	2220	0.01	Fixed	2,277.33	57
89	J-314	475582	989779	2221	0.02	Fixed	2,277.11	56
90	J-87	475907	990403	2233	0.04	Fixed	2,278.22	45
91	J-3	475964	988933	2207	0.05	Fixed	2,277.01	70
92	J-373	477406	989149	2221	0.53	Fixed	2,277.38	56
93	J-297	476542	989051	2219	0	Fixed	2,277.31	58
94	J-8	476180	989783	2198	0.71	Fixed	2,277.54	79
95	J-11	476521	989669	2222	0.06	Fixed	2,277.46	55
96	J-128	475800	989652	2218	0	Fixed	2,277.15	59
97	J-171	475558	989384	2212	0	Fixed	2,277.03	65
98	J-320	476928	990144	2228	0.06	Fixed	2,284.68	57
99	J-120	475871	989606	2218	0	Fixed	2,277.16	60
100	J-191	476125	989790	2221	0.11	Fixed	2,277.41	56
101	J-32	475965	988944	2207	0.02	Fixed	2,277.03	70
102	J-130	476324	989588	2220	0.02	Fixed	2,277.33	57
103	J-321	476958	990248	2229	0.03	Fixed	2,286.29	57
104	J-96	475840	989178	2210	0.02	Fixed	2,277.08	67
105	J-306	475581	989473	2214	0.02	Fixed	2,277.03	63
106	J-237	475688	989825	2221	0.02	Fixed	2,277.13	56
107	J-125	476344	989524	2220	0.02	Fixed	2,277.31	58
108	J-124	475955	988869	2205	0.02	Fixed	2,276.97	71
109	J-293	475958	989475	2216	0	Fixed	2,277.19	61
110	J-277	475938	989400	2215	0.04	Fixed	2,277.10	62
111	J-240	475797	989868	2222	0	Fixed	2,277.17	55
112	J-245	475767	990037	2226	0.04	Fixed	2,277.14	51

APPENDIX E**Steady State Simulation Analysis Results****Improved Nodes at Minimum Consumption Hour**

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H2O)
113	J-66	476406	989536	2220	0.72	Fixed	2,277.31	57
114	J-126	476333	989487	2219	0.01	Fixed	2,277.31	58
115	J-361	476659	988601	2206	0.02	Fixed	2,277.07	71
116	J-71	476639	989729	2224	0	Fixed	2,279.44	56
117	J-272	476454	989253	2219	0	Fixed	2,277.32	58
118	J-22	475463	989293	2227	0	Fixed	2,277.04	49
119	J-172	475550	989342	2211	0	Fixed	2,277.03	66
120	J-285	476904	989334	2225	0	Fixed	2,277.23	52
121	J-274	476229	989520	2219	0	Fixed	2,277.31	59
122	J-39	476438	990417	2212	0.8	Fixed	2,286.59	74
123	J-41	477453	989202	2220	0	Fixed	2,277.12	57
124	J-227	476455	989688	2222	0	Fixed	2,277.47	56
125	J-18	476045	988725	2204	0	Fixed	2,276.95	73
126	J-207	476545	990278	2229	0	Fixed	2,279.83	50
127	J-168	476679	989718	2224	0	Fixed	2,279.44	55
128	J-134	476009	988735	2204	0	Fixed	2,276.95	73
129	J-51	476543	989456	2221	0	Fixed	2,277.26	56
130	J-75	476508	989408	2221	0.84	Fixed	2,277.07	56
131	J-205	475977	989670	2219	0.02	Fixed	2,277.17	58
132	J-161	476406	990388	2232	0.16	Fixed	2,280.04	48
133	J-362	475404	988583	2190	0.01	Fixed	2,266.06	76
134	J-187	476226	989316	2216	0.24	Fixed	2,277.03	60
135	J-164	475911	989293	2213	0.08	Fixed	2,277.06	64
136	J-10	476523	989677	2222	0.02	Fixed	2,277.58	55
137	J-243	476097	989943	2224	0.02	Fixed	2,277.75	54
138	J-335	476382	990405	2232	0.26	Fixed	2,279.13	47
139	J-43	476496	989382	2220	0.07	Fixed	2,277.33	57
140	J-44	476489	989365	2220	0.12	Fixed	2,277.33	57
141	J-131	476323	989451	2219	0	Fixed	2,277.32	58
142	J-327	476091	988976	2210	0.03	Fixed	2,277.04	67
143	J-35	476072	989444	2216	0.06	Fixed	2,277.33	61
144	J-276	475984	989890	2223	0.07	Fixed	2,277.70	55
145	J-81	476549	989397	2221	0.03	Fixed	2,277.12	56
146	J-30	476248	988854	2211	0.04	Fixed	2,277.05	66
147	J-159	475675	990231	2230	0.01	Fixed	2,277.78	48
148	J-111	476273	989506	2219	0.06	Fixed	2,277.31	58
149	J-90	475770	988911	2204	0.06	Fixed	2,276.92	73
150	J-115	475729	989206	2226	0.06	Fixed	2,277.03	51

APPENDIX E**Steady State Simulation Analysis Results****Improved Nodes at Minimum Consumption Hour**

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H2O)
151	J-62	476188	989603	2219	0.06	Fixed	2,277.32	58
152	J-199	475773	989563	2217	0.01	Fixed	2,277.02	60
153	J-94	475984	989138	2211	0.04	Fixed	2,277.04	66
154	J-251	476329	990283	2230	0.06	Fixed	2,279.14	49
155	J-132	476073	988835	2207	0.06	Fixed	2,276.97	70
156	J-38	477169	989424	2226	0.06	Fixed	2,277.13	51
157	J-53	476564	989449	2221	0.06	Fixed	2,277.26	56
158	J-315	476123	990494	2234	0.03	Fixed	2,278.54	45
159	J-247	476104	990277	2231	0	Fixed	2,278.70	48
160	J-211	477310	989324	2225	0.02	Fixed	2,277.13	52
161	J-342	476129	988966	2211	0	Fixed	2,277.04	66
162	J-5	475825	988983	2206	0.02	Fixed	2,277.07	71
163	J-137	476080	989249	2214	0.03	Fixed	2,277.06	63
164	J-278	476455	989696	2222	0.06	Fixed	2,277.90	56
165	J-219	476602	989260	2221	0.06	Fixed	2,277.31	56
166	J-150	475628	989193	2208	0.04	Fixed	2,277.02	69
167	J-216	476081	989814	2222	0.08	Fixed	2,277.33	56
168	J-133	476037	988844	2207	0.02	Fixed	2,276.97	70
169	J-230	475741	989631	2218	0.02	Fixed	2,277.02	59
170	J-50	475848	990173	2228	0.01	Fixed	2,277.71	49
171	J-232	476465	989541	2221	0	Fixed	2,277.36	56
172	J-197	475695	989445	2214	0.1	Fixed	2,277.03	63
173	J-275	476484	990305	2230	0.04	Fixed	2,279.83	50
174	J-34	476077	989458	2216	0.04	Fixed	2,277.35	61
175	J-141	476746	989941	2226	0.02	Fixed	2,279.89	54
176	J-228	476598	989938	2225	0.02	Fixed	2,279.52	54
177	J-329	476777	990083	2227	0.04	Fixed	2,279.88	53
178	J-155	475964	988746	2203	0.01	Fixed	2,276.93	74
179	J-142	476783	989955	2226	0	Fixed	2,279.88	54
180	J-263	476527	989603	2222	0.08	Fixed	2,277.36	55
181	J-67	476598	989624	2223	0.07	Fixed	2,277.36	55
182	J-148	475788	989285	2212	0.03	Fixed	2,277.03	65
183	J-182	477021	989343	2226	0.03	Fixed	2,277.19	51
184	J-312	476170	990117	2227	0.02	Fixed	2,278.02	51
185	J-224	476359	989381	2219	0	Fixed	2,277.33	59
186	J-269	475825	990299	2231	0	Fixed	2,278.03	47
187	J-48	476368	990000	2226	0.03	Fixed	2,278.57	53
188	J-68	476302	990223	2229	0	Fixed	2,279.28	50

APPENDIX E**Steady State Simulation Analysis Results****Improved Nodes at Minimum Consumption Hour**

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H2O)
189	J-270	475846	990237	2230	0.03	Fixed	2,278.03	48
190	J-238	475645	989861	2222	0.02	Fixed	2,277.11	55
191	J-122	475639	989231	2225	0.01	Fixed	2,277.03	52
192	J-313	477134	989260	2226	0.01	Fixed	2,277.16	51
193	J-84	475827	989577	2217	0.04	Fixed	2,277.02	60
194	J-189	477433	989333	2222	0	Fixed	2,277.12	55
195	J-93	475975	989106	2210	0	Fixed	2,277.04	67
196	J-14	475766	990099	2227	0.07	Fixed	2,277.77	51
197	J-202	475923	990061	2226	0.06	Fixed	2,277.74	51
198	J-309	476355	989677	2221	0.04	Fixed	2,277.33	56
199	J-152	476177	990011	2225	0.02	Fixed	2,278.14	53
200	J-296	476566	989127	2220	0.03	Fixed	2,277.31	57
201	J-286	476917	989406	2225	0.02	Fixed	2,277.22	52
202	J-173	476613	989793	2224	0.01	Fixed	2,279.50	56
203	J-225	476408	989371	2219	0.04	Fixed	2,277.33	58
204	J-105	475907	989717	2219	0.02	Fixed	2,277.15	58
205	J-209	475821	989411	2214	0.04	Fixed	2,277.03	63
206	J-363	476656	989425	2223	0.02	Fixed	2,277.37	55
207	J-6	475830	988981	2206	0.05	Fixed	2,277.06	71
208	J-336	476729	990078	2227	0.3	Fixed	2,279.85	53
209	J-116	475751	988844	2202	0.05	Fixed	2,276.90	74
210	J-372	476065	989465	2216	0.05	Fixed	2,277.50	61
211	J-192	476326	990015	2226	0	Fixed	2,278.59	53
212	J-347	476640	989358	2228	0.04	Fixed	2,277.33	49
213	J-151	476139	990024	2226	0.04	Fixed	2,278.02	52
214	J-167	475810	989363	2213	0.02	Fixed	2,277.03	64
215	J-295	476702	988962	2220	0.04	Fixed	2,277.00	57
216	J-218	475951	990101	2227	0	Fixed	2,277.74	51
217	J-86	476184	989336	2216	0	Fixed	2,277.06	61
218	J-143	476152	989503	2218	0.02	Fixed	2,277.32	60
219	J-27	476246	989984	2225	1.6	Fixed	2,278.38	53
220	J-371	476935	989280	2231	0	Fixed	2,277.33	46
221	J-358	476073	989613	2219	0.01	Fixed	2,277.41	59
222	J-110	477482	989357	2221	0.04	Fixed	2,277.12	56
223	J-203	475896	990024	2225	0.06	Fixed	2,277.74	52
224	J-103	475935	988797	2203	0.06	Fixed	2,276.92	74
225	J-214	476036	990349	2232	0	Fixed	2,278.55	47
226	J-49	475832	990186	2229	0.7	Fixed	2,277.71	49

APPENDIX E**Steady State Simulation Analysis Results****Improved Nodes at Minimum Consumption Hour**

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H2O)
227	J-12	476097	988895	2209	0.01	Fixed	2,276.99	68
228	J-217	475865	989748	2220	1.05	Fixed	2,277.14	57
229	J-178	475698	989729	2220	0.01	Fixed	2,277.14	57
230	J-346	477455	989472	2222	0	Fixed	2,277.12	55
231	J-223	477007	989295	2226	0	Fixed	2,277.20	52
232	J-200	475784	989608	2217	0	Fixed	2,277.02	60
233	J-350	476426	990201	2229	0.05	Fixed	2,280.01	51
234	J-37	477166	989409	2226	0.02	Fixed	2,277.14	51
235	J-154	475661	989317	2211	0.05	Fixed	2,277.03	66
236	J-210	477322	989372	2225	0.03	Fixed	2,277.13	53
237	J-332	475991	988999	2209	0.06	Fixed	2,277.04	68
238	J-98	476567	989633	2222	0.04	Fixed	2,277.36	55
239	J-319	475707	989943	2224	0.06	Fixed	2,277.10	53
240	J-158	476277	990309	2230	0.04	Fixed	2,278.94	49
241	J-181	476237	989755	2222	0.02	Fixed	2,277.53	56
242	J-146	475991	989312	2214	0.02	Fixed	2,277.07	63
243	J-117	476009	990062	2226	0.05	Fixed	2,277.76	51
244	J-57	475597	988566	2191	0.24	Fixed	2,249.87	58
245	J-261	476244	989764	2222	0.03	Fixed	2,277.83	56
246	J-366	476341	989372	2218	0.01	Fixed	2,277.33	59
247	J-119	475841	989625	2218	0.03	Fixed	2,277.15	59
248	J-33	476168	989777	2222	0.03	Fixed	2,277.50	56
249	J-26	476238	989997	2225	0.44	Fixed	2,278.33	53
250	J-46	477155	989354	2226	0.01	Fixed	2,277.14	51
251	J-113	475860	988651	2198	0.84	Fixed	2,276.87	79
252	J-45	476387	989994	2225	0.01	Fixed	2,278.53	53
253	J-58	475624	988563	2191	0.1	Fixed	2,249.86	58
254	J-65	476414	989559	2221	0.09	Fixed	2,277.33	57
255	J-273	476434	989189	2218	0.03	Fixed	2,277.32	59
256	J-221	476169	989887	2223	0.06	Fixed	2,277.78	55
257	J-52	476523	989461	2221	0.04	Fixed	2,277.23	56
258	J-165	476470	989421	2220	0.03	Fixed	2,277.14	57
259	J-55	476666	989917	2225	0	Fixed	2,279.92	55
260	J-301	475716	989345	2212	0.2	Fixed	2,277.03	65
261	J-282	476008	989381	2215	0.22	Fixed	2,277.08	62
262	J-19	476054	988723	2204	0.34	Fixed	2,276.95	72
263	J-147	475798	989324	2212	0.22	Fixed	2,277.03	64
264	J-149	476284	989544	2219	0	Fixed	2,277.31	58

APPENDIX E**Steady State Simulation Analysis Results****Improved Nodes at Minimum Consumption Hour**

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H2O)
265	J-343	477084	990152	2228	0.04	Fixed	2,284.68	56
266	J-185	475715	988688	2199	0.06	Fixed	2,276.89	78
267	J-163	475921	989333	2206	0.22	Fixed	2,277.07	71
268	J-360	475874	989167	2210	1.8	Fixed	2,277.14	67
269	J-246	475944	990362	2232	0.04	Fixed	2,278.34	46
270	J-56	476643	989922	2225	0.04	Fixed	2,279.73	55
271	J-340	475761	990286	2231	0.06	Fixed	2,277.71	47
272	J-89	475761	988880	2203	0.06	Fixed	2,276.91	74
273	J-264	476270	989849	2223	0.07	Fixed	2,277.93	55
274	J-7	476186	989781	2222	0.09	Fixed	2,277.54	56
275	J-177	475720	989761	2220	0.04	Fixed	2,277.14	57
276	J-153	475623	989328	2211	0.04	Fixed	2,277.03	66
277	J-140	475743	988807	2201	0.08	Fixed	2,276.90	75
278	J-265	476210	989861	2217	0.36	Fixed	2,277.89	61
279	J-242	476046	989919	2223	0.18	Fixed	2,277.71	54
280	J-100	475983	989274	2213	0.12	Fixed	2,277.06	64
281	J-260	476198	988681	2206	0.02	Fixed	2,276.97	71
282	J-17	476404	989989	2225	0.16	Fixed	2,278.53	53
283	J-352	475873	988544	2195	0.1	Fixed	2,233.07	38
284	J-166	475828	989275	2212	0.18	Fixed	2,277.03	65
285	J-85	476193	989366	2217	0.04	Fixed	2,277.06	60
286	J-250	475619	988505	2189	0.02	Fixed	2,238.08	49
287	J-326	476154	989628	2219	0.4	Fixed	2,277.26	58
288	J-249	475659	989679	2219	0.6	Fixed	2,277.13	58
289	J-337	476818	988954	2222	0.18	Fixed	2,276.91	55
290	J-359	476299	990173	2228	0.44	Fixed	2,278.25	50
291	J-255	475867	989964	2224	0.01	Fixed	2,277.21	53
292	J-287	475530	989261	2209	0.01	Fixed	2,277.03	68
293	J-213	476565	989809	2224	0.09	Fixed	2,279.03	55
294	J-104	475945	988833	2204	0.04	Fixed	2,276.93	72
295	J-289	475553	988471	2186	0.01	Fixed	2,238.08	52
296	J-256	476246	989412	2230	0.02	Fixed	2,277.33	47
297	J-179	477411	989207	2221	0	Fixed	2,277.12	56
298	J-311	475953	989010	2208	0.08	Fixed	2,277.04	69
299	J-204	477103	989531	2226	0.02	Fixed	2,277.13	51
300	J-252	475832	989915	2223	0.4	Fixed	2,277.18	54
301	J-258	476264	990041	2226	0.04	Fixed	2,278.67	52
302	J-268	475810	990018	2225	0	Fixed	2,278.00	53

APPENDIX E**Steady State Simulation Analysis Results****Improved Nodes at Minimum Consumption Hour**

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H2O)
303	J-59	476557	989424	2221	0.12	Fixed	2,277.16	56
304	J-180	476227	989714	2221	0.04	Fixed	2,277.49	57
305	J-99	476017	989264	2214	0.04	Fixed	2,277.06	63
306	J-36	476507	989673	2222	0.01	Fixed	2,277.46	55
307	J-236	475862	989978	2225	0.41	Fixed	2,277.74	53
308	J-349	475944	990200	2229	0.14	Fixed	2,278.34	49
309	J-305	476313	989289	2217	0	Fixed	2,276.99	60
310	J-322	476645	990234	2229	0.26	Fixed	2,279.66	51
311	J-330	475746	988488	2190	0.09	Fixed	2,238.06	48
312	J-157	476239	990323	2231	0.02	Fixed	2,278.88	48
313	J-193	476027	989125	2211	0.02	Fixed	2,277.04	66
314	J-118	476044	990048	2226	0.55	Fixed	2,277.78	52
315	J-369	477002	988923	2223	0.01	Fixed	2,277.07	54
316	J-318	477288	989222	2225	1.2	Fixed	2,277.13	52
317	J-259	476140	988699	2206	0	Fixed	2,276.96	71
318	J-292	475697	988556	2192	0.08	Fixed	2,249.85	57
319	J-235	475708	990276	2231	0.4	Fixed	2,277.78	47
320	J-107	475890	988767	2202	0.01	Fixed	2,276.90	75
321	J-15	475771	990106	2227	0.07	Fixed	2,277.77	51
322	J-92	476107	989355	2216	0.4	Fixed	2,277.06	61
323	J-136	476088	989286	2215	0.06	Fixed	2,277.06	62
324	J-303	476718	989614	2224	0.12	Fixed	2,277.39	54
325	J-367	476823	989639	2225	0.02	Fixed	2,277.37	53
326	J-72	476440	989977	2225	0.07	Fixed	2,278.54	53
327	J-316	475619	988667	2196	0.72	Fixed	2,248.80	53
328	J-334	476961	989756	2226	0.01	Fixed	2,277.22	52
329	J-196	476448	990371	2231	0.02	Fixed	2,280.02	49
330	J-198	475739	989433	2214	0.06	Fixed	2,277.03	63
331	J-16	476413	989986	2225	0.02	Fixed	2,278.53	53
332	J-25	476235	989987	2225	1.32	Fixed	2,278.34	53
333	J-42	477468	989200	2219	0.04	Fixed	2,277.12	58
334	J-333	476951	989626	2225	0.07	Fixed	2,277.22	52
335	J-194	477088	989440	2226	0	Fixed	2,277.14	51
336	J-324	476785	989889	2225	0.22	Fixed	2,281.16	56
337	J-302	476200	990094	2227	0.05	Fixed	2,278.13	51
338	J-31	476252	988868	2211	0	Fixed	2,277.08	66
339	J-61	476630	989636	2223	0	Fixed	2,277.41	54
340	J-364	476363	990499	2234	0.4	Fixed	2,278.86	45

APPENDIX E**Steady State Simulation Analysis Results****Improved Nodes at Minimum Consumption Hour**

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H2O)
341	J-69	476326	990209	2229	0.48	Fixed	2,279.53	51
342	J-73	475870	989134	2209	0.44	Fixed	2,277.03	68
343	J-338	476643	990182	2228	0.05	Fixed	2,279.82	52
344	J-29	475644	990189	2229	0.06	Fixed	2,277.78	49
345	J-370	475378	989001	2232	0.4	Fixed	2,275.90	44
346	J-176	476585	989582	2222	0	Fixed	2,277.35	55
347	J-365	476316	990490	2234	0.01	Fixed	2,278.88	45
348	J-220	476588	989209	2221	0.04	Fixed	2,277.31	56
349	J-40	476423	990424	2232	42	Fixed	2,286.60	54
350	J-78	476306	989743	2222	0.3	Fixed	2,277.93	56
351	J-54	476543	989662	2222	0.48	Fixed	2,277.44	55
352	J-288	475790	988668	2198	0.06	Fixed	2,276.89	78
353	J-91	476117	989386	2216	0.03	Fixed	2,277.06	61
354	J-298	476038	989405	2216	0.12	Fixed	2,277.06	61
355	J-112	476263	989470	2218	0.04	Fixed	2,277.32	59
356	J-63	476197	989628	2220	0.02	Fixed	2,277.33	58
357	J-267	476354	990110	2227	0.01	Fixed	2,278.76	52
358	J-304	476292	989206	2216	0.26	Fixed	2,276.86	60
359	J-76	476178	989578	2219	0.01	Fixed	2,277.31	58
360	J-79	475625	990166	2228	0.02	Fixed	2,277.78	49
361	J-248	475618	989723	2219	0.21	Fixed	2,277.13	58
362	J-368	476584	990660	2225	0.07	Fixed	2,286.59	61
363	J-47	477159	989374	2226	0.07	Fixed	2,277.14	51

APPENDIX F**Steady State Simulation Analysis Results
Improved Nodes at Peak Hour**

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
1	J-138	476131	989136	2213	0.19	Fixed	2,262.48	49
2	J-156	475749	989295	2211	0.18	Fixed	2,262.41	51
3	J-195	477096	989483	2226	0.06	Fixed	2,263.08	37
4	J-375	477343	989182	2223	0.02	Fixed	2,266.23	43
5	J-299	475958	989490	2216	0.19	Fixed	2,265.67	49
6	J-208	476089	990035	2226	0.02	Fixed	2,272.13	46
7	J-102	475756	989160	2209	1.49	Fixed	2,262.33	53
8	J-254	475970	989888	2223	0.58	Fixed	2,265.12	42
9	J-239	476133	989443	2217	0	Fixed	2,266.42	50
10	J-234	477077	989388	2226	0	Fixed	2,263.25	37
11	J-28	475650	990197	2229	0.06	Fixed	2,268.28	39
12	J-328	476081	990170	2228	0.06	Fixed	2,270.79	42
13	J-266	476295	990131	2227	0.19	Fixed	2,277.64	50
14	J-108	475924	988757	2202	0.16	Fixed	2,260.86	59
15	J-121	475602	989240	2225	0.14	Fixed	2,262.41	37
16	J-233	475897	989793	2221	0.13	Fixed	2,264.28	43
17	J-231	476007	989711	2220	0	Fixed	2,264.47	45
18	J-97	475994	989172	2212	0	Fixed	2,262.58	51
19	J-331	476693	990060	2227	0.08	Fixed	2,275.65	49
20	J-374	477246	990928	2237	0.02	Fixed	2,277.71	40
21	J-344	475477	988516	2188	0.03	Fixed	2,236.72	49
22	J-13	476089	988897	2209	0.27	Fixed	2,261.84	53
23	J-339	476300	989056	2226	0	Fixed	2,262.48	36
24	J-279	476524	989952	2225	1.86	Fixed	2,273.68	49
25	J-162	476485	989476	2221	0.7	Fixed	2,264.61	44
26	J-106	475938	989696	2219	0.69	Fixed	2,264.12	45
27	J-281	476731	988797	2216	0.02	Fixed	2,262.93	47
28	J-357	477047	989984	2227	0.29	Fixed	2,276.16	49
29	J-77	476334	989734	2222	0.53	Fixed	2,270.65	49
30	J-74	475876	989161	2206	0.94	Fixed	2,262.56	57
31	J-284	476426	990055	2226	0.34	Fixed	2,273.72	47
32	J-188	475823	989689	2219	0.34	Fixed	2,263.91	45
33	J-82	476396	989506	2220	0.94	Fixed	2,265.97	46
34	J-308	475733	989070	2207	0.42	Fixed	2,262.32	55
35	J-226	476150	990339	2231	0.35	Fixed	2,272.98	42
36	J-212	475727	989577	2217	0.16	Fixed	2,262.35	46

APPENDIX F**Steady State Simulation Analysis Results
Improved Nodes at Peak Hour**

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H2O)
37	J-323	476040	990167	2228	0.29	Fixed	2,270.36	42
38	J-183	477028	989387	2226	0.18	Fixed	2,263.96	38
39	J-201	477178	989468	2226	0.35	Fixed	2,263.07	37
40	J-351	476142	988519	2200	0.35	Fixed	2,261.63	62
41	J-95	475807	989187	2210	0.53	Fixed	2,262.63	53
42	J-348	476215	990484	2234	0.06	Fixed	2,272.98	39
43	J-123	475991	988857	2206	0.11	Fixed	2,261.59	56
44	J-190	476165	989088	2213	0.18	Fixed	2,262.48	49
45	J-290	475817	988787	2202	0.06	Fixed	2,260.65	59
46	J-174	476653	989780	2224	0.06	Fixed	2,274.16	50
47	J-170	475915	989578	2217	0.06	Fixed	2,264.34	47
48	J-144	476165	989540	2218	0.06	Fixed	2,266.02	48
49	J-186	476236	989357	2217	0.26	Fixed	2,262.77	46
50	J-114	475894	988641	2198	0.19	Fixed	2,260.48	62
51	J-222	476140	989846	2222	0.11	Fixed	2,272.17	50
52	J-325	476844	989989	2226	0.69	Fixed	2,276.20	50
53	J-88	475889	990378	2233	0.13	Fixed	2,270.59	38
54	J-345	476427	989173	2218	0.13	Fixed	2,265.95	48
55	J-184	475674	988698	2198	0.03	Fixed	2,260.61	62
56	J-83	475818	989547	2216	0.35	Fixed	2,262.34	46
57	J-135	475744	990068	2226	0.11	Fixed	2,268.93	42
58	J-283	476629	990294	2229	0.11	Fixed	2,276.66	47
59	J-24	476183	989773	2222	0.11	Fixed	2,268.98	47
60	J-160	475729	988921	2204	1.58	Fixed	2,260.64	57
61	J-229	476376	989434	2219	0.08	Fixed	2,266.07	47
62	J-101	475764	989195	2231	0.11	Fixed	2,262.43	31
63	J-253	475933	989841	2222	0.66	Fixed	2,264.61	43
64	J-60	476623	989615	2223	0.02	Fixed	2,266.37	43
65	J-70	476611	989736	2223	0.02	Fixed	2,274.16	51
66	J-139	476123	989097	2212	0.1	Fixed	2,262.49	50
67	J-206	476565	990321	2230	0.1	Fixed	2,276.66	47
68	J-175	475797	990141	2228	1.26	Fixed	2,267.97	40
69	J-262	475844	989041	2207	0.11	Fixed	2,262.50	55
70	J-294	476669	988881	2218	0.21	Fixed	2,262.57	45
71	J-257	476042	989761	2221	0.22	Fixed	2,264.95	44
72	J-241	475764	989822	2221	0.16	Fixed	2,263.95	42
73	J-215	476093	990336	2232	0.02	Fixed	2,272.80	41
74	J-310	476317	989690	2221	0	Fixed	2,266.19	45

APPENDIX F**Steady State Simulation Analysis Results
Improved Nodes at Peak Hour**

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
75	J-23	475466	989299	2210	0	Fixed	2,262.57	52
76	J-341	476130	990170	2228	0.29	Fixed	2,271.86	43
77	J-244	475813	990004	2225	0.16	Fixed	2,263.84	39
78	J-80	476365	989725	2222	0	Fixed	2,270.58	49
79	J-109	477476	989322	2221	0	Fixed	2,262.92	42
80	J-280	476661	988793	2215	0.08	Fixed	2,262.94	48
81	J-64	476516	989435	2221	0.21	Fixed	2,263.37	42
82	J-291	476152	989228	2215	7.78	Fixed	2,262.47	48
83	J-307	475599	989106	2206	2.83	Fixed	2,262.18	56
84	J-169	475894	989542	2217	0.08	Fixed	2,264.60	48
85	J-145	476170	989734	2221	0.48	Fixed	2,268.67	48
86	J-127	475782	989625	2218	0.02	Fixed	2,264.01	46
87	J-271	476716	989759	2224	0.86	Fixed	2,273.19	49
88	J-129	476289	989600	2220	0.05	Fixed	2,266.19	46
89	J-314	475582	989779	2221	0.06	Fixed	2,263.53	43
90	J-87	475907	990403	2233	0.18	Fixed	2,270.59	37
91	J-3	475964	988933	2207	0.21	Fixed	2,262.16	55
92	J-373	477406	989149	2221	2.13	Fixed	2,266.33	45
93	J-297	476542	989051	2219	0	Fixed	2,265.96	47
94	J-8	476180	989783	2198	2.85	Fixed	2,269.15	71
95	J-11	476521	989669	2222	0.22	Fixed	2,267.31	45
96	J-128	475800	989652	2218	0.02	Fixed	2,263.98	46
97	J-171	475558	989384	2212	0.02	Fixed	2,262.37	50
98	J-320	476928	990144	2228	0.22	Fixed	2,276.91	49
99	J-120	475871	989606	2218	0.02	Fixed	2,264.14	47
100	J-191	476125	989790	2221	0.43	Fixed	2,267.45	46
101	J-32	475965	988944	2207	0.1	Fixed	2,262.38	55
102	J-130	476324	989588	2220	0.1	Fixed	2,266.18	46
103	J-321	476958	990248	2229	0.11	Fixed	2,277.58	49
104	J-96	475840	989178	2210	0.1	Fixed	2,263.13	53
105	J-306	475581	989473	2214	0.06	Fixed	2,262.36	48
106	J-237	475688	989825	2221	0.06	Fixed	2,263.72	42
107	J-125	476344	989524	2220	0.06	Fixed	2,266.01	46
108	J-124	475955	988869	2205	0.08	Fixed	2,261.62	56
109	J-293	475958	989475	2216	0.02	Fixed	2,264.51	48
110	J-277	475938	989400	2215	0.16	Fixed	2,263.32	48
111	J-240	475797	989868	2222	0.02	Fixed	2,264.24	42
112	J-245	475767	990037	2226	0.18	Fixed	2,263.84	38

APPENDIX F**Steady State Simulation Analysis Results
Improved Nodes at Peak Hour**

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
113	J-66	476406	989536	2220	2.88	Fixed	2,265.96	46
114	J-126	476333	989487	2219	0.03	Fixed	2,266.02	47
115	J-361	476659	988601	2206	0.06	Fixed	2,262.92	57
116	J-71	476639	989729	2224	0	Fixed	2,274.16	50
117	J-272	476454	989253	2219	0.02	Fixed	2,266.09	47
118	J-22	475463	989293	2227	0.02	Fixed	2,262.52	35
119	J-172	475550	989342	2211	0.02	Fixed	2,262.40	51
120	J-285	476904	989334	2225	0	Fixed	2,264.41	39
121	J-274	476229	989520	2219	0.02	Fixed	2,266.02	47
122	J-39	476438	990417	2212	3.2	Fixed	2,277.71	65
123	J-41	477453	989202	2220	0	Fixed	2,262.95	43
124	J-227	476455	989688	2222	0	Fixed	2,267.65	46
125	J-18	476045	988725	2204	0	Fixed	2,261.42	57
126	J-207	476545	990278	2229	0.02	Fixed	2,274.90	45
127	J-168	476679	989718	2224	0.02	Fixed	2,274.16	50
128	J-134	476009	988735	2204	0	Fixed	2,261.32	58
129	J-51	476543	989456	2221	0.02	Fixed	2,264.70	43
130	J-75	476508	989408	2221	3.36	Fixed	2,262.32	42
131	J-205	475977	989670	2219	0.06	Fixed	2,264.31	45
132	J-161	476406	990388	2232	0.64	Fixed	2,277.63	46
133	J-362	475404	988583	2190	0.03	Fixed	2,246.38	57
134	J-187	476226	989316	2216	0.96	Fixed	2,262.48	46
135	J-164	475911	989293	2213	0.34	Fixed	2,262.83	50
136	J-10	476523	989677	2222	0.1	Fixed	2,267.93	46
137	J-243	476097	989943	2224	0.06	Fixed	2,271.84	48
138	J-335	476382	990405	2232	1.06	Fixed	2,274.83	43
139	J-43	476496	989382	2220	0.27	Fixed	2,266.23	46
140	J-44	476489	989365	2220	0.48	Fixed	2,266.23	46
141	J-131	476323	989451	2219	0.02	Fixed	2,266.05	47
142	J-327	476091	988976	2210	0.13	Fixed	2,262.49	52
143	J-35	476072	989444	2216	0.26	Fixed	2,266.30	50
144	J-276	475984	989890	2223	0.27	Fixed	2,270.44	48
145	J-81	476549	989397	2221	0.13	Fixed	2,262.92	42
146	J-30	476248	988854	2211	0.18	Fixed	2,262.71	52
147	J-159	475675	990231	2230	0.03	Fixed	2,268.28	39
148	J-111	476273	989506	2219	0.24	Fixed	2,266.02	47
149	J-90	475770	988911	2204	0.26	Fixed	2,260.94	57
150	J-115	475729	989206	2226	0.22	Fixed	2,262.42	37

APPENDIX F**Steady State Simulation Analysis Results
Improved Nodes at Peak Hour**

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
151	J-62	476188	989603	2219	0.22	Fixed	2,266.02	47
152	J-199	475773	989563	2217	0.03	Fixed	2,262.34	46
153	J-94	475984	989138	2211	0.14	Fixed	2,262.53	51
154	J-251	476329	990283	2230	0.24	Fixed	2,274.96	45
155	J-132	476073	988835	2207	0.26	Fixed	2,261.59	54
156	J-38	477169	989424	2226	0.22	Fixed	2,263.12	37
157	J-53	476564	989449	2221	0.22	Fixed	2,264.74	43
158	J-315	476123	990494	2234	0.11	Fixed	2,272.14	38
159	J-247	476104	990277	2231	0	Fixed	2,272.95	42
160	J-211	477310	989324	2225	0.1	Fixed	2,263.08	38
161	J-342	476129	988966	2211	0	Fixed	2,262.49	52
162	J-5	475825	988983	2206	0.1	Fixed	2,262.87	57
163	J-137	476080	989249	2214	0.11	Fixed	2,262.74	49
164	J-278	476455	989696	2222	0.24	Fixed	2,270.05	48
165	J-219	476602	989260	2221	0.24	Fixed	2,265.96	45
166	J-150	475628	989193	2208	0.16	Fixed	2,262.33	54
167	J-216	476081	989814	2222	0.32	Fixed	2,266.30	45
168	J-133	476037	988844	2207	0.08	Fixed	2,261.59	55
169	J-230	475741	989631	2218	0.08	Fixed	2,262.34	45
170	J-50	475848	990173	2228	0.03	Fixed	2,268.40	40
171	J-232	476465	989541	2221	0.02	Fixed	2,266.48	45
172	J-197	475695	989445	2214	0.38	Fixed	2,262.36	48
173	J-275	476484	990305	2230	0.18	Fixed	2,274.85	45
174	J-34	476077	989458	2216	0.18	Fixed	2,266.54	50
175	J-141	476746	989941	2226	0.08	Fixed	2,275.65	50
176	J-228	476598	989938	2225	0.1	Fixed	2,276.47	51
177	J-329	476777	990083	2227	0.18	Fixed	2,275.50	49
178	J-155	475964	988746	2203	0.03	Fixed	2,261.12	58
179	J-142	476783	989955	2226	0.02	Fixed	2,275.51	50
180	J-263	476527	989603	2222	0.3	Fixed	2,266.09	44
181	J-67	476598	989624	2223	0.29	Fixed	2,266.03	43
182	J-148	475788	989285	2212	0.13	Fixed	2,262.43	51
183	J-182	477021	989343	2226	0.11	Fixed	2,263.84	38
184	J-312	476170	990117	2227	0.1	Fixed	2,273.73	46
185	J-224	476359	989381	2219	0.02	Fixed	2,266.27	48
186	J-269	475825	990299	2231	0	Fixed	2,269.57	39
187	J-48	476368	990000	2226	0.11	Fixed	2,274.76	49
188	J-68	476302	990223	2229	0	Fixed	2,276.04	47

APPENDIX F**Steady State Simulation Analysis Results
Improved Nodes at Peak Hour**

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
189	J-270	475846	990237	2230	0.11	Fixed	2,269.56	40
190	J-238	475645	989861	2222	0.08	Fixed	2,263.54	41
191	J-122	475639	989231	2225	0.05	Fixed	2,262.40	38
192	J-313	477134	989260	2226	0.03	Fixed	2,263.42	38
193	J-84	475827	989577	2217	0.18	Fixed	2,262.34	45
194	J-189	477433	989333	2222	0.02	Fixed	2,262.93	41
195	J-93	475975	989106	2210	0.02	Fixed	2,262.49	52
196	J-14	475766	990099	2227	0.27	Fixed	2,268.26	41
197	J-202	475923	990061	2226	0.22	Fixed	2,270.55	44
198	J-309	476355	989677	2221	0.18	Fixed	2,266.11	45
199	J-152	476177	990011	2225	0.06	Fixed	2,275.18	50
200	J-296	476566	989127	2220	0.11	Fixed	2,265.96	46
201	J-286	476917	989406	2225	0.06	Fixed	2,264.29	39
202	J-173	476613	989793	2224	0.03	Fixed	2,274.89	51
203	J-225	476408	989371	2219	0.14	Fixed	2,266.26	47
204	J-105	475907	989717	2219	0.1	Fixed	2,264.03	45
205	J-209	475821	989411	2214	0.18	Fixed	2,262.39	48
206	J-363	476656	989425	2223	0.06	Fixed	2,266.19	44
207	J-6	475830	988981	2206	0.19	Fixed	2,262.81	57
208	J-336	476729	990078	2227	1.18	Fixed	2,275.13	48
209	J-116	475751	988844	2202	0.19	Fixed	2,260.76	58
210	J-372	476065	989465	2216	0.19	Fixed	2,268.55	52
211	J-192	476326	990015	2226	0.02	Fixed	2,275.46	50
212	J-347	476640	989358	2228	0.14	Fixed	2,266.23	38
213	J-151	476139	990024	2226	0.14	Fixed	2,273.75	48
214	J-167	475810	989363	2213	0.06	Fixed	2,262.44	49
215	J-295	476702	988962	2220	0.16	Fixed	2,262.05	42
216	J-218	475951	990101	2227	0.02	Fixed	2,270.31	43
217	J-86	476184	989336	2216	0.02	Fixed	2,262.81	47
218	J-143	476152	989503	2218	0.06	Fixed	2,266.05	48
219	J-27	476246	989984	2225	6.4	Fixed	2,277.70	53
220	J-371	476935	989280	2231	0.02	Fixed	2,266.23	35
221	J-358	476073	989613	2219	0.05	Fixed	2,267.44	49
222	J-110	477482	989357	2221	0.18	Fixed	2,262.89	42
223	J-203	475896	990024	2225	0.22	Fixed	2,270.55	45
224	J-103	475935	988797	2203	0.24	Fixed	2,260.94	58
225	J-214	476036	990349	2232	0.02	Fixed	2,272.20	40
226	J-49	475832	990186	2229	2.82	Fixed	2,268.16	39

APPENDIX F**Steady State Simulation Analysis Results
Improved Nodes at Peak Hour**

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
227	J-12	476097	988895	2209	0.03	Fixed	2,261.85	53
228	J-217	475865	989748	2220	4.19	Fixed	2,263.88	44
229	J-178	475698	989729	2220	0.05	Fixed	2,263.90	44
230	J-346	477455	989472	2222	0.02	Fixed	2,262.92	40
231	J-223	477007	989295	2226	0.02	Fixed	2,263.94	38
232	J-200	475784	989608	2217	0.02	Fixed	2,262.34	45
233	J-350	476426	990201	2229	0.19	Fixed	2,277.15	49
234	J-37	477166	989409	2226	0.1	Fixed	2,263.13	37
235	J-154	475661	989317	2211	0.19	Fixed	2,262.39	51
236	J-210	477322	989372	2225	0.13	Fixed	2,263.10	38
237	J-332	475991	988999	2209	0.24	Fixed	2,262.49	54
238	J-98	476567	989633	2222	0.18	Fixed	2,266.01	44
239	J-319	475707	989943	2224	0.24	Fixed	2,263.40	39
240	J-158	476277	990309	2230	0.18	Fixed	2,273.69	43
241	J-181	476237	989755	2222	0.06	Fixed	2,268.95	47
242	J-146	475991	989312	2214	0.06	Fixed	2,262.91	49
243	J-117	476009	990062	2226	0.19	Fixed	2,270.56	44
244	J-57	475597	988566	2191	0.98	Fixed	2,237.14	46
245	J-261	476244	989764	2222	0.13	Fixed	2,270.60	49
246	J-366	476341	989372	2218	0.03	Fixed	2,266.30	48
247	J-119	475841	989625	2218	0.11	Fixed	2,264.05	46
248	J-33	476168	989777	2222	0.13	Fixed	2,268.58	47
249	J-26	476238	989997	2225	1.76	Fixed	2,277.65	52
250	J-46	477155	989354	2226	0.05	Fixed	2,263.20	37
251	J-113	475860	988651	2198	3.36	Fixed	2,260.37	62
252	J-45	476387	989994	2225	0.05	Fixed	2,273.94	48
253	J-58	475624	988563	2191	0.38	Fixed	2,237.01	45
254	J-65	476414	989559	2221	0.35	Fixed	2,266.18	46
255	J-273	476434	989189	2218	0.11	Fixed	2,266.09	48
256	J-221	476169	989887	2223	0.24	Fixed	2,273.51	50
257	J-52	476523	989461	2221	0.14	Fixed	2,264.33	43
258	J-165	476470	989421	2220	0.11	Fixed	2,263.16	43
259	J-55	476666	989917	2225	0.02	Fixed	2,276.02	51
260	J-301	475716	989345	2212	0.78	Fixed	2,262.36	50
261	J-282	476008	989381	2215	0.86	Fixed	2,263.09	48
262	J-19	476054	988723	2204	1.36	Fixed	2,261.42	57
263	J-147	475798	989324	2212	0.86	Fixed	2,262.43	50
264	J-149	476284	989544	2219	0.02	Fixed	2,266.01	47

APPENDIX F**Steady State Simulation Analysis Results
Improved Nodes at Peak Hour**

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
265	J-343	477084	990152	2228	0.18	Fixed	2,276.90	48
266	J-185	475715	988688	2199	0.26	Fixed	2,260.60	62
267	J-163	475921	989333	2206	0.86	Fixed	2,262.95	57
268	J-360	475874	989167	2210	7.2	Fixed	2,263.84	54
269	J-246	475944	990362	2232	0.18	Fixed	2,271.33	39
270	J-56	476643	989922	2225	0.14	Fixed	2,276.04	51
271	J-340	475761	990286	2231	0.24	Fixed	2,268.29	38
272	J-89	475761	988880	2203	0.26	Fixed	2,260.86	58
273	J-264	476270	989849	2223	0.29	Fixed	2,272.21	49
274	J-7	476186	989781	2222	0.37	Fixed	2,269.10	47
275	J-177	475720	989761	2220	0.14	Fixed	2,263.91	44
276	J-153	475623	989328	2211	0.18	Fixed	2,262.39	51
277	J-140	475743	988807	2201	0.34	Fixed	2,260.67	59
278	J-265	476210	989861	2217	1.42	Fixed	2,272.22	55
279	J-242	476046	989919	2223	0.72	Fixed	2,271.21	48
280	J-100	475983	989274	2213	0.5	Fixed	2,262.83	49
281	J-260	476198	988681	2206	0.1	Fixed	2,261.68	56
282	J-17	476404	989989	2225	0.64	Fixed	2,273.74	48
283	J-352	475873	988544	2195	0.38	Fixed	2,232.98	38
284	J-166	475828	989275	2212	0.72	Fixed	2,262.43	51
285	J-85	476193	989366	2217	0.16	Fixed	2,262.78	46
286	J-250	475619	988505	2189	0.06	Fixed	2,236.72	48
287	J-326	476154	989628	2219	1.58	Fixed	2,265.33	46
288	J-249	475659	989679	2219	2.38	Fixed	2,263.69	45
289	J-337	476818	988954	2222	0.72	Fixed	2,260.84	39
290	J-359	476299	990173	2228	1.78	Fixed	2,276.53	48
291	J-255	475867	989964	2224	0.05	Fixed	2,264.81	40
292	J-287	475530	989261	2209	0.03	Fixed	2,262.48	53
293	J-213	476565	989809	2224	0.35	Fixed	2,273.60	50
294	J-104	475945	988833	2204	0.18	Fixed	2,261.17	57
295	J-289	475553	988471	2186	0.03	Fixed	2,236.72	50
296	J-256	476246	989412	2230	0.08	Fixed	2,266.32	37
297	J-179	477411	989207	2221	0.02	Fixed	2,262.96	42
298	J-311	475953	989010	2208	0.32	Fixed	2,262.49	54
299	J-204	477103	989531	2226	0.1	Fixed	2,263.07	37
300	J-252	475832	989915	2223	1.58	Fixed	2,264.35	41
301	J-258	476264	990041	2226	0.18	Fixed	2,277.67	51
302	J-268	475810	990018	2225	0.02	Fixed	2,270.48	45

APPENDIX F**Steady State Simulation Analysis Results
Improved Nodes at Peak Hour**

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
303	J-59	476557	989424	2221	0.48	Fixed	2,263.43	42
304	J-180	476227	989714	2221	0.14	Fixed	2,268.40	47
305	J-99	476017	989264	2214	0.18	Fixed	2,262.79	49
306	J-36	476507	989673	2222	0.05	Fixed	2,267.37	45
307	J-236	475862	989978	2225	1.65	Fixed	2,270.41	46
308	J-349	475944	990200	2229	0.58	Fixed	2,271.38	42
309	J-305	476313	989289	2217	0.02	Fixed	2,261.96	45
310	J-322	476645	990234	2229	1.04	Fixed	2,272.66	44
311	J-330	475746	988488	2190	0.35	Fixed	2,236.37	46
312	J-157	476239	990323	2231	0.06	Fixed	2,273.46	43
313	J-193	476027	989125	2211	0.06	Fixed	2,262.51	51
314	J-118	476044	990048	2226	2.19	Fixed	2,270.80	45
315	J-369	477002	988923	2223	0.03	Fixed	2,262.93	40
316	J-318	477288	989222	2225	4.8	Fixed	2,263.01	38
317	J-259	476140	988699	2206	0	Fixed	2,261.49	56
318	J-292	475697	988556	2192	0.32	Fixed	2,236.93	44
319	J-235	475708	990276	2231	1.58	Fixed	2,268.28	38
320	J-107	475890	988767	2202	0.03	Fixed	2,260.69	59
321	J-15	475771	990106	2227	0.29	Fixed	2,268.25	41
322	J-92	476107	989355	2216	1.58	Fixed	2,262.81	47
323	J-136	476088	989286	2215	0.26	Fixed	2,262.80	48
324	J-303	476718	989614	2224	0.48	Fixed	2,266.49	43
325	J-367	476823	989639	2225	0.08	Fixed	2,266.18	42
326	J-72	476440	989977	2225	0.27	Fixed	2,273.66	48
327	J-316	475619	988667	2196	2.88	Fixed	2,223.18	27
328	J-334	476961	989756	2226	0.03	Fixed	2,264.18	39
329	J-196	476448	990371	2231	0.1	Fixed	2,277.33	46
330	J-198	475739	989433	2214	0.26	Fixed	2,262.36	48
331	J-16	476413	989986	2225	0.08	Fixed	2,273.70	48
332	J-25	476235	989987	2225	5.28	Fixed	2,277.72	52
333	J-42	477468	989200	2219	0.18	Fixed	2,262.95	43
334	J-333	476951	989626	2225	0.27	Fixed	2,264.18	39
335	J-194	477088	989440	2226	0.02	Fixed	2,263.13	37
336	J-324	476785	989889	2225	0.88	Fixed	2,276.04	51
337	J-302	476200	990094	2227	0.21	Fixed	2,275.09	48
338	J-31	476252	988868	2211	0.02	Fixed	2,263.03	52
339	J-61	476630	989636	2223	0.02	Fixed	2,266.74	44
340	J-364	476363	990499	2234	1.62	Fixed	2,272.64	39

APPENDIX F**Steady State Simulation Analysis Results
Improved Nodes at Peak Hour**

S.no	Label	X	Y	Elevation (m)	Demand (Calculated) (l/s)	Pattern	Calculated Hydraulic Grade (m)	Pressure (m H ₂ O)
341	J-69	476326	990209	2229	1.92	Fixed	2,277.63	49
342	J-73	475870	989134	2209	1.78	Fixed	2,262.44	53
343	J-338	476643	990182	2228	0.21	Fixed	2,274.72	47
344	J-29	475644	990189	2229	0.22	Fixed	2,268.29	39
345	J-370	475378	989001	2232	1.58	Fixed	2,247.74	16
346	J-176	476585	989582	2222	0.02	Fixed	2,265.92	44
347	J-365	476316	990490	2234	0.03	Fixed	2,273.46	40
348	J-220	476588	989209	2221	0.16	Fixed	2,265.97	45
349	J-40	476423	990424	2232	168	Fixed	2,277.73	46
350	J-78	476306	989743	2222	1.18	Fixed	2,270.68	49
351	J-54	476543	989662	2222	1.92	Fixed	2,267.14	45
352	J-288	475790	988668	2198	0.26	Fixed	2,260.53	62
353	J-91	476117	989386	2216	0.13	Fixed	2,262.80	47
354	J-298	476038	989405	2216	0.46	Fixed	2,262.80	47
355	J-112	476263	989470	2218	0.18	Fixed	2,266.05	48
356	J-63	476197	989628	2220	0.06	Fixed	2,266.24	47
357	J-267	476354	990110	2227	0.03	Fixed	2,276.01	49
358	J-304	476292	989206	2216	1.04	Fixed	2,260.19	44
359	J-76	476178	989578	2219	0.03	Fixed	2,266.02	47
360	J-79	475625	990166	2228	0.08	Fixed	2,268.32	40
361	J-248	475618	989723	2219	0.83	Fixed	2,263.69	44
362	J-368	476584	990660	2225	0.29	Fixed	2,277.71	52
363	J-47	477159	989374	2226	0.29	Fixed	2,263.17	37