JIMMA UNIVERSITY

INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

HYDRAULIC ENGINEERING MASTER OF SCIENCE PROGRAM

ESTIMATION OF WATER LOSS IN WATER SUPPLY DISTRIBUTION NETWORK: A CASE STUDY IN GONDAR TOWN

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

BY

GEBRIE SEMAGN NIGUSSIE

NOVEMBER, 2016

JIMMA, ETHIOPIA

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NOVEMBER, 2016

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DECLARATION

I, the undersigned, declare that this thesis entitled; Estimation of Water Loss in Water Supply Distribution Network: A Case study in Gondar Town; is my original work and has not been presented for a degree in any other university, and that all sources of material used for the thesis have been fully acknowledged.

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ABSTRACT

Leakage in water network pipes is a major problem that hinders the water industry. Quantifying and characterizing water loss and leakage in a city water supply system is by its nature a complex task. Leakage identification needs detailed field investigation sometimes using sophisticated equipment. In this study, an attempt is made to evaluate both the water supply coverage and the water loss with the available primary and secondary data that was not particularly designed for this purpose. Reduction of non-revenue water is one of the major challenges facing many water industries in Ethiopia in general and particularly Gondar Town water supply utilities as well. So, the study focuses on the estimation of water loss in water supply networks in Gondar Town by using statistical analysis, Water Audit, and WaterGEMS V8i software's.

A statistical analysis was applied to analyze the current water supply coverage of the town. Water audit software was used to analyze water loss components and the efficiency of the system was evaluated using different performance indicators. WaterGEMS V8i (Select Series 6) software was also used to simulate and calibrate the distribution water supply network.

Discussions were made with local experts' to support the quantitative analysis. From the result of the analysis, it was observed that the total water loss in Gondar Town water supply system reaches up to 25.27% of the system input volume in average in the last ten years and 20.29% of the system input volume in which about 13.08% of the total system loss is real losses and 7.21% are apparent losses in the year 2015. Besides, the average daily per capita water consumption of the town is 25.53 liter/person/day.

In general, the low water supply coverage of the town was highly influenced by the availability of water. However, the main reasons for the high loss of water in the entire city water supply network system are the present way of water network maintenance and insufficient financial resources of the utility. Thus, it is necessary to identify the losses encountered in the water supply system so as to take remedial actions in reducing the water loss more significantly.

Key Words: *Gondar, Hydraulic Modeling, Pressure Zone, WaterGEMS, Water Loss, Water Loss Estimation.*

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ABBREVIATIONS

AC	Asbestos Cement
ADB	African Development Bank
ADD	Average Daily Demand
ADT	Angereb Dam Turbine
AHD	Average Hour Demand
AL	Apparent Loss
AROL	Azezo Reservoir Outlet
ATP	Angereb Treatment Plant
AV	Air Valve
AWWA	American Water Works Association
BSR	Before Sillassie Reservoir
CAD	Computer Aided Design
CP	Cotton Plant
CSA	Central Statistical Agency
CU	Commercial Use
CWP	Clear Water Pump
D	Pipe Diameter
DB	Dashen Beer
DC	Digital Camera
DCI	Ductile Cast Iron
DI	Direct Interview
DNP	Distribution Network Parameter
DPWSS	Design Period of the Water Supply System
DU	Domestic Use
DWDS	Drinking Water Distribution System
EBCS	Ethiopian Building Code Standard
ERW	Electric Resistance Welded
FCV	Flow Control Valve

FM	Flow Meter
GD	Group Discussion
GI	Galvanized Iron
GIS	Geographical Information System
GO	Governmental Organization
GoROL	Goha Reservoir Outlet
GPS	Geographical Positioning System
GROL	Gebreal Reservoir Outlet
GTWSSS	Gondar Town Water Supply Sewerage Service
GUH	Gondar University Hospital
GUMC	Gondar University Maraki Campus
H	Head Loss
HC	House Connection
HDPE	Highly Density Polyethylene
HG	Hydraulic Grade
HGL	Hydraulic Grade Line
HH	Household
HHS	Household Survey
Hr.	Hour
ICT	Information Communication Technology
IU	Industrial Use
IWA	International Water Association
J	Junction
km^2	square kilo meter
L	Pipe Length
l	liter
l/cap/day	liter per capita per day
l/day	liter per day
m^2	meter square

m^3	cubic meter
MS	Mild Steel
MSDF	Moha Soft Drinks Factory
MSDS	Minimum Size of Distribution System
MSDS	Maximum Size of Distribution System
MS-Excel	Microsoft Excel
MoWR	Ministry of Water Resource
NAP	National Academic Press
NDG	New Demand Group
NGO	Non-Governmental Organization
NRG	New Roughness Group
NRW	Non-Revenue Water
O&M	Operation and Maintenance
P	Pipe
PE	Polyethylene
PF	Public Fountain
PF	Peak Factor
PHD	Peak Hour Demand
PHF	Peak Hour Factor
PI	Performance Indicator
PMCS	Pipe Materials and Class Selection
PRV	Pressure Reducing Valve
PSI	Pound per-Square Inch
PSV	Pressure Sustaining Valve
PVC	Polyvinyl Chloride
R	Reservoir
RL	Real Loss
RS	Remote Sensing
RWS	Rate of Water Supply

SaROL	Samunaber Reservoir Outlet
SIV	System Input Volume
SR	Sillassie Reservoir
SROL	Sillassie Reservoir Outlet
StROL	Stadium Reservoir Outlet
SU	Social Use
T	Tank
TP	Treatment Plant
UARL	Unavoidable Annual Real Loss
UFW	Unaccounted For Water
UN	United Nation
UNDP	United Nations Development Program
uPVC	Unplastisized Polyvinyl Chloride
WB	Water Balance
WB	World Bank
WD	Water Distribution
WDS	Water Distribution System
WLM	Water Loss Management
WSC	Water Supply Coverage
WSS	Water Supply Service
WSSO	Water Supply Service Office
WSZ	Water Supply Zone
YCO	Yard Connection On
YCS	Yard Connection Share

CHAPTER ONE

INTRODUCTION

1.1 Background

Provision of adequate quantity of water has been a matter of concern since the beginning of civilization. Even in ancient cities, local supplies were often inadequate and aqueducts were built to convey water from distant sources. Such supply systems did not distribute water to individual residences, but rather brought it to a few central locations from which the peoples could carry it to their homes.

Until the middle of the seventeenth century, pipes which could withstand significant pressures were not available. Pipes made of wood, clay or lead was used. The development of cast iron pipe and the gradual reduction in its cost, together with the development of improved pumps driven by steam, made it possible for even small communities to provide public supplies and deliver the water to individual residences. The provision of an adequate quantity of water responded to only a part of the need since, most natural water is not suitable for consumption (Terence, 1991).

Problems in provision of adequate water supply to the rapidly growing urban population in developing countries are increasing dramatically. Moreover, reduction of non-revenue water remains one of the major challenges facing many water utilities in Ethiopia (Asmelash, 2014).

At the beginning of year 2000, one sixth of the world population was without access to potable water supply. The 2000 year coverage of water supply for the urban population of Africa and Ethiopia was 85% and 77%, respectively. On the other hand, in Africa largest Cities, only 43% inhabitants have house connection water supply services (Welday, 2005).

In Ethiopia, it has been found out that operation and maintenance of water supply facilities are poor. There is poor technical and financial capacity among the urban service providers that leads to high levels of water losses mainly through leakages (MoWR, 2000).

Leakage in water distribution pipes is a major problem faced by the water supply system. Water utilities often employ traditional audit methods to estimate water lost as leakage. As a result demand for additional water sources and infrastructure is growing. Moreover, nearly 37% of the total water production is loss at different level of distribution system before reaching to the consumer (Shimeles, 2011).

Gondar town has been through a problem of sustainable potable water supply in the past ten years. Even if the modern water supply system was installed since 1930's and has been expanding its service for some years, till the demand is not satisfied and large number of people do not have access to adequate amount of potable water. As a result residents are forced to get water from unprotected sources which are far from their homes. Besides, they also buy water frequently from illegal persons and incur additional cost (Wonduante, 2013).

According to a research conducted by Wonduante (2013), Gondar Town will be in shortage of water supply unless new infrastructure will be constructed or the current water management efficiency is improved.

Gondar Town, one of the towns of Amhara National Regional State, is suffering from the shortage of water and high water loss. Managing the existing water is therefore quite important and will find to be better than expansion of water supply infrastructures to increase the supply that synchronize with the coming high demand. Generally, the reduction of water loss can partly solve water shortage in the town.

Little is known about water loss management issues in the country in general and Gondar Town in particular. There are no studies conducted so far to take measure to improve the efficiency of water supply system of the town through controlling water loses mainly leakage.

1.2 Statement of the Problem

The world's water resources are rapidly deteriorating due to the combined effects of climate change, population growth and fast development. Hence, Water loss management is becoming even more vital. It has long been recognized that fresh water supplies are a finite resource that require careful and sound proactive strategic management (water conservation) to ensure that adequate supplies are available to meet the demands (Miya, 2008). More people mean more fresh water demand. The demands for water continue to increase, and the quality and quantity of water continues to decline. To meet increasing demand, water suppliers have relied heavily on supply management, focusing on expansion of systems which is problematic and costly as water becomes scarce; this necessitates use of water conservation practices like water loss management (Park, 2006).

Water loss or Non-Revenue Water (NRW) represents inefficiency in water delivery and measurement operations in transmission and distribution networks and, for some systems, can amount to a sizeable proportion of total water production. The water losses for a whole system or for a partial system are calculated as the difference of Systems Input Volume and Authorized Consumption. Water loss occurs on all the systems, it is only the volume that varies and it reflects the ability of a utility to manage its network.

To understand the reasons why, how and where water is being lost managers have to carry out an appraisal of the physical characteristics of the network and the current operational practice of the system. In many instances the problem of water loss is caused by poor infrastructure, bad management practice, network characteristics, operational practices, technologies, skills and social and cultural influences.

A high level of real or physical loss reduces the amount of precious water reaching customers, increases the operating costs of the utility and makes capital investments in new resource schemes larger. A high level of apparent or commercial losses reduces the principal revenue stream to the utility. Components of water loss or Non-Revenue Water (NRW) are real losses or physical losses. Real (physical) losses are; background leakage on pipes and fittings, reported and unreported bursts on pipes, and leakage and overflows from service reservoirs. Apparent losses are errors on source and production meters, Errors on customer's meters, unauthorized use (illegal connections and theft).

The factors that affect the amount of water loss are pressure in the system, frequency of bursts and their flow rates, length of time the leak runs before it is located and repaired, level of undetectable small leaks (background losses). The level of apparent losses depends upon: Utility's customer meter change policy and Utility's law enforcement policy for dealing with unauthorized use.

Based on Addis Ababa City Water Supply Authority report (2014), the total loss of water in Addis Ababa city has 54,094,795 m^3, out of the total supply to the system 120,088, 391 m^3 and the loss is estimated to be 45.04% of the total supplied to system. Asmelash (2000) estimated that the total water loss in Axum Town has 113,448 m^3 out of the total supply to the system 290,148 m^3 estimated to be 39.1% the system input volume. Although the total loss of water can be easily estimated by comparing billing on water consumption and the total water produced and distributed to the distribution system, there have been inadequate studies on identifying where and how much water is lost and what are the main causes of water loss in many towns such as Gondar Town. Thus, this study is designed to highlight on the issue of water loss in water supply systems, estimate the total water loss and indicate the main causes of water losses in the water supply distribution system in Gondar Town.

1.3 Objective

1.3.1 General Objective

The general objective of this study is estimation of water loss in the main water supply distribution networks by using a statistical analysis of water balance and a comprehensive hydraulic modeling software (WaterGEMS).

1.3.2 Specific Objectives

- To evaluate the total loss of water and coverage of the water supply distribution system.
- To identify the main causes of water losses, and its impact.
- To investigate the pressure distribution system with modeling.

1.4 Research Questions

The objectives of the study would be achieved by way of seeking answers to the following questions.

Table 1.1 Research questions corresponding with specific objectives

Specific Objectives	Research Questions
❖ To evaluate the total loss of water and coverage of the water supply distribution system.	How much water is produced and distributed to the network system?
❖ To identify the main causes of water losses, and its impact.	What will be the main causes, and impacts of water losses? What are the possible solutions to reduce the water loss?
❖ To investigate the pressure distribution system with modeling.	How to analyze the distribution system with modeling?

1.5 Significance of the Study

The results of this study was used to indicate implications for water loss control in urban water supply management and strategy. The study can also fill the existing research gap and help to plan or replicate the findings for sustainable development of urban water supply in other towns of the Region and the country in general. Therefore, it is necessary to estimate the water loss situation and its management strategy in the water supply distribution system of Gondar Town to create effective and efficient water supply distribution system management.

1.6 Scope and Limitation of the Study

1.6.1 Scope

The study was done in Gondar Town to estimate the water loss in the main water supply distribution network which has a serious problem of water accessibility. The sources of water for the town are surface water and ground water; but this study was not including evaporation loss for surface water, it was applied only on water losses from water supply distribution network. Also, the study was not covering all the areas of the town; it was applied on the main water supply distribution systems of the town.

1.6.2 Limitation

Quantifying water loss and leakage in the town water supply system is by its nature a complex task. Leakage identification needs detailed field investigation using sophisticated equipment like; sounding, detailed survey, acoustic noise logging, laser beam, ultra-red, detections by chemicals, etc. But, in this study; an attempt was made to evaluate the water supply coverage, the water loss analysis and the water loss control with available primary and secondary sources of data.

There are very little data giving complete, accurate and systematic information about the evaluation and measurement of the water loss management. There are some contradictions in the data and information from different sources. The fact is that multiple uncertainties would affect the accuracy of water demand and supply figures.

CHAPTER TWO

LITERATURE REVIEW

2.1 General Concept of Water Supply Distribution System

Water demand is defined as the volume of water quested by users to satisfy their needs. In a simplified way it is often considered equal to water consumption, although conceptually the two terms do not have the same meaning (Wallingford, 2003). Urban water demand is usually quoted in terms of liter per capita per day (l/cap/day) (Mwendera *et al*., 2003).

Water distribution systems (WDS) are generally designed for a predicated time span called design period. It varies from 20 to 40 years, whereas the working life of pipelines varies from 60 to 120 years. It has been found that the pipelines laid more than 100 years ago are still in operation. Generally, 75% to 80% of pipe construction work pertains to reorganization of the existing system and only 20% to 25% constitutes new water supply system.

In general, WDS can be divided into four main components: (1) water sources and intake works, (2) treatment works and storage, (3) transmission mains, and (4) distribution network (Prabhata and Ashok, 2008).

2.2 Population Forecasting

Design of water supply and sanitation scheme is based on the projected population of a particular city, estimated for the design period. Any underestimated value will make system inadequate for the purpose intended; similarly overestimated value will make it costly.

The present and past population record for the city can be obtained from the census population records. After collecting these population figures, the population at the end of design period is predicted using various methods as suitable for that city considering the growth pattern followed by the city. Some of these methods are: (1) Arithmetical Increase Method, (2) Geometrical Increase Method, (3) Incremental Increase Method, (4) Graphical Method, (5) Comparative Graphical Method, (6) Master Plan Method, (7) Logistic Curve Method (Huien, 1994).

2.3 Water Losses in Distribution System

2.3.1 Water Loss and Leakage

Regardless of the magnitude that greatly varies from city to city or from one area to another, water loss is a problem experienced in all water distribution systems. The first and foremost cause of water loss is leakage. Water put to inappropriate or excessive uses may also be considered as loss (Welday, 2005).

2.3.2 Types of Water Losses in Drinking Water

Two broad types of losses occur in drinking water utilities:

Apparent Losses consist of Unauthorized Consumption (theft and illegal use) and Metering Errors. Calculations of these volumes are preferably based on structured sampling tests, or estimated by a robust local procedure (which should be defined for audit purposes).

Real losses are the physical losses of water from the distribution system, including leakage and storage overflows (Lambert, 2002). Unavoidable Annual Real Losses (UARL): It is impossible to eliminate all real losses from a distribution system: some losses are unavoidable; some leakages are believed to be undetectable (too small to detect) or uneconomical to repair.

2.4 Comparing Water Losses

The amount of water loss differs from country to country, city-to-city and even from one network to another network within one city. Different countries use different indicators to evaluate their status in comparison with other and to compare the distribution system in order to take action based on the level of losses. As stated above comparison using unaccounted for water (UFW) expressed as a percentage has limitation when used for comparison as it highly depends on the volume of the water produced. The performance indicators of water losses are frequently expressed as a percentage of input volume. However, this indicator fails to take account of any of the main local influences. Consequently, it cannot be considered to be an appropriate performance indicator (PI) for comparisons (WHO, 2001). Depending upon the consumption per service connection, the same volume of real losses/services connection/day, in percentage terms, is anything from 44% to 2.4%. Thus countries with relatively low consumption like the developing countries can appear to have high losses when expressed in percentage terms in contrast percentage losses for urban areas in developed countries with high consumption can be equally misleading (Farley and Trow, 2003). To avoid for the wide diversity of formats and definitions related to water loss, many practitioners have identified an urgent need for a common international terminology that among them task forces from the international water association (IWA) recently produced a standard approach for water balance calculation with a definition of all terms involved as indicated in table 2.1 below.

Table 2.1 IWA standard international water balance and terminology

<table>
<tr><td rowspan="8">System Input Volume</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="6">Non-Revenue Water</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="4">Water Losses</td><td rowspan="2">Apparent Losses</td><td>Customer Metering Inaccuracies Systematic Data Handling Errors</td></tr>
<tr><td>Leakage on Transmission and/or Distribution Mains</td></tr>
<tr><td rowspan="2">Real Losses</td><td>Leakage and Overflows at Utility's Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections</td></tr>
</table>

According to IWA the above abbreviated terminologies are defined as below:

- System input volume is the annual volume input to that part of the water supply system.
- Authorized consumption is the annual volume of metered or non-metered water taken by registered customers, the water supplier and other who are explicitly or implicitly authorized to do so. It includes water exported, and leaks and overflows after the point of customer metering.
- Non-revenue water (NRW) is the difference between system input volumes and billed authorized consumption.
- Water losses are the difference between systems in put volume and authorize consumption, and consist of apparent losses and real losses.
- Apparent losses consist of unauthorized consumption and all types of metering inaccuracies.
- Real losses are the annual volume lost through all types of leaks, bursts and over flows on mains service reservoirs and service connection up to the point customer metering.

2.4.1 Factors Causing Loss of Hydraulic Integrity

Factors causing a loss of system hydraulic integrity include (1) pipe leaks and breaks, (2) rapid changes in pressure and flow conditions, (3) planned or poor maintenance networks and emergencies, (4) tuberculation and scale formation in pipes, (5) improper operational control, (6) age of pipe network, and (7) lack of proper design (8) illegal connections (NAP, 2006).

2.4.2 Consequences of Water Losses

The primary consequence of leaks in a distribution system is financial. Reduction in water loss enables water utilities to use existing facilities efficiently, alleviate shortage of water supply. Beside to directly affected production and management costs, leaks have great consequence on the quality of services (Kartiki and Madelyn, 2015).

2.4.3 Water Loss Management

This work represents a major step to define the best practice approach for assessing and presenting basic elements of water loss management program in Gondar city, and it was focused on international water loss approach to promote and facilitate the application of International Water Association (IWA) recommended methodology of leakage monitoring and pressure management system.

2.5 Essential Parameters for Pipe Network Sizing

The selection of the design period of a water supply system, projection of water demand, per capita rate of water consumption, design peak factors, minimum prescribed pressure head in distribution system, maximum allowable pressure head, minimum and maximum pipe sizes, and reliability considerations are some of the important parameters required to be selected before designing any water system. A brief description of these parameters is provided in this section (Prabhata and Ashok, 2008).

2.6 Quantity of Water

When design a water supply scheme for communities first evaluate the amount of water demanded by the community. In fact the first study is to consider the demand and then to find out sources to fulfill this demand. Usually a compromise is sought between the two. Demand data for two basic reasons: to manage existing systems and to plan new works to meet future demand (Shimelis and Tamirat, 2012).

2.7 Water Audits

An audit has been defined as an examination of records or financial accounts to check their accuracy. The water audit typically traces the flow of water from the site of water withdrawal or treatment, through the water distribution system, and into customer properties (AWWA, 2012).

Flow measurements taken in the distribution network give more precise estimates of leakage rates. A portion of the network is isolated using valves and measurements of flows entering the isolated portion of the network are taken for at least a period of 24 hours. Mass conservation principle is applied to that part of the network to estimate the average amount of leakage rate. However, such methods give only an approximate estimate of leakage rates (Thornton, 2003).

2.8 Water Loss Monitoring and Control

Reducing water loss in a water supply system remains one of the major challenging tasks in many water utilities of developing countries. The ultimate goal of the water loss reduction plan is to reduce the level of losses to a point where the “acceptable level” or “economic level of losses” is reached and maintained.

Experience in many water loss reduction programs has shown that the following indicators are realistic guidelines for water loss in water supply systems with per capita consumption of less than 150 l/day (Saroj, 2008); Good condition of system (<250 liter/connection/day and <10, 000 liter/km main/day), Average condition (250 - 450 liter/connect/day and 10, 000 – 18, 000 liters/km main/day) and Bad condition of system (> 450 liters/connection/day and >18,000 liters/km main/day).

2.9 Water Distribution Network Model Setup

The approach to building the model is to first sketch out the system practically on existing topographic maps. The concept of a network is fundamental to a water distribution model. The network contains all of the various components of the system, and defines how those elements are interconnected. Networks are comprised of nodes, which represent features at specific locations within the system, and links, which define relationships between nodes.

Water distribution models have many types of nodal elements, including junction nodes where pipes connect, storage tank and reservoir nodes, pump nodes, and control valve nodes. Models use link elements to describe the pipes connecting these nodes. In addition, elements such as valves and pumps are sometimes classified as links rather than nodes. Intelligent use of element labeling can make it much easier for users to query tabular displays of model data with filtering and sorting commands. Rather than starting pipe labeling at a random node, it is best to start from the water source and number outward along each pipeline. In addition, just as pipe elements were not laid randomly, a pipe-labeling scheme should be developed to reflect that.

2.9.1 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. Two basic equations that govern in WaterGEMS modeling network of these interconnections (Bentley Water CAD/GEMs, 2008).

- Conservation of mass
- Conservation of energy

2.9.1.1 Conservation of Mass

For steady incompressible flow:

Net flow into junction = Use at junction; Mass in = Mass out

$$\sum Q_{IN} \Delta t = \sum \left(Q_{OUT} \Delta t + \Delta V_S \right) \qquad (2.1)$$

Where: Q_{IN} = Total flow into the node (m^3/s)

Q_{OUT} = Total demand at the node (m^3/s)

ΔVs = Change in storage volume (m^3)

Δt = Change in time (s)

2.9.1.2 Conservation of Energy

The Energy equation is known as Bernoulli's equation (Daugherty.R.L, 1989). It consists of the pressure head, elevation head, and velocity head. There may be also energy added to the system (such as by a pump), and energy removed from the system (due to friction). The changes in energy are referred to as head gains and head losses (Shaher, H., 2003).

In hydraulics, energy is converted to energy per unit weight of water, reported in length units called "head". Balancing the energy across any two points in system, the energy equation will be as follow: Figure 2.1 shows head losses in a pipe line.

$$\frac{P_1}{\gamma} + Z_1 + \frac{V_1^2}{2g} = \frac{P_2}{\gamma} + Z_2 + \frac{V_2^2}{2g} + h_L \qquad (2.2)$$

Where P = the pressure (N/m^2), γ = the specific weight of the fluid (N/m^3), Z = the elevation at the centroid (m), V = the fluid velocity (m/s), g = gravitational acceleration (m/s^2), h_L = the combined head loss (m)

The energy at any point within a hydraulic system is often represented in three parts:

- Pressure Head=P/γ
- Elevation Head=Z
- Velocity Head=$V^2/2g$

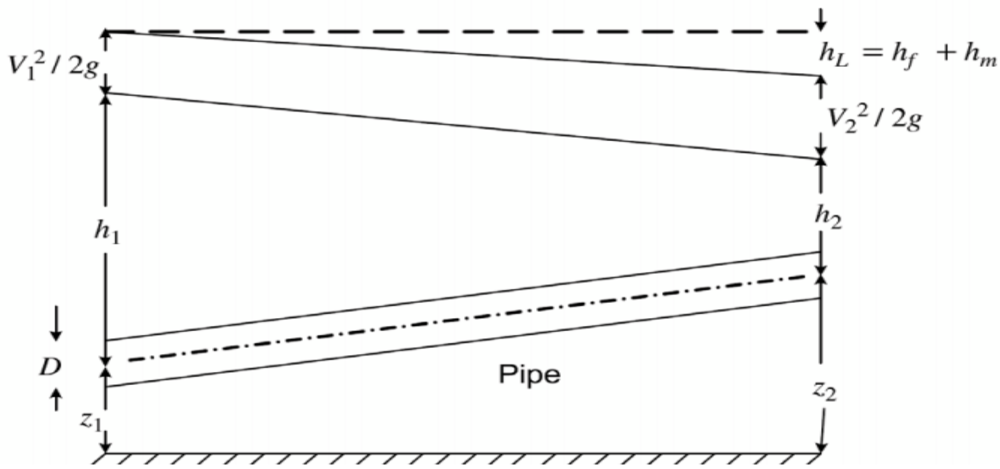

Figure 2.1 Forms of energy in pipes

Source: (Bentley Water CAD/GEMs, 2008)

2.9.2 Water Flow Resistance (Head Loss)

The total water loss in a distribution pipe and pipe fittings between two points of consideration is called head loss. There two types of head losses; surface resistance and form resistance.

2.9.2.1 Surface Resistance

Head loss on the account of surface resistance, Surface resistance is categorized as major loss. Friction loss depends on pipe length, coefficient of surface resistance, and friction factor

2.9.2.2 Form Resistance

The form-resistance losses are due to bends, elbows, valves, enlargers, reducers, and so forth categorized as minor loss.

2.9.3 Head Loss Equations

Energy loss resulting from friction in a pipeline is commonly termed the friction head loss (h_f). This is the loss of head caused by pipe wall friction and the viscous dissipation in flowing water. For head loss calculation see table 2.2.

Table 2.2 Head loss equations and their application area

Equation	Formula	Remark
Maning's	$v = \frac{1}{n} R^{2/3} S^{1/2}$	This equation is commonly used for open channel flow
Chezy's (Kutter's)	$v = C\sqrt{RS}$	Widely used in sanitary sewer design and analysis
Hazen-Williams	$v = 0.85 C R^{0.63} S^{0.54}$	Commonly used in the design and analysis of pressure pipe system
Darcy-Weisbach	$v = \sqrt{\frac{8g}{f} RS}$	Can be used for pressurized pipe systems and open channel flows

Where, f = friction factor, v = mean velocity (m/s), g = acceleration due to gravity (m/s^2), R=hydraulic radius (m), S=head loss per unit length of pipe, C=Coefficient, n=Manning's roughness coefficient, C=Chezy coefficient (Prabhata, K. & Ashok, K., 2008).

2.9.4 Water Distribution Modeling

2.9.4.1 WaterGEMS V8i

WaterGEMS is a powerful, easy-to-use, which is:

- A water distribution modeling software;
- Used in the modeling and analysis of water distribution systems;
- Used for firefighting flow and constituent concentration analyses, energy consumption and capital cost management; and popular for water supply design.

WaterGEMS provides sensitive access tool needed to model complex hydraulic situations. Some of the key features allow us to;

- Perform steady state and extended period simulations.
- Analyze multiple time-variable demands at any junction node.
- Quickly identify operating inefficiencies in the system.
- Perform hydraulically equivalent network skeletonization including data scrubbing, branch trimming, and series and parallel pipe removal and efficiently manage large data sets and different "what if" situations with database query and edit tools.

2.9.4.2 Water Distribution Simulation

Simulation refers to the process of imitating the behavior of one system through the functions of another. In our case, the term simulation refers to the process of using a mathematical representation of 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).

2.9.4.1.1 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.

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.

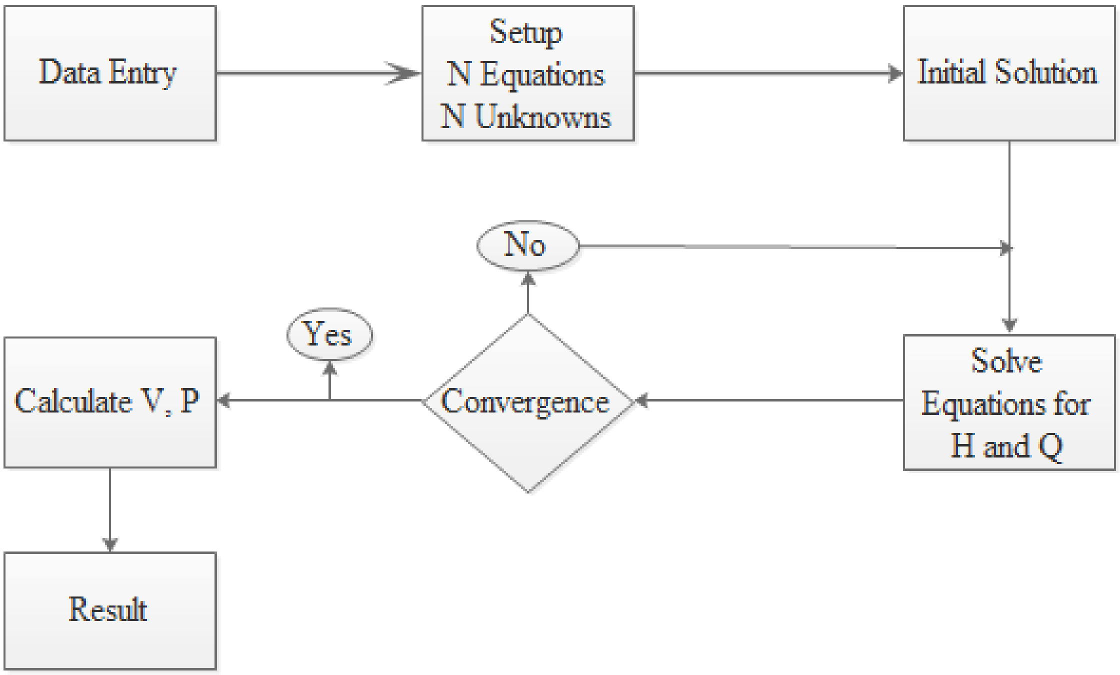

Figure 2.2 Flow chart for steady state simulation (Bentley Water CAD/GEMs, 2008)

2.9.4.1.2 Extended Period Simulation

Extended period simulation tracks a system over time, and it is a serious of linked steady state run/analysis. 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

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.

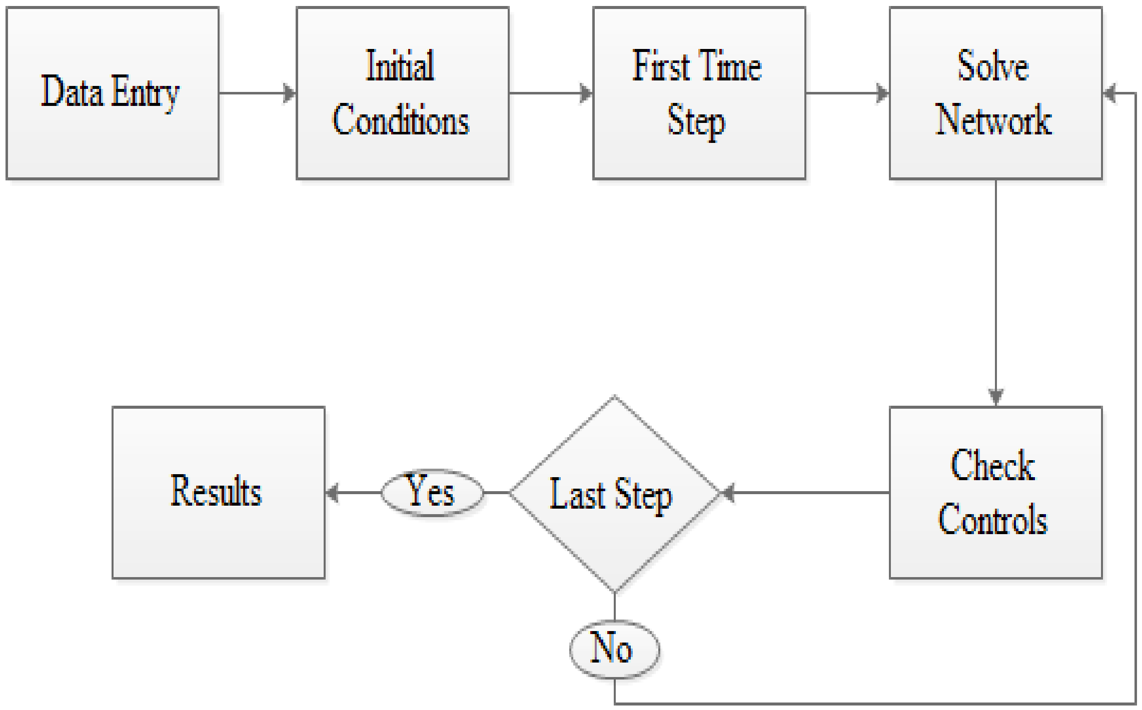

Figure 2.3 Flow chart for extended period simulation (Bentley Water CAD/GEMs, 2008)

2.10 Comparison of WaterGEMS with other Software's

The main reason that WaterGEMS is chosen than other hydraulic software's like Epanet, WaterCAD (Stand-alone), and WaterCAD (Bentley) is shown in table 4.15 below.

Table 2.3 Comparison of WaterGEMS with other Hydraulic Software's

A. Ease of Use	EPANET	WaterCAD	WaterGEMS
Model Layout/Data Entry	Limited	Available	Available
Graphs	Limited	Available	Available
Tabular Reports	Limited	Available	Available
Profiles	Limited	Available	Available
Contours	Limited	Available	Available
Element Symbology	Limited	Available	Available
Pressure Zone Manager	Not Available	Available	Available
Network Navigator	Not Available	Available	Available
Export to Google Earth	Not Available	Limited *	Available **
* Available in the MicroStation Platform Only			
** Available in Microstation and ArcGIS Platform			
Availabe / Limited / Not Available			

B. Modeling Element	EPANET	WaterCAD	WaterGEMS
Reservoir	Available	Available	Available
Tank	Available	Available	Available
Junction	Available	Available	Available
Pipe	Available	Available	Available
PRV, PSV, PBV, FCV, TCV, GPV	Available	Available	Available
Air Valves at High Points	Not Available	Available	Available
Hydropneumatic Tanks	Not Available	Available	Available
Isolation Valves	Not Available	Available	Available
Hydrants	Not Available	Available	Available
Variable Speed Pump	Limited	Available	Available
Variable Speed Pump/Battery	Not Available	Available	Available
Availabe / Limited / Not Available			

C. CAD, GIS Interporability	EPANET	WaterCAD	WaterGEMS
Database Import/Export	Not Available	Available	Available
Convert CAD to Pipes	Not Available	Available	Available
Shape File Import/Export	Not Available	Available	Available
Runs Inside of ArcGIS	Not Available	Not Available	Available
Runs Inside of AutoCAD	Not Available	Available *	Available
Runs Inside of MicroStation	Not Available	Available	Available
Background CAD, Shape files, .jpg	Not Available	Available	Available
Excel Emport/Export	Not Available	Available	Available
Oracle, SQL Import/Export	Not Available	Available	Available
Import/Export EPANET Files	Available	Available	Available
* Available at an Additional Cost			
Availabe / Limited / Not Available			

D. Model Building Tools	EPANET	WaterCAD	WaterGEMS
Demand Allocation Using Meter Data	Not Available	Available	Available
Demand Allocation Using Population	Not Available	Available	Available
Demand Allocation by Land use or Area	Not Available	Available	Available
Includes Average Demand Libraries?	Not Available	Available	Available
Includes Material Libraries?	Not Available	Available	Available
Terrain Elevation Extractor	Not Available	Available	Available
SCADA Connection	Not Available	Available	Available
Network Skeletonization	Not Available	Available	Available
User Defined Attributes	Not Available	Available	Available
Associate External Files/Photos, Videos, etc./	Not Available	Available	Available

Availabe Limited Not Available

E. Advanced Hydraulic Features	EPANET	WaterCAD	WaterGEMS
Scenario Management	Not Available	Available	Available
Autometed Fire flow Analysis	Not Available	Available	Available
Model Calibration/Genetic Algorithms/	Not Available	Available	Available
Pump Scheduling	Not Available	Available	Available
Autometed Design and Rehabilitation	Not Available	Available	Available
Criticality Analysis and Flushing Studies	Not Available	Available	Available
Source Tracking	Not Available	Available	Available
Leakage Detection	Not Available	Available *	Available
Pressure Dependent Demands	Not Available	Available	Available
Pipe Renewal Planner/Asset Management/	Not Available	Available *	Available
Water Hammer Modeling	Not Available	Available **	Available **

* Available WaterCAD as an Add-On

** Use Same WaterCAD/GEMS File in Bentley HAMMER ®

Availabe Limited Not Available

F. Training and Technical Support	EPANET	WaterCAD	WaterGEMS
Technical Support	Not Available	Available	Available
Virtual Instructor-led Training	Not Available	Available	Available
Virtual On-Demand Training	Not Available	Available	Available
Local Classroom Training	Not Available	Available	Available
Internet Forums	Limited	Available	Available
Online Knoledgebase	Not Available	Available	Available
Modeling Books, Text Books	Not Available	Available	Available

Availabe Limited Not Available

Source: Bentley WaterCAD (2008), Model Analysis (2016)

Table 4.15 indicates that WaterGEMS incorporates many tools, components, and new features as compared to other software's. So for better design of water supply system WaterGEMS is better than the other hydraulic software's.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location of the Study Area

Gondar Town, former capital of North-Western Ethiopia during the reign of Emperor Fasilidas (1632-1667), is located in the northwestern part of Ethiopia at a distance of 737 km from Addis Ababa, the national capital, 180 km north of Bahir Dar, the regional capital, and 250 km from Gedarif, the Sudanese border town. The city has a latitude and longitude of 12°35’ N and 37°27′E respectively. The town is linked to a neighboring country Sudan via Metema and as a result expected as a promising center for transit of goods and services with Sudan. The total coverage area of the town is approximately 51.27 square kilometers. The town is endowed with many historical sites registered by UNESCO at international level and it provides good stimulus to the economy by attracting tourists to the area.

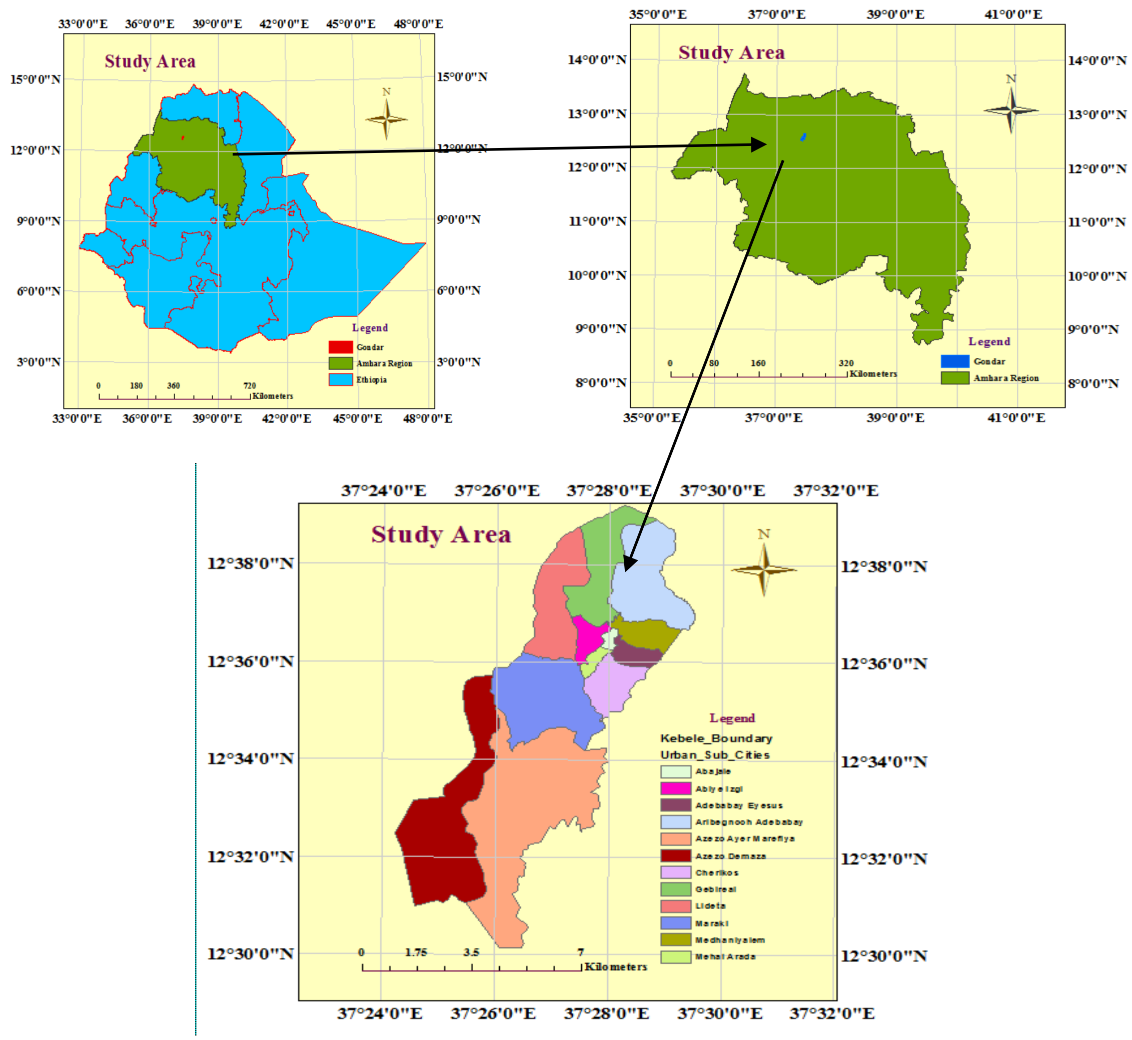

Figure 3.1 Location of the Study Area (Source: Ethio Arc-GIS)

3.1.2 Population Characteristics

According to the 2007 National Census Report, which was compiled in the year 2008 the total population of the Town is 206,987 (CSA, 2008) and the average annual growth rate is 4.69%. The total population of the town in 2015 is 296,937; the 2007 CSA report has been taken as base line for this projection. The town is divided in to twenty administrative units named as kebeles and the current (newly) administrative divided the town in to twelve units named as sub-city.

3.1.3 Climate

Rainfall of Gondar is characterized as mono-modal type. The annual rainfall varies from 711.8 to 1822.42 mm with a mean annual value of 1200mm. Long-term distribution of rainfall data indicates that most of the rain occurs in July followed by August. The rainfall in May and June is also quite significant. The mean annual temperature in Gondar Town varies between 16˚C and 20˚C which makes it in Weina Dega zone. Maximum temperature occurs in March and April and minimum temperatures are at their lowest in November to February (GTWSSS, 2014).

3.1.4 Hydrology

There are several small streams and springs originating from the mountainous topography and they feed Angereb River that finally joins Megech River. Some of the major tributaries of Angereb are Korebreb, Keybahir, Embuaymesk, Ingodo, Abamatebo, Arbagirifa, Debteramesk, and Kokoch. The Megech watershed upstream of the dam site is characterized as a steep mountainous watershed with circular shape. During the rainy months, Megech River flow has high velocity and the sediments transported by the floods are mainly boulders, gravel, sand and silt. This is a typical behavior of a mountainous river such as the Megech River. During the dry season, flows frequently disappear into the permeable streambed gravels. Generally the major streams maintain a small flow throughout the dry season.

3.1.5 Hydrogeology

Volcanic and alluvial aquifers exist in Gondar and Azezo areas. Gondar area is characterized with basalts which are black and massive, greenish-brown vascular basalts and scoria. The scoriaceous aquifers are found inter-bedded with basalts in Angereb well-field. The fractured and/or weathered basaltic aquifers are the predominant sources and reservoirs of ground water in the area. The alluvial formation mainly clays and boulders are the other but minor ground water potential of the area. A hydrological and geophysical investigation was carried out in 1998 by Geo-Engineering Service to identify potential ground water fields in Azezo and Gondar area. The areas covered in the study were West Azezo area, Shinta-Demaza and Angereb valley. The study concluded that Shinta- Demaza could not be used as a well field to supply water for Gondar. West Azezo could be developed as a well field. The area covers about 15km^2 with an estimated recharge amount of 1.1 million m^3 per year. The chemical content of the water is also acceptable. Angereb valley was also identified as a water potential area that could be used as well field for Gondar. Previous studies indicated that high nitrate content were recorded which might have caused from the surface or ground water pollution of the town.

3.1.6 Topography

The town of Gondar is situated on a mountainous land at an average elevation of 2116.5m a.m.s.l. Development has taken place between elevations 1964m and 2269m. The topography of the town is characterized as fairly mature with rounded hills and gentle slopes. There are two rivers running across the boundaries of the town: Angereb River and Keha River, and the main parts of the town are located on the ridge between the two rivers. The topography of the town facing Angereb River is steeper than the slope facing Keha River and as result most of the population of the town is concentrated on the slope facing the Keha River. The topography of the majority of the town that includes the airport and Azezo is also gentle slope (Teshager, 2001).

3.1.7 Soils

Silty clay and silty clay loam are the characteristics of soils in Gondar Town. The soils of Azezo area is generally considered as black clay. The depth of soil in the area generally ranges from 20 cm to 70 cm. The soils have brown color on the sloppy areas and dark to gray color on the flatter parts of the town (GTWSSS, 2014).

3.2 The Research Process

The water supply coverage of the city was first evaluated before analyzing the water loss, in evaluating the water supply coverage the focus was on the volume of consumption and level of water connection as these are highly related to the issue of water loss. After evaluating the distribution of water coverage in the town the total water loss was analyzed. The total water produced and actual water consumption as aggregated from the individual customer meters was used as an input for the analysis. After evaluating the total water losses, the possible causes of water losses were tried to be identified. And then the existing water supply distribution system had been modelled and evaluated by using WaterGEMS.

3.3 Study Materials

The study was conducted on estimation of water loss in the main water supply distribution network. To achieve the goal of the research study materials were used to review applicable practices, research findings, information on impact and cause of water loss in water distribution system, and its possible remedies. The materials that were used for this study were;

- Ultrasonic flow meter
- Pressure gauge
- Mechanical flow meter (installed)
- Software: Water-CAD, GIS 10.1 were used for distribution modelling
- Analysis software's: Origin Pro 8, Water Audit, MS-Excel
- GPS (Geographical Positioning System) GARMIN 72

3.4 Data Collection Techniques

The instrument used to gather the required information includes questionnaire, interview and field observation.

3.4.1 Questionnaire

To get additional information, questionnaires were distributed for customers and officials of the water utilities.

Primary data related to the level of consumer satisfaction for the service provided, physical condition of water supply points under study, willingness of beneficiaries to sustain the system, repair and maintenance for the water supply services, technical and institutional issues, causes of water loss were collected through questionnaires (See Appendix-O).

3.4.2 Field Observation

It was mainly employed to gather data related to the presence of pipe lines in selected households, to check the presence of water at any time, the areal coverage of water pipe lines and the factors behind some varieties like location and altitude. It was carried out through the help of checklists according to the objectives of the study.

3.4.3 Interviews

Key informant interview was conducted with the town's residents from different offices, like Kebele leaders, with persons of different responsibilities, knowledge and experience about the town's water coverage, the balance between demand and supply of water in the town, major challenges facing in the provision of the service, level of community awareness and participation in the provision of the service.

These key informants were purposively selected from different offices assuming that they have deep and relevant information from their official responsibilities and continue involvement about the issues.

3.5 Sample Size and Sampling Technique

One of the central objective of this thesis was estimation of water loss and assess the water supply coverage of Gondar Town; to this end to get the representative population and the necessary information accordingly, this research used systematic random sampling techniques to select household respondents, officials and stakeholders.

To carry out the study, two sub-cities has been selected out of twelve sub-cities in the study area based on the new administrative division system (refer Appendix-B).

The sample sub-cities are Maraki (kebele 18) and Abajale. These two sub-cities selected to participate in this study differ in various ways, including population size, living standard, socio-economic status (both good and bad) of households, topography of the area, and water sources.

In general the study covered only 150 households from a total of 8,652 households of the selected sub-cities and in each sub-city every 50th households were selected for the study. According to the information obtained from Ministry of Water, Irrigation and Energy (MoWIE), the study area faces severe challenges on water supply schemes. As to the sample size determination, from among different methods, the one which has been developed by Carvalho (1984), as cited by Wonduante (2013), was used (see table 3.1).

Table 3.1 Sample size determination (Carvalho, 1984 and Wonduante, 2013)

Population Size (Household Size)	Sample Size		
	Low	Medium	High
51-90	5	13	20
91-150	8	20	32
151-280	13	32	50
281-500	20	50	80
501-1200	32	80	125
1201-3200	50	125	200
3201-10000	80	200	315
10001-35000	125	315	500
35001-150000	200	500	800

3.6 Sources of Data Collection

According to the work plan indicated in the proposal primary and secondary data were collected from the town water supply service and at the land in-situ (field) testing was carried out. Some supplementary information was also collected from other respective offices; supportive qualitative information through discussion with local experts of water supply service was also carried out.

3.6.1 Primary Data Sources

3.6.1.1 Hydraulic Flow Measurement

With this site observation flow measuring systems have been applied to get firsthand information on the system. The main assignment started with flow measurement work starting from city main water source areas, distribution systems and reservoirs.

The above flow measurement work has been done with the help of highly sensitive Ultrasonic flow measurement apparatus attached externally to the targeted pipe wall. It is highly sensitive instrument to detect all ranges of flow measurement in relatively better condition than the existing Gondar Town distribution and customer meter of typically mechanical type.

Figure 3.2 Photo during flow measurement by Ultrasonic and Mechanical flow meter

Figure 3.2 shows that flow measurement during field visit at Goha reservoir; the left one is the Ultrasonic flow meter and the right one is the installed mechanical flow meter. This practical measurement work has sensitized the strengthening of this unit both technically and structurally means enabling to avail a significant of water to the distribution system to relief some of the needy. The city water demand cannot only be met with new water source development work but also with justification of wise use of the already developed system through non-revenue water (NRW) reduction work.

Practical skill transfer work has been done while working on the site with Gondar Town water supply utility technicians during this assessment work from the source up to the reservoir/tank. The measured data's are shown in Appendix-D.

3.6.1.2 Pressure Measurement

Pressure measurement throughout the entire day was conducted at different zones in the distribution system. At location where pressure gauges were installed, elevation readings were also taken. Critical times were selected while pressure gauges were taken. These critical times were fixed based on the demand rate of the users which covers the time between 8:00-12:00 (early mid noon) 2:00-6:00 (afternoon) 8:00-12:00 (early mid night) and 2:00-4:00 (early morning) (Lambert, 2003). Figure 3.3 below shows location of sample pressure nodes field-test on the distribution network.

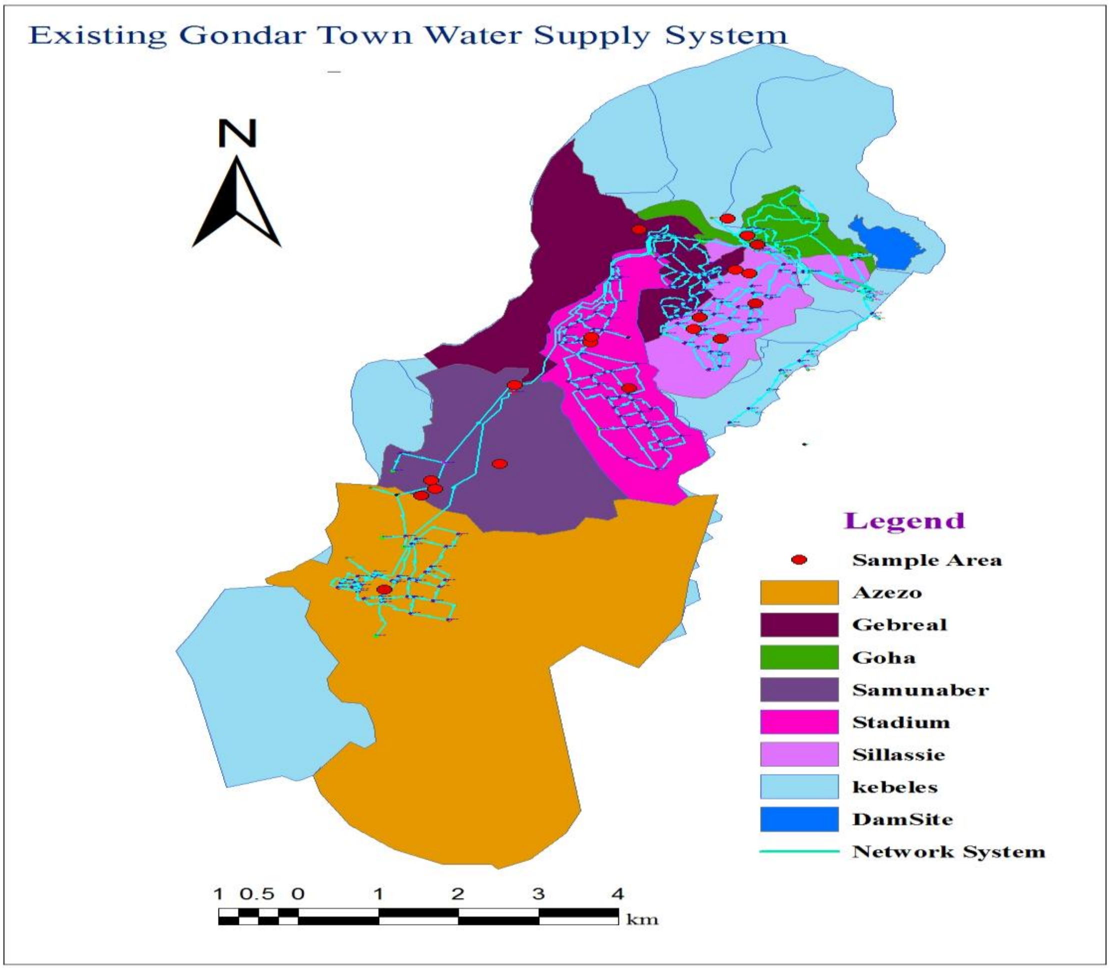

Figure 3.3 Locations of sampling sites in distribution system

As shown in figure 3.3 field investigation was done to identify the existing situation of the study area and based on preliminary survey eighteen sampling sites were selected to determine the average operating pressure for the calculation of unavoidable annual real loss, and the distribution system of each zone is vital for model calibration. These sample points have been selected based on low, medium and high elevation under each pressure zone.

Table 3.2 Pressure reading value in selected zones in the distribution system

S.N	Sample Area	Elevation (m)	Pressure Day Average		Pressure Night Average		Distribution Zone Elevation (m)	
			mH_2O	bar	mH_2O	bar		
1	J-8	2222	12	1.2	24.1	2.41	Sillase	2298
	J-40	2158	30	3	41.6	4.16		
	J-41	2100	50	5	60.6	6.06		
2	J-42	2269	5	0.5	14.5	1.45	Goha	2301
	J-50	2220	30	3	37.5	3.75		
	J-60	2132	50	5	59.9	5.99		
3	J-64	2099	30	3	41	4.1	Gebreal	2170
	J-68	2089	50	5	63.9	6.39		
	J-67	2069	60	6	71.5	7.15		
4	J-92	2114	10	1	20.6	2.06	Stadium	2144
	J-106	2082	40	4	48.8	4.88		
	J-144	2015	50	5	61.2	6.12		
5	J-131	2039	10	1	24	2.4	Samunaber	2048
	J-146	2020	25	2.5	34.5	3.45		
	J-136	1993	40	4	49.8	4.98		
6	J-183	2012	37.5	3.75	47.7	4.77	Azezo	2047
	J-152	1997	50	5	61.3	6.13		
	J-183	1964	17	17	183.2	18.3		
Average Pressure			33.14	4.2	52.54	5.25		
			42.84 mH_2O		4.28 bar			

3.6.1.3 Missed Data Filling

The water supply utilities of Gondar has no full data; especially GPS locations of different places like reservoirs, tanks, pumps and some nodes had no easting, northing, and elevation data. So, to solve this problems field observation was conducted and the necessary data were collected by using GPS Garmin 72 (Appendix-C).

3.6.2 Secondary Data Sources

Secondary data were collected from GTWSSS documents, journals, dissertations, newspapers, reports, internet, as well as institutions related to drinking water and sanitation like UNDP, UN, WB, ADB, and different NGOs and GOs.

3.6.2.1 Water Supply Networks of the City

The existing water supply network of the system including their attribute like the length, diameter, material types, pressure capacity of the pipes, pump characteristics, reservoir and tank section has been collected from the town water supply service office. The collected pipe network mainly comprises of main pipes and secondary pipes that covers the major part of the town (hard copy). The length of the entire network was summed up according to their diameter of further determination of unavoidable annual real loss.

3.6.2.2 Town Water Reservoirs

Gondar Town water supply system, has six service reservoirs/tanks, one booster stations, clear water reservoir, and backwash reservoir. The subsystem service reservoirs are described in table 3.3.

Table 3.3 Gondar Town service reservoirs/tanks description (GTWSSS, 2015)

S.N	Reservoir Name	Easting (m)	Northing (m)	Elevation (m)	Construction Material	Volume (m^3)
1	Azezo	329074.40	1388549.44	2119	RC	1000
2	DB Sillassie	334834.61	1394473.15	2278	RC	2000
3	FB(Booster)	333841.00	1395079.00	2248	RC	300
4	Gebreal	332976.89	1395105.40	2230	RC	1000
5	Goha	333677.75	1395499.09	2301	Masonry	300
6	Samuna Ber	330772.37	1392380.27	2199	RC	500
7	Stadium	332683.40	1395361.61	2170	RC	500
8	Clear Water	335281.41	1394174.20	2130	RC	1000
9	Back Wash	335215.24	1394225.69	2137	RC	100

3.6.2.3 Main Sources of Water for the System

The system is supplied from springs, surface water (Angereb) reservoir, and ground water wells. The existing Water Supply System was examined in close co-operation with the representatives of Gondar Town water supply service regarding the fields of water production, treatment, transmission, and storage and water distribution network. Table 3.4 shows the main sources of the system and their daily/yearly planned water production up to the end of 2015 year (GTWSSS, 2015).

Table 3.4 Daily planned Gondar Town water supply system productions

S.N		Source Name	Discharge (l/s)	Working Time (Hr.)	Water Production (m^3/day)	Cuurent Status
1	Spring					
	1.1	Dokemit	0.98	24	84.67	F
	1.2	Felefelit	0.74	24	63.94	F
	1.3	Sanita-1	0.45	24	38.88	F
	1.4	Sanita-2	0.87	24	75.17	F
2	Surface Water					
	2.1	Angereb TP	90	24	7,776	F
3	Ground Water					
	3.1	NW-1	5.26	10	189.36	F
	3.2	NW-2	2.56	8	73.73	F
	3.3	NW-3	7.00	10	252.00	F
	3.4	NW-4	4.50	10	162.00	F
	3.5	NW-5	18.00	8	518.40	F
	3.6	TW-5	3.00	8	86.40	F
	3.7	TW-6	4.00	8	115.20	F
	3.8	GTW-7	20.00	10	720.00	F
	3.9	Sanita-3	2.05	_	_	NF
Total					10,155.74	F=Functional NF=Non-Functional
Total Water Production				m^3/day	10,155.74	
				m^3/year	3,706,846.56	

3.6.2.4 Water Consumption

In order to evaluate the water loss in the distribution system, consumption data of each customer were collected from the computerized bill information report (2006-2015). There are 26,336 active customers within the entire town in the year 2015. Water consumption in this context is metered, billed and unbilled authorized consumption. While the consumption data was reviewed, significant differences between consecutive month were observed that might be caused due to non-regular meter readings the authority do not have a cross checking mechanism.

3.6.2.5 Population and other Documents

Based on the CSA (2007), the numbers of the population figures in the year 2015 has been also collected from planning commission of the town.

3.6.2.6 Water Audit Study Period

The water audit study period was selected to analyze and evaluate total system water use. A twelve month study period starting in July to June is recommended. Most water system records are kept by either calendar or fiscal year. System normally makes twelve months of data available for review. It is recommended that a fiscal year (July through June) be used in order to reduce the effects of any meter reading lag time.

3.7 Study Variables

The study variables were achieved based on independent and dependent variables.

Dependent variable: variables that was observed and measured to determine the effectiveness of the independent variables, which is directly, related to the general objectives. The dependent variable includes; flow, water consumption or water demand, water loss, leakage, etc.

Independent variables: are variables that are more related to specific objectives. The independent variables include; population, size of reservoir, water meter, pipe size, pipe joint, etc.

3.8 Methods of Data Analysis

3.8.1 Existing Water Supply Distribution System

The current water distribution system of Gondar Town consists of the two main components of water distribution system.

In the system, water is distributed to consumers in the following ways:

- Gravity distribution system
- Distribution by means of pumps with storage (pumping + gravity)

3.8.1.1 Methods of Supply

Methods of supply to one another of the above service reservoirs and their service area are pumping and gravity systems (see Appendix-E).

3.8.1.2 Pump Stations

In the water supply system pump stations are installed for all pumps of boreholes and booster stations.

Table 3.5 Gondar water supply systems pump stations (GTWSSS, 2015)

Pump Stations	Pump ID	Design Discharge (l/s)	Head (m)	Delivered To	Pump Position
Bilko Fire Birgade	BFB	3.06	53	Goha Reservoir	Working
All Well Fields	NW-1	5.26	84	Clear Water Tank	Working
	NW-2	2.56	89	Clear Water Tank	Working
	NW-3	7.00	85	Clear Water Tank	Working
	NW-4	4.50	79	Clear Water Tank	Working
	NW-5	18.00	70	Clear Water Tank	Working
	TW-5	3.00	71	Clear Water Tank	Working
	TW-6	4.00	39	Clear Water Tank	Working
	GTW-7	20.00	61	Clear Water Tank	Working
Angereb Dam (Intake)	ADT-1	41.67	25	Clear Water Tank	Duty
	ADT-2	41.67	25	Clear Water Tank	Duty
	ADT-3	41.67	25	Clear Water Tank	Standby
	ADT-4	41.67	25	Clear Water Tank	Standby
Angereb Treatment Plant	ATP-1	29.17	175	Clear Water Tank	Duty
	ATP-2	29.17	175	Clear Water Tank	Duty
	ATP-3	29.17	175	Clear Water Tank	Duty
	ATP-4	29.17	175	Clear Water Tank	Duty
	ATP-5	29.17	175	Clear Water Tank	Standby
	ATP-6	29.17	175	Clear Water Tank	Standby
Clear Water Pump	CWP	29.17	175	Sellassie Reservoir	Working

3.8.2 Water Supply Coverage Analysis

The water supply coverage of the city was evaluated based on the average per capita consumption and by mode of services. The average per capita consumption has been derived from the annual consumption that was aggregated from the individual domestic water meters. Beside to the average per capita water consumption, the distribution of number of domestic mode of service has been also evaluated. Statistical analysis has been used to evaluate the water supply coverage for the entire city.

3.8.2.1 Average Daily Per-capita Consumption

The total volume of water consumed for domestic purpose has been aggregated to all twenty kebeles (twelve sub-cities) of the entire town to analyze the water supply distribution coverage among different localities or areas of the entire city. The annual water consumption data has been converted in to average daily per capita consumption by using the number of population. The average daily per capita consumption of the town was derived from the following expression (MoWR, 2000);

$$\text{Per-capita Consumption (l/person/day)} = \left[\frac{\text{Annual Consumption } (m^3) \times 1000 l/m^3}{\text{Population number of town} \times 365 \text{ days}}\right] \quad (3.1)$$

3.8.3 Water Loss Analysis

3.8.3.1 Water Loss in the Entire City

The average per-capita consumption and level of water connection was evaluated as these are highly related to the issue of water loss. And the total water loss was analyzed. After calculating the water losses, comparison was made using performance indicators. Then, the possible causes of the water losses were identified by comparing the losses in conjunction with factors like age of pipes, potential pressure, customer meters, etc. To estimate and analyze the water loss the following formulas were used (MoWR, 2000).

3.8.3.1.1 Water Loss Performance Indicators

$$\text{Total water loss (\%)} = \left[\frac{\text{Total water produced } (m^3) - (\text{Total water billed } (m^3))}{(\text{Total water produced } (m^3))}\right] \times 100 \quad (3.2)$$

$$\text{Total Water Loss (l/connection/day)} = \left[\frac{\text{Total water produced (l)} \times 1000}{\text{Total No of Connections} \times 365 \text{ days}}\right] \quad (3.3)$$

$$\text{Total water loss } (m^3/\text{km/day}) = \left[\frac{\text{Total water produced } (m^3)}{(\text{Length of main pipes (km)} \times 365 \text{ days})}\right] \quad (3.4)$$

$$\text{Total loss } (m^3) = \text{Apparent loss} + \text{Real loss} \quad (3.5)$$

3.8.3.1.2 Performance Indicator Assessment

Unavoidable Annual Real Losses (UARL):

Considerable work was undertaken to assess the minimum level of leakage for any system (Lambert, A. and Wallace, E., 1993) and after careful analysis a relatively simple and straightforward equation was developed as follows;

$$\text{UARL (liters/day)} = 18xLm + 0.8xNc + 25xLp) \text{ x P} \quad (3.6)$$

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

3.8.3.1.3 Infrastructure Leakage Index (ILI)

Calculating Infrastructure Leakage Index:

The IWA methodology of determine and comparing leakage in water distribution system is now generally accepted as world's best practice. However, there has been healthy debate regarding the use of various performance indicators and this is expected to continue for many years to come. The ILI is sometimes criticized for being too simplistic and not incorporating some of the key factors, which can influence leakage from a water distribution system. The main point of discussion includes;

- ILI values less than 1.0 should not occur since this shows that the actual leakage is less than the theoretical minimum level of leakage.
- The unavoidable annual real loss (UARL) equation is too simplistic as it is based only on the length of mains number of service connections, length of underground pipe from the mains to the point of metering and the average system pressure.
- The use of the ILI in cases where a water utility operates under either abnormally high or unusually low pressures.

While all of the above points are clearly valid concerns and can be debated at length. The ILI has proved to be extremely useful over the entire world, it is recognized that an ILI of 1.0 is attainable from a theoretical viewpoints many utilities have challenged themselves to demonstrate economic viability. In other words, a utility should not spend more than a dollar to save a dollar.

The ILI indicators are defined as a relation of real losses (RL) and unavoidable annual real losses (URAL). It is a new indicator of water supply systems expressing the technical condition of the system from the point of view of water loss. This indicator is proposed and recommended by the international water association (IWA) (Lambert, 2002). As the operating records kept by the operator do not make it possible to determine the actual real losses (RL) individually for each pressure zone. The infrastructure leakage index calculation uses simplified values of non-revenue water (NRW) as;

$$\mathrm{ILI} = \frac{\mathrm{NRW}}{\mathrm{UARL}} \tag{3.7}$$

Where, NRW=non-revenue water (m^3/year), UARL=unavoidable annual real loss (m^3/year)

The UARL is based on the results of an international survey containing data from 27 various water systems in twenty countries (Lambert, 2002).

Additionally, the water loss in the town water supply distribution system was evaluated using top down water balance software. Detail analysis of the water loss components has been done using the AWWA water audit software (WB-EasyCalc300, version 5.08).

3.8.4 Distribution System Analysis

3.8.4.1 Modeling Software

The hydraulic modeling software WaterGEMS was carried out for the purpose of pressure regime for customers demand, velocity, and head loss and overall systematically studying and better understand network operation.

The use of the above software is recommended that the up to date WaterGEMS V8i and WaterGEMS for ArcGIS platform software for an unlimited number of pipes is appropriate for the development of the skeletal and all mains models of Gondar water supply network.

The following steps were performed during data preparation for modeling;

- The network representation of the distribution system of the main water supply distribution system was drawn.
- The properties of the objects that make up the system were edited.
- The GPS survey of locations of reservoirs, pumps, pipelines, nodes, etc. was conducted.
- The data was exported from GPS Survey Pro to a text format.
- The exported text files were re-read into Excel and manipulate it into the Water GEMS input format.
- The node data was imported into WaterGEMS.
- The pipe network was drawn and the model or simulation was started.
- Calibration of the system was conducted
- Describe how the system was operated.
- A set of analysis options was selected.
- A hydraulic analysis was run and the results of the analysis were carried out.

3.8.4.2 Population Forecasting

Different population forecasting methods are in fact available and can be used for population projection. But their result varies from one method to another. Preference of the method appropriate for particular town needs to consider only current situations of the targeted town.

For fast population growth, where relatively high economic activity is observed and at the same time continuous expansion of town due to various reasons is experienced. So, 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 Gondar City. Moreover, it is based on the assumption that the percentage increase in population remains constant. Geometrical increase population forecasting method is expressed as follows;

$$P_n = P_O\left(1 + \frac{r}{100}\right)^n \quad (3.8)$$

Where, P_n = Population at year n, P_o = Base/initial population, r = Population growth rate, n = Projection year/decade

3.8.4.3 Nodal Demand Calculation

Demand allocation to consumption points are estimated using the following procedures (Bentley WaterCAD, 2008).

- Population size for each kebeles of Gondar Town is projected.
- From the known areas of kebeles and projected population for the design year, population density of the kebele is calculated.
- Water demand is projected based on the pressure zones.
- Location of nodal demand or consumption points is selected for demand allocating in the project area.
- Service areas for each consumption point are delineated.
- The delineated areas are overlapped to the kebeles and pressure zones.
- Nodal demand is calculated using the following formulae.

$$N_d = \sum p_i \cdot d_j \quad (3.9)$$

Where, N_d = Nodal demand, p_i = Population in each kebeles of the service area, d_j = Per capita demand for each pressure zones of the service area, i = Subscript referring to the i^{th} kebele in the service area, j = Subscript referring to the j^{th} pressure zone in the service area

3.8.5 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.

3.8.5.1 Input Parameters for Model Analysis

The main input parameters used for this model analysis were junctions, pipes, tanks, pumps, reservoirs (sources), valves, hydrants and turbines data (list of these parameters are shown in Appendix-N).

3.8.5.2 Steady State Analysis

The model has been performed in steady state analysis 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.

3.8.5.3 Extended Period Simulation

The system conditions have been computed over twenty-four hours with a specified time increment of two hours and starting model analysis at 7:00 PM. The software simulates non-steady State hydraulic calculation based on mass and energy conservation principle.

The model can be simulated for every two-hour time setup in the twenty-four hour duration. However, for the analysis the peak and minimum hour demand has been simulated to identify the current problems of the system.

3.8.5.4 Model Calibration and Validation

For model calibration and validation effort data were collected from field visits. Collected data include: Tank section, reservoir elevation, pump characteristics, and pipe size, diameter, material types. For this study pipe roughness, demand and pipe status were taken as model parameter to be adjusted. Model calibration and validation were undertaken based on the following set of recommendations.

Acceptable levels of calibration;

Pressure criteria (Bentley Water CAD, 2008)

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

Flow criteria (Bentley Water CAD, 2008)

- Modelled flow rate (where the flow is more that 10% of the total demand) to be within ± 5% of measured flow rate.
- Modelled main flow rate (where flow is less than 10% of the total demand) to be within ± 10% of measured flow rate.

3.9 Data Presentation

The data analyzed has been presented using tables, graphs, and charts.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Domestic Water Supply Coverage and Demand

Access to water supply may be evaluated using the amount of water consumed and by mode of service for evaluating the amount of water consumption, the annual water consumption is converted to average daily per capital consumption using the population data of town. Besides population distribution by mode of service has been also used as elaborated below.

4.1.1 Domestic Water Supply Coverage in Percentage

Problem of adequate water supply to the rapid growth of urban population is increasing now a day. In domestic sector of developing cities including Gondar City water demand increases through time that as a result demands for additional water sources and infrastructure. This shortage or constraint of finance is one of the major factors that lead low water coverage of the water supply, additionally; poor management of the existing water supply system also has a great influence to have low water supply coverage. Beside to the total low supply coverage, a great supply disparity occurs among different areas or localities. Therefore, evaluating the city distribution of the water supply system is important to identify the problematic areas and intervene accordingly.

Mostly water supply coverage is evaluated based on the quantity, quality, paying capacity of the people, etc., but the main intention of this research is not to identify and evaluate all these but, related to the quantity of water supply and level of connection that are related to the issue of water loss. In this part of the analysis, the number of domestic connections per family and the average daily per capita demand/consumption was used to evaluate the domestic water supply coverage for the entire city.

Table 4.1 Total consumption and number of connections

Time (Year)	Consumption (m^3/year)	Number of Domestic Connection	Number of Commercial Connection	Number of Public Connection	Number of Public Tap Connection	Total Number of Connection
2015	2,767,383	22,305	2,722	402	8	25437

As shown from table 4.1 the total water consumption in 2015 (2,767,383m^3), 87.69% was shares of domestic (household) consumption while the rest volume of consumption was shares of commercial/industrial, Public Organization/institution and Bono (Public Tap) were 10.7%, 1.58% and 0.03% respectively.

4.1.2 Average Daily per-capita Consumption

The level of water consumed for domestic purpose has been aggregated to analyze the distribution of the water coverage among different localities. The annual consumption data has been converted to average daily per capita consumption using the number of population.

Table 4.2 Water consumption and total population of Gondar Town in 2015

Time (Year)	Consumption (m^3/year)	Total Population (Number)	Consumption (l/person/day)
2015	2,767,383	296,937	25.53

Table 4.2 shows the average per capita domestic water supply coverage of the town in the year 2015 is found to be 25.53 l/capita/day. But, the Ethiopian Building Code Standard nine (EBCS 9) shows that the country standard used 30 to 60 l/capita/day for design purpose. This average per capita consumption is very low while compared with the country standard used for design purpose (30 to 60). According to some literatures, a minimum quantity of 26.5 l/capita/day domestic water supply categorized as basic level of service (Wallingford, 2003) which is higher than the average domestic consumption of Gondar Town.

4.1.3 Population Distribution by Mode of Service

Mode of service is an important element to evaluate the level of water coverage that was the focus of this section and on the other hand it has a direct impact on the water loss that was dealt separately. The adopted per capita water demands of each of the modes of services are described in the table here under.

Table 4.3 Population distribution by mode of service

Population service level		Unit	Year
			2015
Total Population		No	296,937
Percentage of Population Served	HC	%	12
	YCS	%	30
	YCO	%	42
	PF	%	16
Population by Service Level	HC	No	35,632
	YCS	No	89,081
	YCO	No	124,714
	PF	No	47,510

Table 4.3 above shows the household survey analysis identified the surveyed households who have access to safe water supply by mode of services. The survey indicates that, the majority of the inhabitants (12%) get their water from household connections, 30% have a private yard connection share, 42% yard connection on, and 16% have public fountain connections.

4.1.4 Correlation between Population and Billed Consumption

It is necessary to evaluate consumption versus population. This has been evaluated using the correlation between the water billed consumption and number of population. Plotting water consumption by number of population graphically illustrates R-square values for regression models.

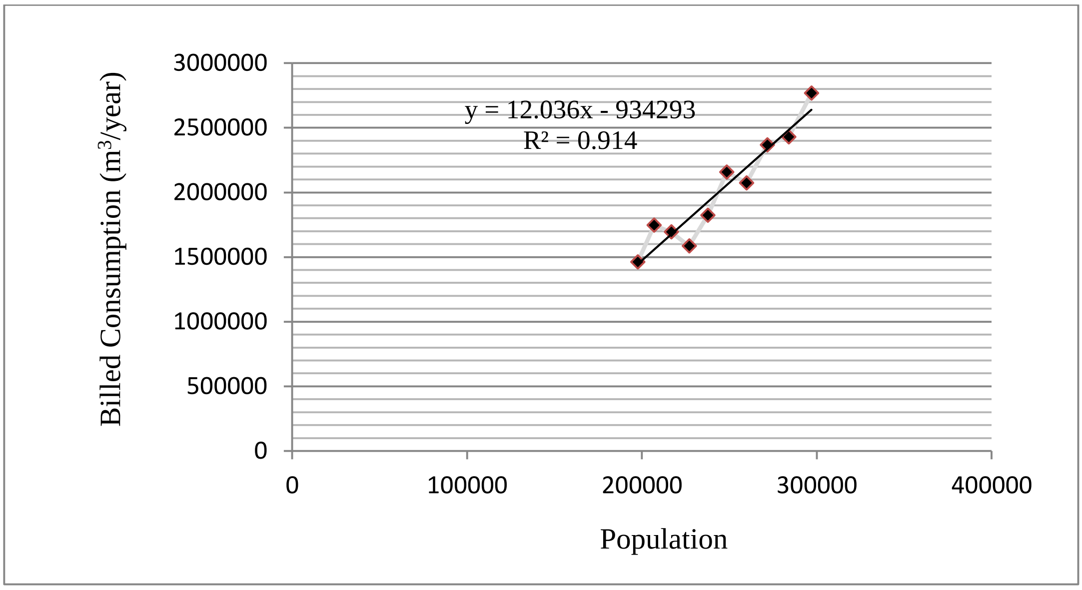

Figure 4.1 Scatter plot for volume of water consumption and number of population

As shown in figure 4.1 the coefficient of determination (R^2) is 0.914, indicates that the regression model accounts for 91.4% of water consumption is influenced by population size. So, population is one of the major influential factors for water industries.

4.2 Water Loss Analysis

The reduction and control of water loss is in a distribution system is becoming an issue in this age of increasing demand and changing weather patterns that bring droughts to a considerable number of locations in the world. Many water projects have been developing new strategies to reduce losses to an economic and acceptable level in order to observe valuable water resources (Hossam, 2011).

The aim of this study was to identify the water supply coverage and estimate water loss in the main water supply network of the town. Thus, water loss approach was advised for present study to control and manage water loss problem in Gondar Town.

4.2.1 Water Loss in the Entire City

The total annual water produced and distributed to the water supply distribution system and the water billed that was evaluated from the individual customer meter reading was used to estimate the total water loss for the town.

4.2.1.1 Monthly Water Production, Consumption and Loss in Cubic Meter

The monthly annual water production, consumption and loss trend of Gondar Town in the year 2015 estimated in the figure below.

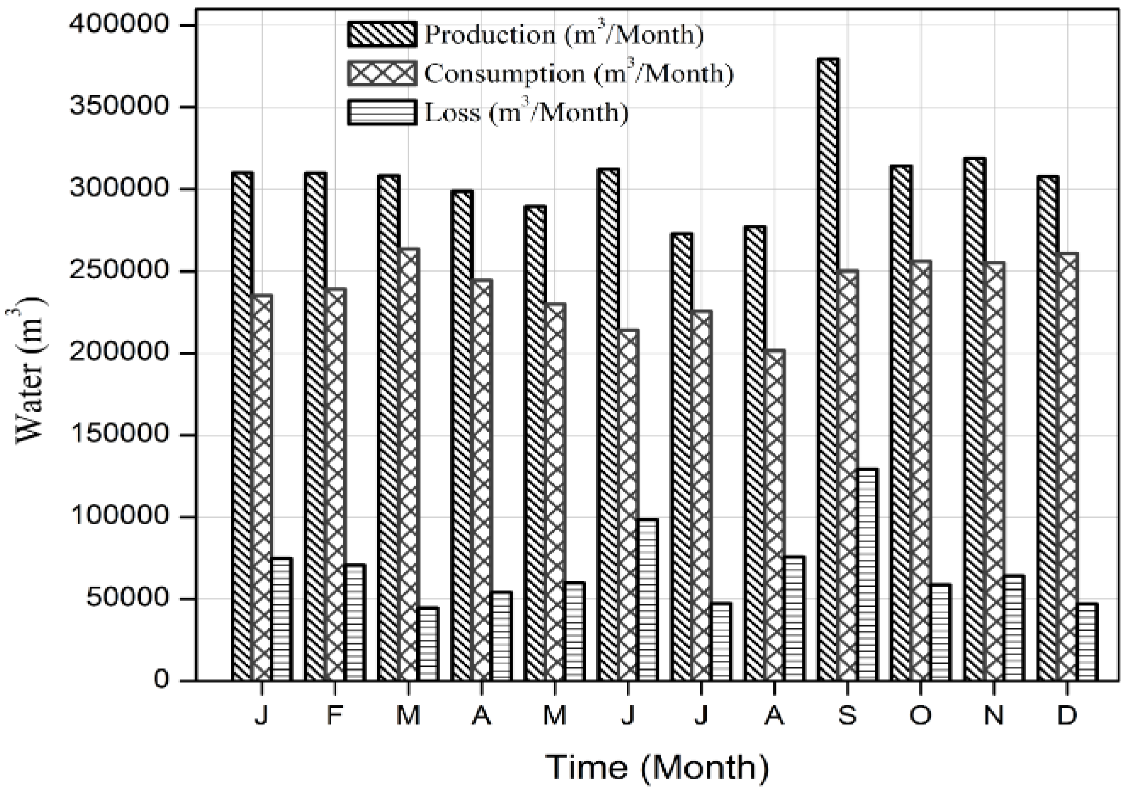

Figure 4.2 Monthly annual water production, consumption, and loss trends (GTWSSS, 2015)

Figure 4.2 shows that the maximum production and loss, and consumption is recorded in the month of September and December respectively; but the lowest production, consumption and loss is happened in the month of July, August and December respectively in year 2015.

4.2.1.2 Yearly Water Production, Consumption and Loss

The yearly water production, consumption and loss trend of Gondar Town in the last consecutive ten years expressed in the following figure.

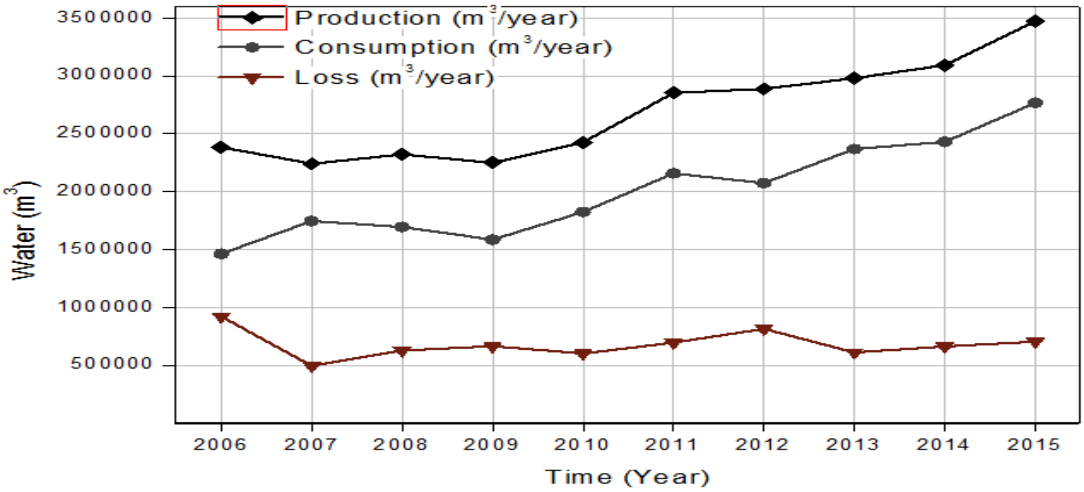

Figure 4.3 Yearly annual water production, consumption, and loss trends of Gondar Town

In the last ten years production and consumption of water increases; but water loss in the entire town shows a decreasing tendency (figure 4.3) (Appendix-A).

4.2.1.3 Total Water Loss Expressed as Percentage

Water loss in a distribution system expressed as percentage was an appropriate means to show the extent of the loss. The total water loss calculated in the distribution system with in the last consecutive ten years is shown below.

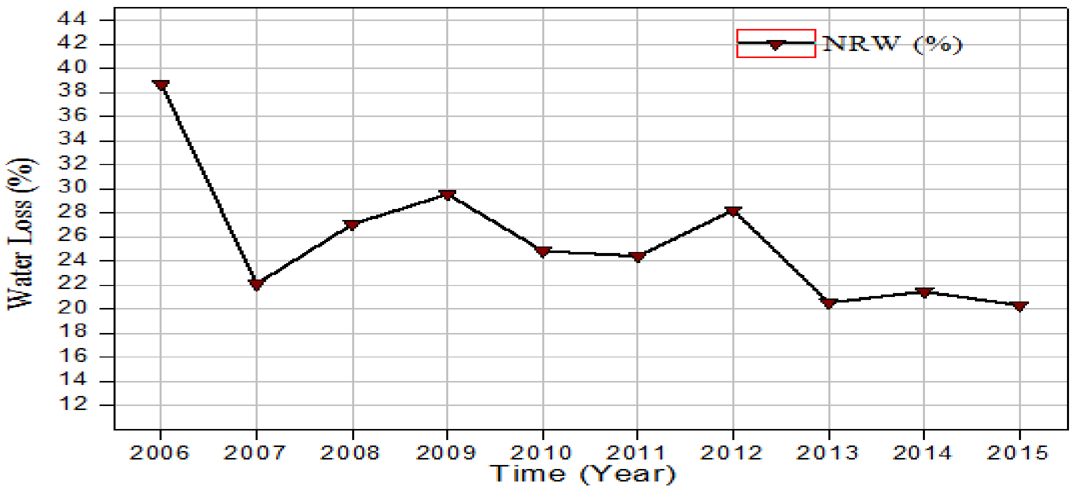

Figure 4.4 Total water loss trends in Gondar Town in the last ten years (GTWSSS, 2015)

Figure 4.4 describes the water loss trend of Gondar Town shows a decreasing tendency from year 2006 to 2015. The main reason behind is the yield (discharge) of Angereb Reservoir is decreasing due to high sediment deposition that comes from the upper part of the dam and high evaporation loss.

The water loss trend of the town shows that loss was varied from year to year. This could be due to infrastructure development like road rehabilitation, building construction in Gondar and breakage of pipes was occurred. The interview result shows that, assessment of leakage identification is taken place once a weak by staff on average. This implies that, leak was not a timely response and it maximized water loss. However, the increasing and decreasing of water loss depends on time of construction and awareness creation among people. In the last ten years (2006-2015), the average annual water produced and distributed to the system was 2,690,785m^3 and average annual water loss was 679,953m^3, which account to 25.27% of the total production.

Taking the newly average tariff of water Gondar City as 5.86 birr/m^3, the water loss is estimated to be 3,984,524.58 birr every year. However, the real loss is beyond this as the water tariffs like other developing countries are usually subsidized (see Appendix-A).

According to Saroj (2008) the recommended 10% of the loss is taken as a benchmark for UFW. Saroj (2008) states that when the loss is <10% (acceptable) monitoring and controlling is continued, 10-25% (intermediate) which could be controlled, and >25% a matter of concern to reduce the water loss. According to this study, water loss in Gondar Town was 25.27% in the last ten years; this shows that the loss in the town was >25% above intermediate level, as stated by Saroj (2008). Thus, water loss could be controlled and monitored and special attention must be given in the entire city to reduce this loss.

4.2.1.4 Leakage

The role of leakage is very significant in affecting water supply service in the town. As indicated in figure 4.4 above, every year from the total clean water produced 25.27% (in average) is lost at the time of distribution.

Table 4.4 Is there any water leakage problem?

Category	Frequency	Percent
Yes	126	84
No	18	12
I don't know	6	4
Total	150	100

Source: Survey data, 2016

During the household survey of this study, the sample respondents assured what is written on the water office report above. As it is clearly shown on the table 4.4, the majority of the household samples 126 (84%) responded that there is problem of leakage on the water supply systems, whereas 18 (12%) and 6 (4%) of them answered no problem of leakage and no idea about the problem respectively. From this we can conclude that leakage is a very common phenomenon occurring repeatedly in the town and putting its significant role on the distribution of clean tap water, the amount of revenue collected and efficiency of the Water Supply Service Office (WSSO) at large.

In addition to this the sample households were also interviewed about the main causes of water loss which they consider for this problem and they have responded in the following manner:

Table 4.5 Causes water loss given by respondents

Category	Frequency	Percent
Pipe breakage	31	24.60
Lack of maintenance	52	41.27
System distribution failure	10	7.94
Pipe burst	28	22.22
Others	5	3.97
Total	126	100

Source: Survey data, 2016

As shown in table 4.5; 24.6 %, 41.27%, 7.94% and 22.22 % of them put pipe breakage, lack of maintenance, system distribution failure, and pipe burst as prior causes respectively while 3.97% put theft and irresponsibleness of the residents as causes.

4.2.1.5 Water Loss Expressed as per Number of Connection

Water loss expressed as a percentage could be an appropriate means to show the extent of the loss within a given environment, but it is not a good indicator for comparing the losses from one area to another. According to some literatures, comparison of water loss between different areas is recommended to be done using the water loss per service connection per day. Taking the total number of connections in the town as 26,336 out of this around 900 are disconnected; the water loss in liter/connection/day for the similar duration was derived as;

Water loss (liter/connection/day) =2,690,785x1000÷ (26,336×365) =279.92 liter /connect /day (average condition) (Saroj, 2008). This figure shows 279.92 liter of water loss experienced per connection per day.

4.2.1.6 Water Loss Expressed as per Length of Pipes

Water loss expressed as per kilometer length of main pipes is also used as indicator to compare water loss. The total length of main pipes of greater or equal to 150mm diameter have been used to evaluate total water loss of the entire town is 47.22km length of mains. Using total main pipe length of the entire town, the water loss per kilometer length of main pipes was derived to be;

Water loss (m^3/km/day) =2,690,785÷ (47.22km×365days) =156.12m^3/km/day (bad condition) (Saroj, 2008). This figure shows that in every 1km of pipe distance 156.12m^3 of water is lost in a day (bad condition).

4.2.2 Pressure and Leakage

One of the major factors influencing leakage is the pressure in the water distribution system. In the past the conventional view was that leakage from water distribution systems is relatively insensitive to pressure (Greeley, 1992). Figure 4.5 illustrates the effect of pressure on leakage rate for sample nodes location in the distribution network.

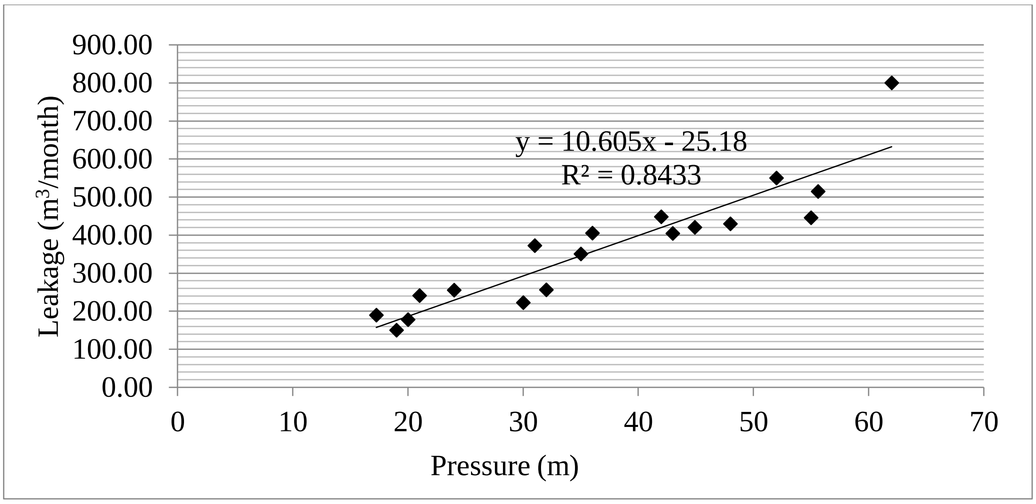

Figure 4.5 Plot of pressure versus leakage (Source; GTWSSS, 2014)

The above numerical equation generating from continuous water flow and within the same duration the recorded pressure and the water loss (leakage) at the same period, the pressure is varied with time during supply the water to the system. The coefficient of determination (R^2) shows that nearly 84.33% leakage is explained by pressure in the system. As shown above as pressure increases leakage also increases.

4.2.3 Quantifying the Components of Non-Revenue Water

4.2.3.1 Determination of Unavoidable Annual Real Loss (UARL)

This category represents the allowable volume of real losses from the system, which estimates a volume of leaks that are undetectable or would be uneconomical to repair during the year. This can help to evaluate the feasibility of real loss minimization (provides better understanding of real loss components). One of the most important concepts used in the burst and background estimate procedures concerns the minimum or unavoidable level of leakage for any given system. Effectively it is a simple concept based on the fact that no system can be entirely free from leakage, which cannot be reduced any further. Even a new distribution system with no use will have some level of leakage, although it may be relatively small. The minimum level of leakage for a system is termed the unavoidable annual real losses (UARL). This is the level of leakage that can be achieved if the system

- Is in top physical conditions and is well maintained
- All reported leaks are repaired quickly and effectively
- Active leakage control is practiced to reduce losses from unreported leaks

Considerable work was undertaken to assess the minimum level of leakage for any system (Lambert et al., 1999) and after careful analysis a relatively simple and straight forward equation was developed;

$$UARL = (18\times Lm + 0.8\times N_C + 25\times Lp)\times P$$

Where, UARL=unavoidable annual real losses (l/d), Lm=length of mains (km), Nc=Number of service connections (main to customer meter), Lp=length of unmetered underground pipe from street edge to customer meter (km), P=average operating pressure (m). The minimum pressure in the system is 15.4 m column of water.

Accordingly, in the case of Gondar water supply UARL is calculated as;

UARL=(18×47.22+0.8×25,436+25×0)×15.40=326,460.90l/day=326.46m^3/day=119,157.9 m^3/year

4.2.3.2 Unauthorized Consumption

This volume of water includes theft and illegal connections. As there is no any means to determine this quantity of water, its volume is estimated based on the system input volume. According to the water service office, 2015 report unauthorized consumption amounts 1,102 m^3/year. But from the water balance calculation this consumption is estimated to be 1,050 m^3/year (error margin of 4.7% under registration).

4.2.3.3 Calculating Infrastructure Leakage Index

The infrastructure leakage index (ILI) indicators are defined as a ratio of real losses (RL) and unavoidable annual real losses (UARL). It is a new indicator of water supply systems expressing the technical condition of the system from the point of view of water loss. This indicator is proposed and recommended by the IWA (Lambert, 2002). As the operating records kept by the operator do not make it possible to determine the actual real losses (RL) individually for each pressure zone. The ILI calculation uses simplified values of NRW as;

$ILI = \frac{NRW}{UARL}$; Where, ILI= Infrastructure Leakage Index, NRW = Non -Revenue Water (m^3/year), UARL = Unavoidable Annual Real Loss (m^3/year)

The UARL is based on the results of an international survey containing data from 27 various water systems in 20 countries (Lambert, 2002). Based on the above equation the infrastructure leakage index for Gondar Town water supply distribution system is calculated as 704,386÷119,157.9=5.91.

This shows that the current annual real losses are assessed as being around six times as high as the unavoidable annual real losses for the system.

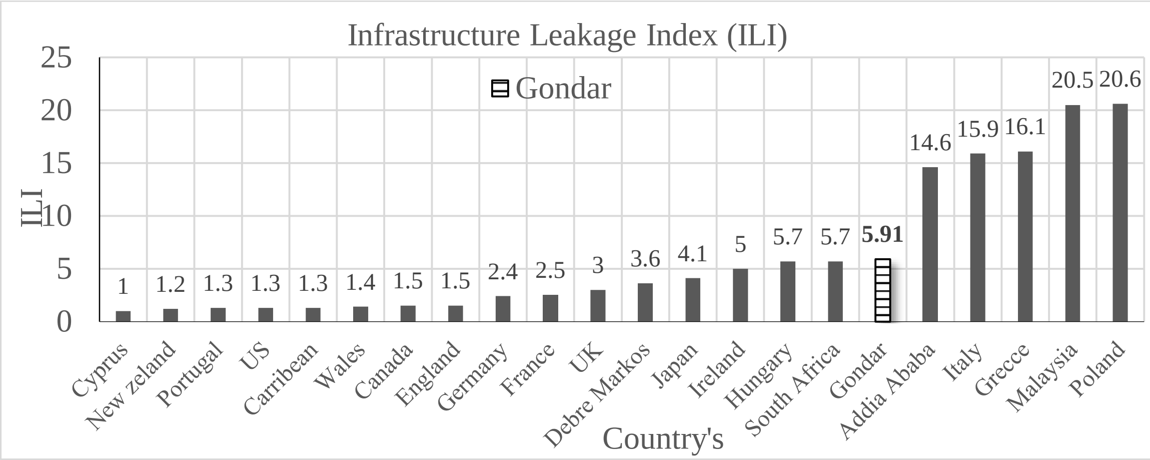

Figure 4.6 Infrastructure leakage index (ILI) values for 20 counties
Source: Rizzo, (2000), Melaku, (2014), and Hussien, (2010)

Interpreting ILI Values:

If the ILI for a particular system is calculated and as say 5.91 this means that the current annual real losses are assessed as being around 5.91 times as high as the unavoidable annual real losses for a system with this length of mains, number of connections and customer meter location under the same pressure management regime as the particular system under review.

Additional changes in real losses will result from changes in the pressure management regime. In practical terms ILI values close to 1.0 mean that world class leakage management is ensuring that annual real losses are close to the unavoidable or technical minimum value at current operating pressures.

According to World Bank Institute (Liemberger, 2005), this ratio (5.91) is explained as: Band B (poor category), inefficient use of resources; leakage reduction program is imperative and high priority, reviewing asset management policy, deal with deficiencies in manpower, training, communications, fundamental peer review of all activities are required. Potential for marked improvements; consider pressure management, better active leakage control practices, and better network maintenance.

4.2.4 Quantifying loss by Water Balance Method

For the years 2015 IWA water balance components are obtained by using data and estimated in the above. The results are summarized in table 4.6 below.

Table 4.6 Water Balance for Gondar Town Water Utility, Year 2015 (Appendix-J)

<table>
<tr><th colspan="5">Water Balance Analysis</th></tr>
<tr><td rowspan="7">System Input Volume 3,471,767 (m^3/year) 100%</td><td rowspan="4">Authorized Consumption 2,767,381 (m^3/year) 79.71%</td><td rowspan="2">Billed Authorized Consumption 2,767,381 79.71%</td><td>Billed Metered Consumption 2,767,381 (m^3/year) 79.71%</td><td rowspan="2">Revenue Water 2,767,381 (m^3/year) 79.71%</td></tr>
<tr><td>Billed Unmetered Consumption (m^3/year)</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption (m^3/year) 0%</td><td>Unbilled Metered Consumption (m^3/year)</td><td rowspan="5">NRW 704,386 (m^3/year) 20.29%</td></tr>
<tr><td>Unbilled Unmetered Consumption (m^3/year) 0%</td></tr>
<tr><td rowspan="3">Water Losses 704,386 (m^3/year) 20.29%</td><td rowspan="2">Real Losses 454,188 (m^3/year) 13.08%</td><td>Unauthorized Consumption 1,050 (m^3/year) 0.03%</td></tr>
<tr><td>Customer Meter Inaccuracies and Data Handling 453,139 (m^3/year), 0.03%</td></tr>
<tr><td colspan="2">Apparent Losses 250,198 (m^3/year), 7.21%</td></tr>
</table>

As shown in table 4.6, the result of Non-Revenue Water (NRW) by water balance method is 20.29% has serious impact on Gondar Town water supply service office finances and available water resources.

4.3 Evaluating Possible Causes of the Water Loss

There are several reasons for the high level of water loss in Gondar town. These factors are given below, and some advisory solutions were briefly proposed in next sections.

4.3.1 Evaluating Loss based on Age of Pipe Network

Pipe age is one of the factors that affects the magnitude of the loss specially that of physical loss. Aged pipes are more likely having more water loss through leakage than newly installed pipes. It is estimated that nearly more than 27.9% of the pipe network in the town was laid over 20 years ago (table 4.7).

All these materials suffer from degradation over time due to operational measures, environmental conditions and general wear and tear result in increased leakage in the network. It is therefore necessary to replace older mains so that less leakage occurs. The ages of pipes in the system and the corresponding loss per length of pipes is summarized as shown in Table 4.7.

Table 4.7 Pipe distribution by age category (GTWSSS, 2015)

S.No	Material Type	Age Category (years)	Length (km)	Length (%)
1	uPVC	<12	9.92	10.20
2	DCI	<10	30.02	30.88
		20-25	20	20.57
3	GI	30-40	3.13	3.22
		>40	4	4.11
4	HDPE	<8	2.24	2.30
5	PVC	<10	17.91	18.42
		10 & more	10	10.29
Total			97.22	100

4.3.2 Poor Maintenance of Networks

In some places like expansion areas water supply office service has performed a maintenance program for distribution system. According to GTWSSS (2014) report, nearly 20% of network system was replaced in the expansion areas. In some parts of the town, poor materials or workmanship to maintenance of water supply network. Thus, lack of finance to buy proper materials and poor construction resulted in increased leakage in the system.

4.3.3 Lack of Design

Proper design has a great role for water supply utilities to achieve its design period. In Gondar Town there is high expansion of water supply system, but for that expansion area simply the system is directly connected to an older system that was tapped for many years. So, for an expansion of the system proper design must be done to reduce high water loss.

4.3.4 Poor Infrastructure

In Gondar Town, it has been observed that pipe network is very old which is laid many years ago. With age there is considerable reduction in carrying capacity of the pipelines due to corrosion. In most of the places the consumer pipes get corroded and leaks occur resulting in loss of water and reduced pressure. Especially DCI pipes as seen in table 4.7 their age is older than 10 years this leads the material's to be corroded and leakage to occur. These materials suffer from degradation over time due to operational measures, environmental conditions and general wear and tear and result in increased leakage in the network. It is, therefore, necessary to replace older main pipes so that less leakage occurs.

4.3.5 Illegal Connection (Theft)

There are a number of illegal users of water within distribution system in Gondar Town. According to GTWSSS report (2015) the number of households who do not pay water rates, but receive water from its distribution system without knowledge of the Authority, but as compared to other causes of losses it is less in figure and controlled easily.

4.4 Distribution System Modeling

4.4.1 Model Representation

The concept of a network is fundamental to a water distribution model. The network contains all of the various components of the system, and defines how those elements are interconnected. Networks are comprised of nodes, which represent features at specific locations within the system, and links, which define relationships between nodes (Walski, 2000).

4.4.1.1 Developing a Geo-database

Geo-database is an object oriented model. Every table becomes a class with properties methods and events. The idea behind the geo-database is to provide a uniform approach to reducing the complex behavior of the real world to a set of tables in a database with extended and customizable behavior (Prabhata, K., and Ashok, K., 2008).

One of the biggest benefits of the Geo-database is that it unifies a common location and in a common formats all geographic relevant data which is accessed by a common set of tools. Geo-database allows an organization to physically store the geometry of the feature (point, line, polygon) and the attribute that describe that feature inside a relational database management system as a single row in a table. The geo-database also models the relation between the tables and each feature in geo-database model.

These data should be tied together in a geometric network. Ideally, the data representing the distribution network should be linked to scanned as-built drawings so they are easy to access for additional information. The utility data should also be linked to the work order system so that changes to the infrastructure can be available to the GIS user.

As shown in table 4.8 below the geo-database of sample Sellassie Pressure Zone water supply distribution system layout (pressure zones, pipe network, nodal points, administrative boundaries, etc.) was prepared by using ArcGIS 10.1 tools ArcCatalog and ArcMAP. The GIS techniques used for None Revenue Water reduction project of Gondar Town started with reviewing previous studies. However, various studies and reports have never or less establishes the geographical information system of existing water system network which can be linked to other secondary data sources.

The other five pressure zones (Azezo, Gebreal, Goha, Samunaber, and Stadium) geo-database were prepared in the same manner as Sellassie Pressure Zone.

Table 4.8 Gondar Town water supply system Geo-database (Ethio-ArcGIS)

Water_Main_Sellassie						
OBJ_ID	Diameter (mm)	Material	Age	Shape_Length	X	Y
1	350	DCI	1992	646. 23	334628	1394709
2	300	DCI	1992	83. 12	334276	1394799
3	250	DCI	1992	280. 71	334157	1394920
4	250	PVC	1992	38. 74	333935	1394833
5	250	PVC	1992	550. 23	333845	1394591
6	350	DCI	1992	47. 36	333805	1394286
7	80	PVC	1992	88. 81	333913	1394267
8	80	PVC	1992	153. 94	333726	1393621
9	100	PVC	1993	32. 27	333416	1393337
10	100	PVC	1993	21. 89	333390	1393332
11	80	PVC	1993	115. 62	333325	1393310
12	80	PVC	1993	92. 11	333240	1393255
13	150	PVC	1993	309. 12	333370	1392850
14	150	PVC		91. 73	333369	1392650
15	150	PVC		311. 05	333290	1392476
16	250	PVC		56. 08	333184	1392151
17	300	PVC		47. 34	333134	1392139
18	200	PVC	1992	152. 46	333056	1392190
19	100	DCI	1993	314. 33	334275	1394644
20	100	DCI	1992	33. 29	334181	1394524
21	100	DCI	1992	71.00	334150.	1394566.

4.4.1.2 Data Entry and Analysis

The GPS digital format data were entered into the ArcGIS database (geo-database) using import /Export facilities inbuilt in the GIS software. The use of the automatic data entry simplifies the task of data entry and ensures that data is entered accurately and in the required format.

The GPS data were visualized and analyzed according to size variations and in relation to the control structure locations (Gondar master plan). The existing network data was reviewed in its original format, the pipe diameter; year of construction and its material type were written as an annotation.

These attributes were analyzed thoroughly in conjunction with contour map, cadastral map, road network map and map of kebeles boundaries of the city for consistency using ArcGIS 10.1. Figure 4.7 below shows list of the twenty kebeles (01-20) prepared by using GIS tools to create the new sub-cities and for the installation of Gondar Town distribution system with its appropriate pressure zone location.

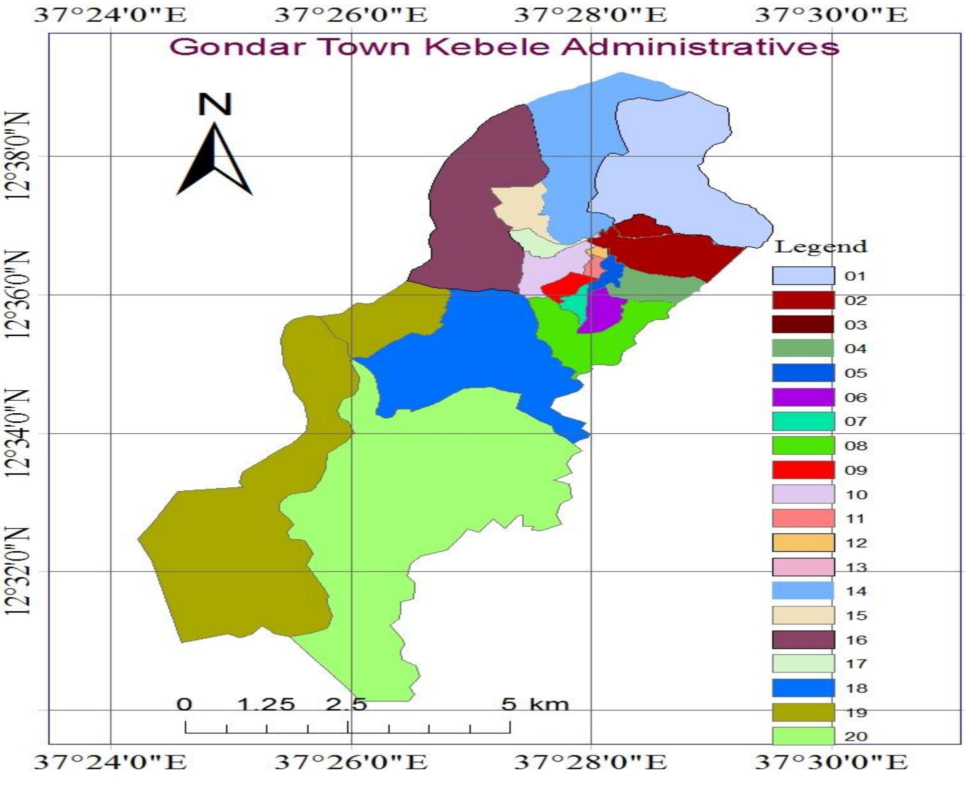

Figure 4.7 Map showing the Kebeles' boundaries in Gondar Town (Ethio-ArcGIS)

The next step was to combine kebeles boundary (Figure 4.8) shape information to determine the aerial extent of each new sub-cities.

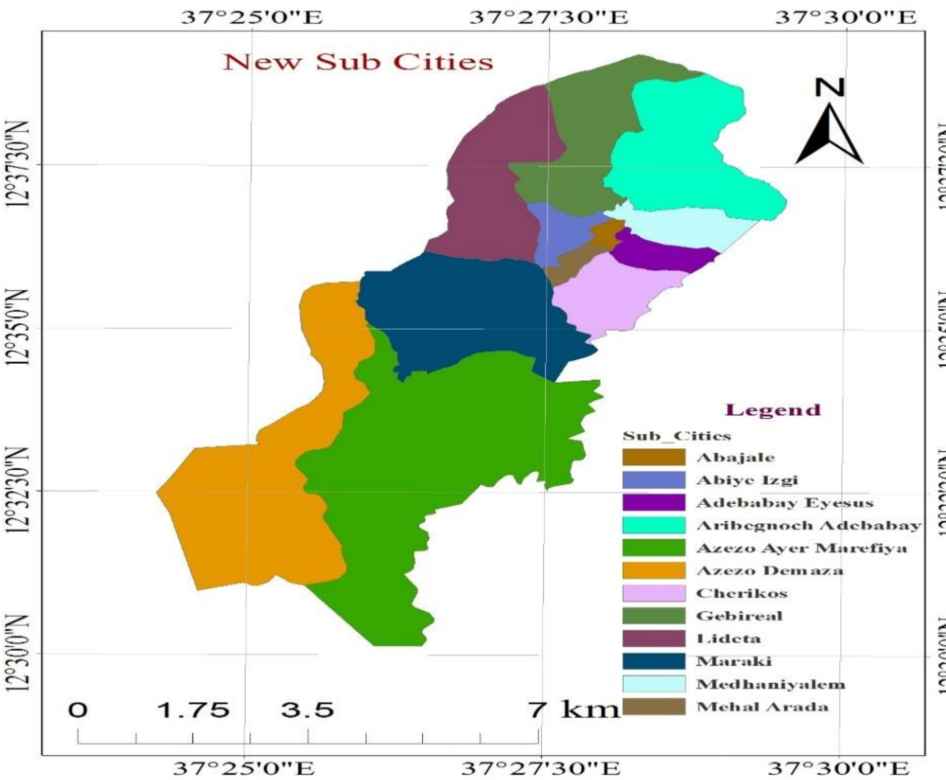

Figure 4.8 Map showing the sub-cities boundaries in Gonder Town (Ethio-ArcGIS)

4.4.2 Pressure Zone Distribution System

The six pressure zones were established by combining sub-city boundaries and pipe lines. WaterGEMS in ArcGIS platform were used to overlap the distribution system with the appropriate location of pressure zones.

System maps are drawn as combination of various system components enclosed in water distribution system. The resulting sketch fairly represents the actual water network. With little difference the real water distribution system represented as combination of nodes and links. Junctions, reservoirs and tanks are usually referred as nodes. Pipes, pumps and valves are categorized as links. Figure 4.9 below illustrates layout of Gondar distribution system pressure zones.

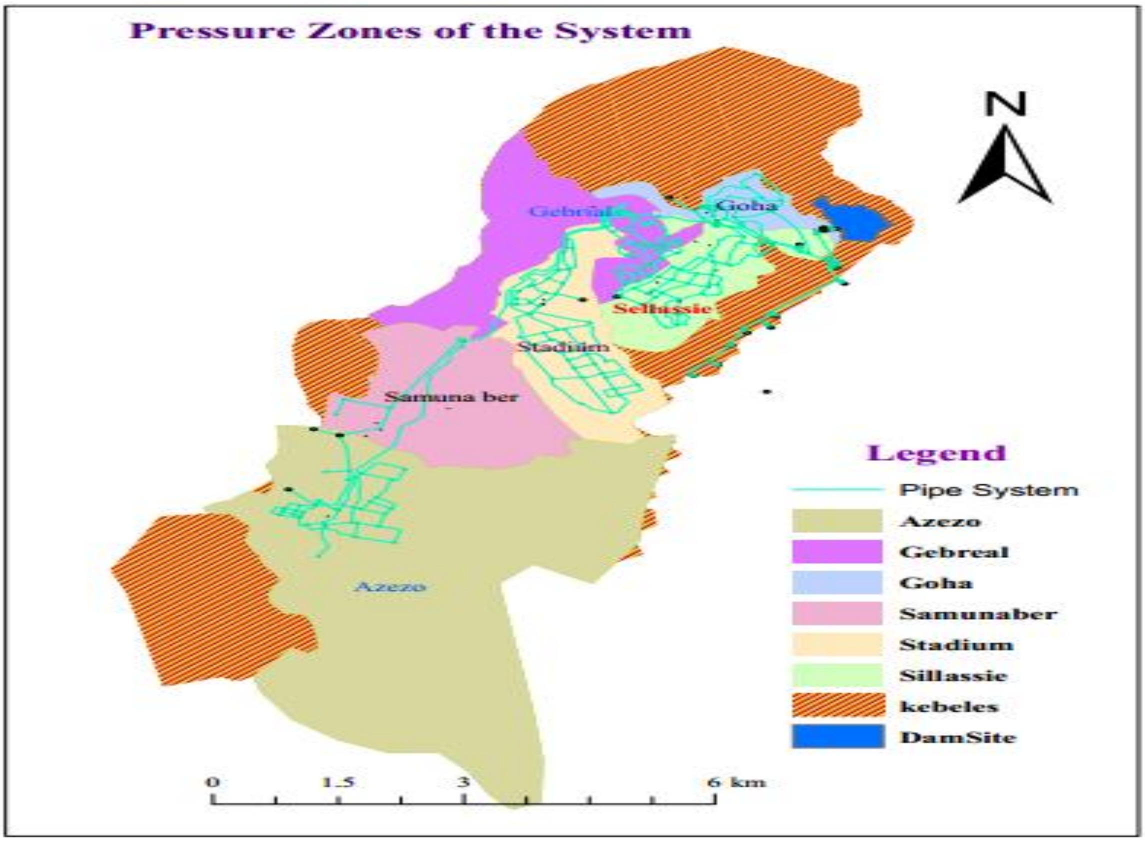

Figure 4.9 Map showing pressure zones

4.4.3 Distribution Network

For Gondar Town water supply distribution network modeling WaterGEMS V8i and ArcGIS 10.1 were used. From the model analysis the total length of water network in the system is approximately 119 km (25mm to 350mm); but in this study pipes less than 80 mm are skeletonized/not included. Diameters 80mm to 350mm (main transmission and distribution) were used and covered approximately 92 km; out of this main transmission line (150mm to 350mm) covers 47km.

Table 4.9 Summary of network inventory

No	Network Components	Number
1	Pipes	325
2	Junction	187
3	Tanks	9
4	Reservoirs	13
5	Pumps	11
6	Turbines	4
7	Valves	9

Table 4.9 shows the total main components of the distribution network installed for Gondar Town main water supply distribution network layout.

Table 4.10 Summary of pressure pipe inventory

Diameter (mm)	Length (PVC) (m)	Length (HDPE) (m)	Length (DCI) (m)	Length (GI) (m)	Length (DI) (m)	Length (All Materials) (m)
80.0	9,326	26	18,538	-	-	27,890
100.0	19,681	2,211	6,178	4,966	228	33,264
150.0	2,863	-	6,579	942	-	10,384
200.0	4,717	-	3,505	510	-	8,731
250.0	1,140	-	7,030	482	-	8,652
300.0	94	-	7,568	-	-	7,662
350.0	-	-	610	-	-	610
Total	37,820	2,237	50,007	6,900	228	97,192

Table 4.10 shows the total length of each pipe corresponding with its diameter and material type.

4.4.4 Contour of Gondar Town Water Supply System

The contouring features in Bentley WaterGEMS V8i were enabled to generate contours for reporting attributes such as elevation, pressure, and hydraulic grade. As shown in figure 4.10 below the minimum and maximum elevation of Gondar Town water supply distribution system is 1964m and 2297.55m respectively.

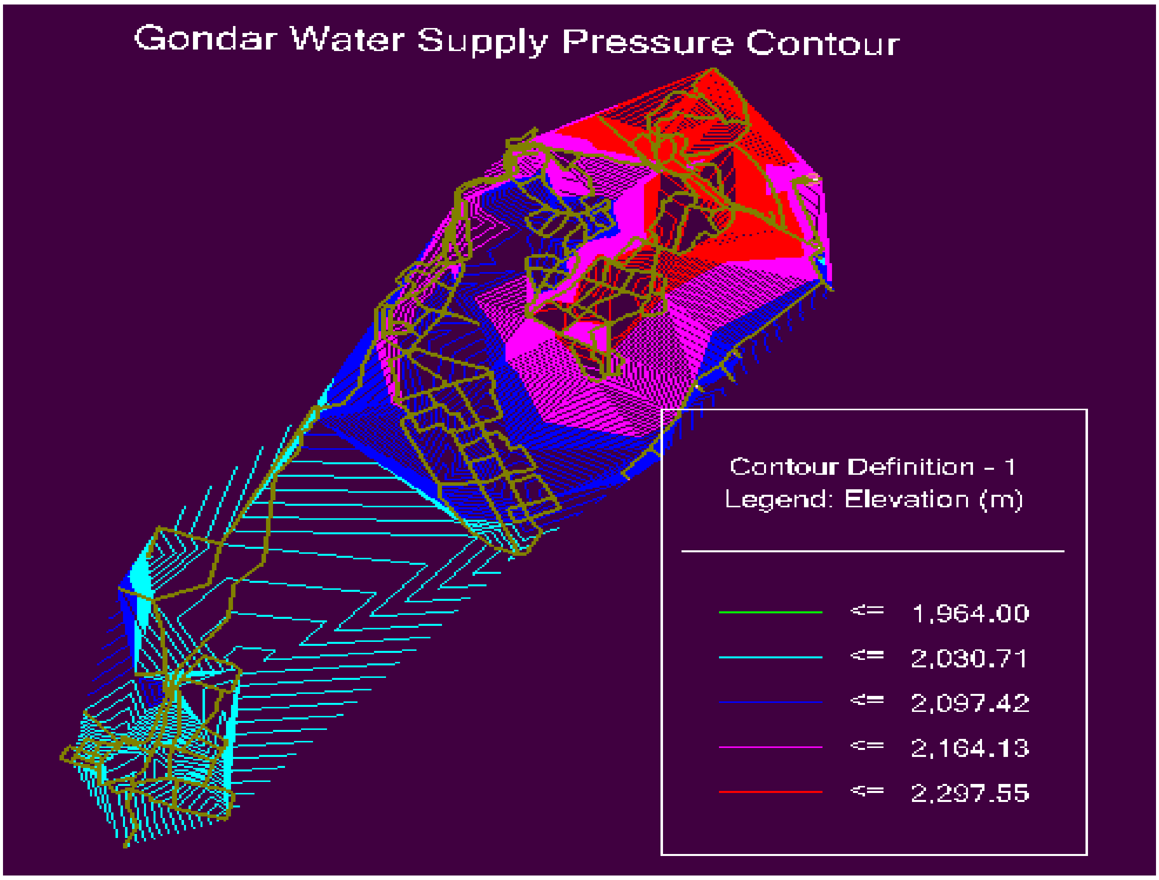

Figure 4.10 Contouring of the distribution system

4.4.5 Velocity Distribution of the System

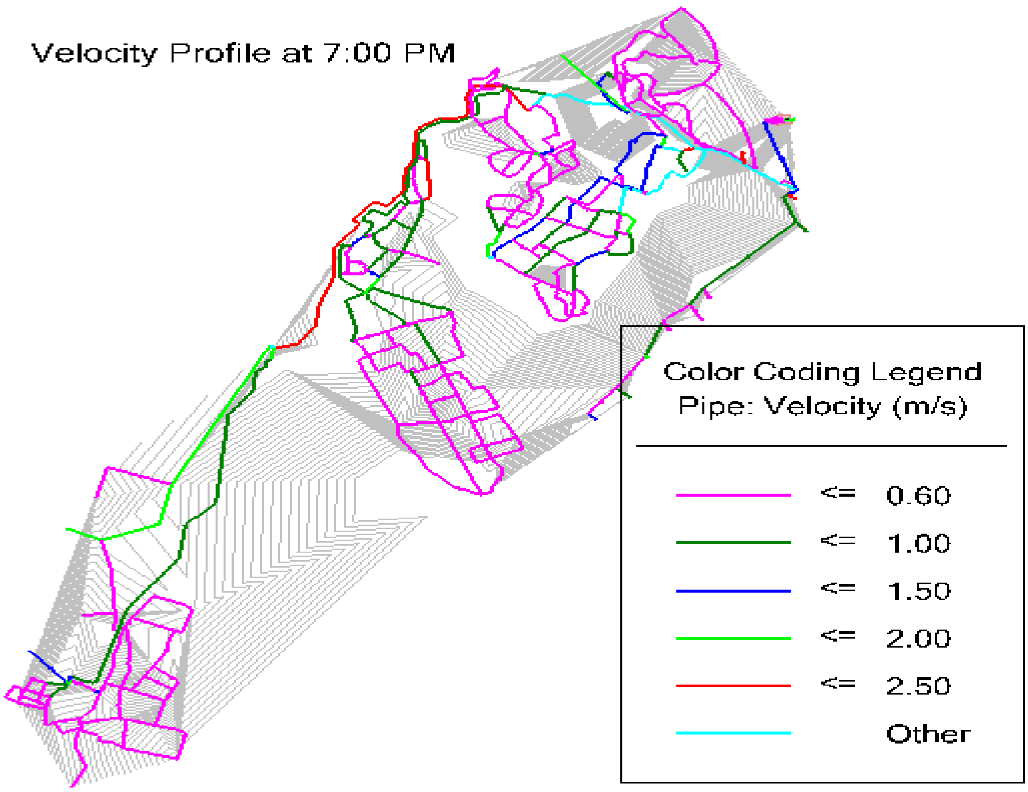

Figure 4.11 Velocity Distribution at peak hour consumption

The minimum and maximum recommended velocity for water supply distribution system is 0.6 m/s and 2.0 m/s respectively (MoWIE, 2006).

Table 4.11 Recommended velocity for design of WSDS

Velocity Range (m/s)	Status
<0.6	Sedimentation
0.6-2.0	Acceptable
>2.0	Erosion and high head loss

Table 4.12 Velocity distribution for Gondar Town water supply

Velocity (m/s)	Length of pipe (km)	Coverage (%)
<0.6	37.07	38.13
0.6 to 2.0	49.94	51.37
>2.0	10.21	10.50
Total	97.22	100

Based on table 4.12 and figure 4.11 the velocity coverage of Gondar Town water supply 38.13%, 51.37%, and 10.5% is in the range of <0.6m/s, 0.6 to 2.0m/s and >2m/s respectively. Approximately 48.63% the velocity distribution is not in the range of recommended values; this shows that there is a sedimentation and erosion problem in Gondar Town water supply system. The full tabular reports at 7:00 PM for velocities are shown in Appendix-F.

4.4.6 Pressure Distribution System

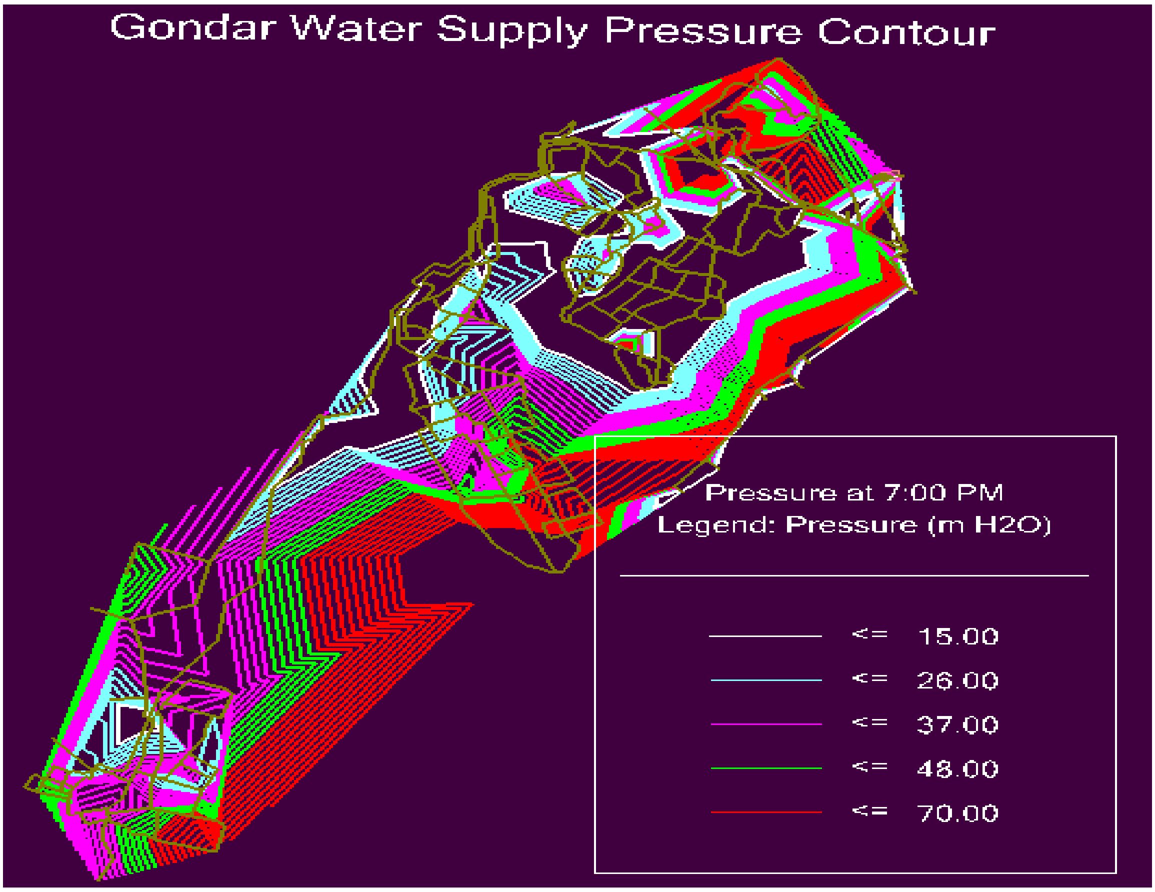

Figure 4.12 Pressure distribution at peak hour consumption

As shown in figure 4.12 the white color shows the pressure distribution less than or equal to 15 mH_2O (below the recommended pressure for design purpose) and the red color indicates that the pressure distribution greater than or equal to 70 mH_2O (above the recommended pressure for design) (see table 4.13 below). Water distribution systems are designed for optimal configuration that could satisfy minimum nodal pressure criteria at required flows.

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 difficultly to assess and compare the demand and loss of water in its spatial distribution. Pressure distribution system on the one hand 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 system has been shown to be directly proportional to the square root of the distribution system pressure (Wallingford, H., 2003).

The system losses are a function of the age of the system, minimum prescribed pressure, and maximum pressure in the system. Moreover, water leakage losses increase with the increase in system pressure in a water distribution system (Prabhata, K. and Ashok, K., 2008).

For any node in the network the pressure should not be less than 15 m of water. Moreover, the maximum pressure should be limited to 70m of water (MoWIE, 2006).

Table 4.13 Pressure range from WaterGEMS V8i analysis

Pressure (mH_2O)	Count	Coverage (%)
<15	74	39.57
15 to 70	98	52.41
>70	15	8.02
Total	187	100

According to this study, pressure range varied throughout the system. Table 4.13 shows; pressure ranges that count below, above and fulfill the criteria of Ethiopian design guideline are 39.57%, 8.02% and 52.41% respectively. The full tabular reports at 7:00 PM for pressure are shown in Appendix-G.

4.4.6 Pump

A pump is an element that adds energy to the system in the form of an increased hydraulic grade. Since water flows downhill (from higher energy to lower energy), pumps are used to boost the head at desired locations to overcome piping head losses and physical elevation differences.

4.4.6.1 Pump capacity curve

A pump curve shows the relationship between the head and flow rate that a pump can deliver at its nominal speed setting. An efficiency curve determines the efficiency of the pump in vertical percent as a function of pump flow rate in horizontal flow.

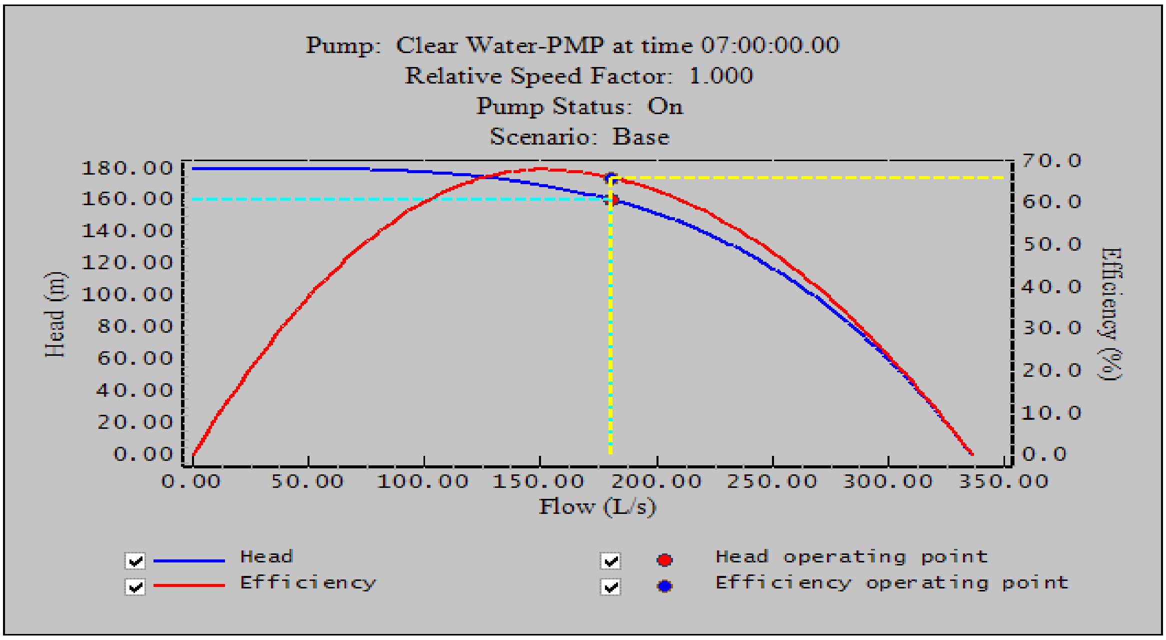

Figure 4.13 Pump head, efficiency and flow curve in the system (clear water pump)

As shown in figure 4.13 the blue curve indicates the head curve which shows a decreasing tendency throughout the system. The red curve indicates the efficiency curve which increases till it reaches the maximum efficiency operating point (67%) and decreases after maximum operating point throughout the flow system.

Generally, a good pump curve in water supply distribution system shows a decreasing head with an increasing flow (MoWIE, 2006).

4.4.7 Direction of Flow

The flow hydraulics covers the basic principles of flow such as continuity equation, equations of motion, and Bernoulli's equation for close conduit. Pipe flow is the most commonly used mode of carrying fluids for small to moderately large discharges (Prabhata, K. and Ashok, K., 2008).

As shown in figure 4.14 below the flow arrow symbol on the pipe indicates the direction of flow. If water is flowing from the end node to the start node, the flow arrow direction will point that way and the flow result value will be negative. A negative flow indicates orientation of flow with regard to the orientation of the pipe itself. Showing the negative sign in front of the calculated flow value is one way for the user to distinguish the current direction of flow.

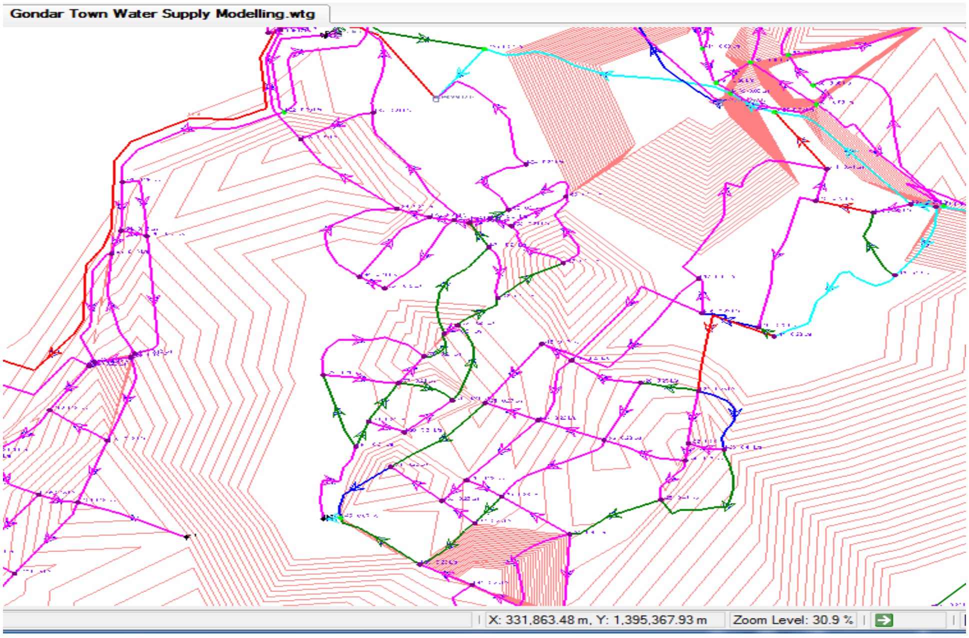

Figure 4.14 Layout of flow direction in the existing system

4.5 Calibrating Hydraulic Network Models

Model Calibration is vital to the creation of an accurate water distribution model that can successfully serve to both realistically reflect the behavior of the actual network being modeled and help to predict future changes in network conditions (Haestad Methods, 2002).

Calibration is the process of making small adjustments in order to achieve the best performance of a model results to field observations. The process of calibration may include changing system demands, fine-tuning the roughness of pipes, altering pump operating characteristics, and adjusting other model attributes that affect simulation results (Walski, 2000).

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.

Validation: Once a model is calibrated to match a given set of field data, the user can gain full confidence in the model by validating it, using additional sets of field data under different operational conditions (Bentley Water CAD, 2008). In performing validation, system demands, pipe roughness, initial conditions and operational regimes need to be adjusted to match the conditions at the time the additional field data set was collected.

4.5.1 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, tanks, pumps (Bentley WaterCAD/GEMs, 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.

4.5.1.1 Sampling Location

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 distribution mains, high pressure zone, low pressure zones, and leakage prone area at different zone in the systems (Thornton, 2003).

As shown in table 4.14 eighteen representative sampling points (eighteen data sets from observed and eighteen data sets from simulated) were taken. The water mains 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 only in this junction. The size of water main in the study model integrates a size greater or equal to 150 mm.

For the calibration, the head loss between the supply main nodes and the site where pressure is measured had been considered. The head loss included the elevation head and pipe friction loss between a two corresponding locations. These head losses and the total head loss are shown in table 4.14.

Table 4.14 Locations of samples of supply main nodes and the corresponding field test locations

S.N	Label	Sample Location			Corresponding field test location			Head loss between sample node and field test location		
		X	Y	Z	X	Y	Z	Elevation head (m)	Friction loss (m)	Total head loss (m)
1	J-8	334491	1394660	2222.1	334415	1394670	2222	0.10	0.05	0.15
2	J-40	333231	1392673	2158.3	333368	1392737	2156	2.30	0.74	3.04
3	J-41	333095	1393128	2100.0	333256	1393028	2100	0.00	0.75	0.75
4	J-42	333725	1395484	2269.9	333744	1395549	2269	0.90	0.43	1.33
5	J-50	334304	1396301	2220.2	334608	1395674	2220	0.20	0.03	0.23
6	J-60	334121	1395151	2132.5	334047	1395275	2131	1.50	0.02	1.52
7	J-64	333257	1394832	2098.6	333204	1394647	2095	3.60	0.51	4.11
8	J-68	333213	1394582	2089.0	333149	1394611	2089	0.08	0.28	0.36
9	J-67	333369	1394432	2069.3	333173	1394290	2069	0.30	0.01	0.31
10	J-92	332529	1395044	2114.0	332042	1394760	2113	1.00	0.34	1.34
11	J-106	331908	1393463	2082.1	331997	1393712	2082	0.10	1.23	1.33
12	J-144	332217	1390860	2015.0	332589	1390646	2015	0.00	0.08	0.08
13	J-131	330791	1392213	2039.0	329079	1388555	2039	0.05	0.16	0.21
14	J-146	330800	1392347	2020.4	330777	1392386	2019	1.40	0.02	1.42
15	J-136	329287	1390611	1993.0	329379	1390965	1991	2.00	0.09	2.09
16	J-183	329983	1387575	1963.8	329790	1387964	1962	1.80	0.02	1.82
17	J-152	328809	1388328	1997.0	328887	1388282	1996	1.00	0.07	1.07
18	J-139	332610	1391210	2050.0	332506	1391479	2047	3.00	0.03	3.03

4.5.1.2 Comparison of Pressures

Table 4.15 Comparison of simulated pressure results with field measured pressure data

S.N	Sample Node	Simulated model pressure (mH_2O)	Observed pressure (mH_2O)	Total head loss (m)	Error (m)	Time from Start (hr)
1	J-8	18.48	17.40	0.15	0.93	8:00-12:00 (AM)
2	J-40	12.09	10.52	3.04	-1.47	
3	J-41	69.97	67.00	0.75	2.22	
4	J-42	19.59	18.25	0.52	0.82	2:00-6:00 (PM)
5	J-50	68.07	67.52	0.23	0.32	
6	J-60	155.96	150.00	1.52	4.44	
7	J-64	9.34	7.50	4.11	-2.27	8:00-12:00 (PM)
8	J-68	18.46	17.20	0.36	0.90	
9	J-67	38.36	37.00	0.31	1.05	
10	J-92	7.01	6.50	1.38	-0.87	2:00-6:00 (AM)
11	J-106	30.12	28.36	1.33	0.43	
12	J-144	92.87	88.21	0.08	4.58	
13	J-131	2.67	2.00	0.21	0.46	8:00-12:00 (AM)
14	J-146	27.64	25.00	1.42	1.22	
15	J-136	48.05	46.00	2.09	-0.04	
16	J-183	66.34	60.89	1.82	3.63	2:00-6:00 (PM)
17	J-152	34.35	32.08	1.07	1.20	
18	J-139	57.89	56.10	3.03	-1.24	

Figure 4.15 below is illustrating plots of observed versus simulated pressure values along with minimum and maximum difference between them. The regression model accounts for

85% of the variance shows that there is a strong correlation between observed and simulated pressure values and the calculation detailed is attached in Appendix-M.

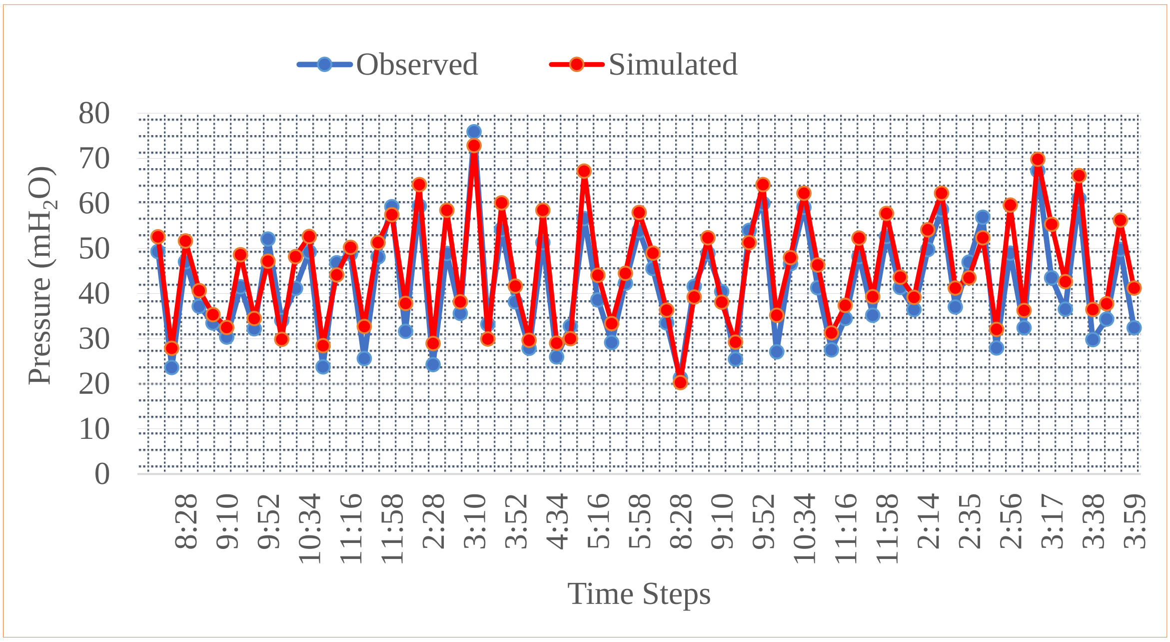

Figure 4.15 Model calibration using time series data

4.5.1.3 Correlation between Observed and Simulated Pressure

Figure 4.16 indicates plots of observed versus simulated pressure values of 18 sampled points that used for calibration of pressure along with minimum and maximum difference between them. The regression model accounts for 85.2% of the variance shows that there is a strong correlation between the observed and simulated pressure values in the network.

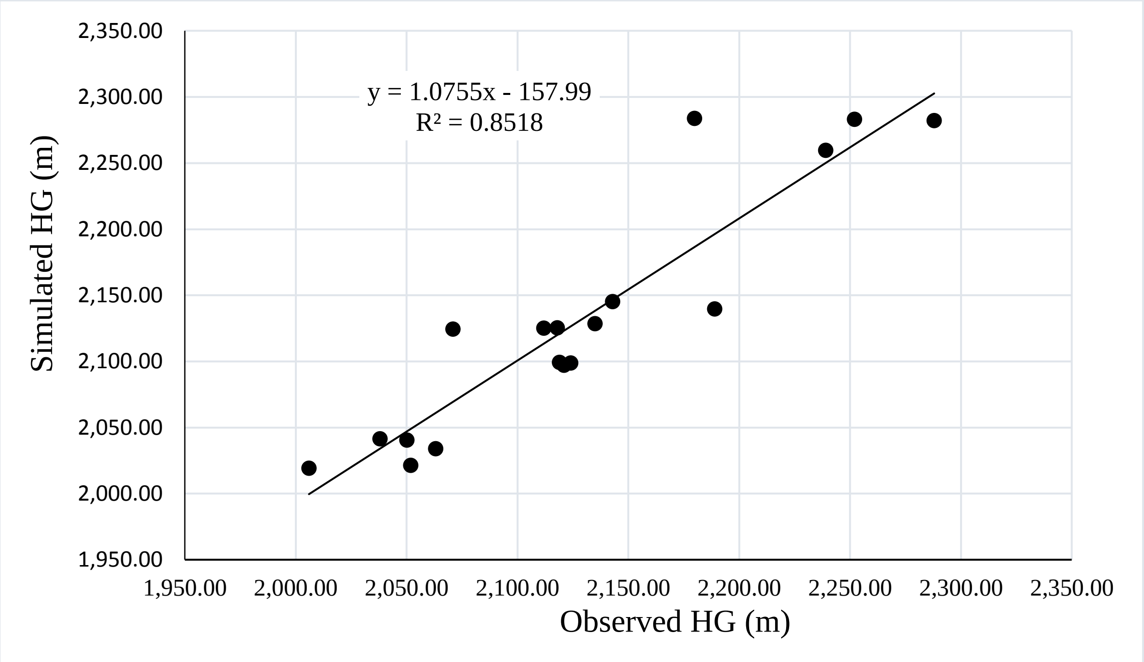

Figure 4.16 Correlation between observed and simulated pressure in the system

4.5.1.4 Correlation between Observed and Simulated Flow

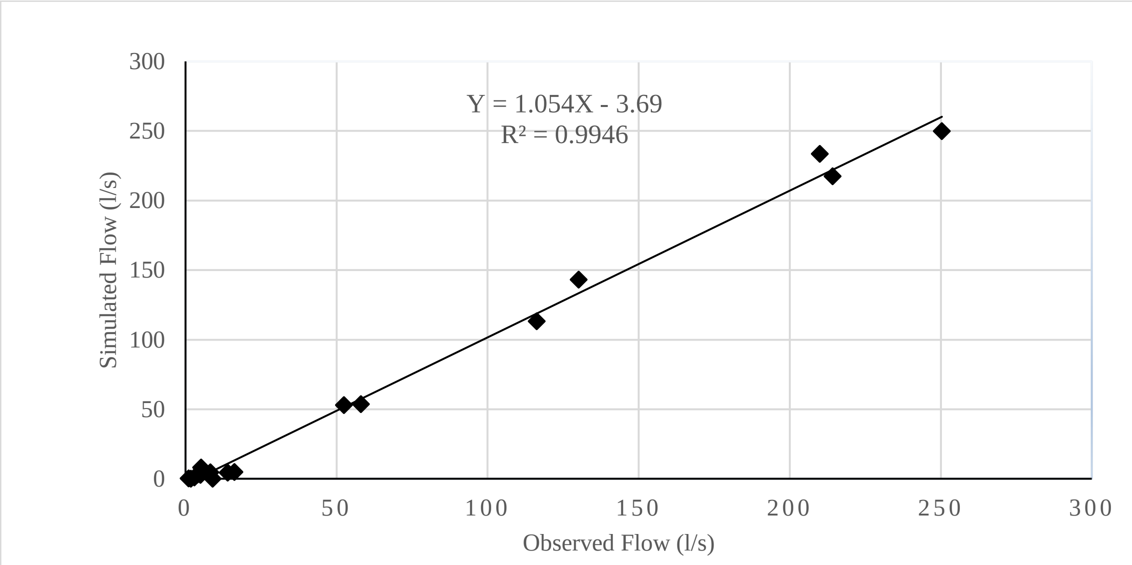

Figure 4.17 Correlation between observed and simulated flow in the system

Figure 4.17 states plots of observed versus simulated flow values of 18 sampled points that used for calibration of flow. The regression model accounts for 99% of the variance shows that there is a strong correlation between the observed and simulated flow values in the network.

4.5.1.5 Adjustment Groups

After calibration is done the original groups are changed in to adjustment groups. These adjustment groups are roughness (for selected pipe), demand (for selected junctions) and status of pipes (open to close or close to open). Lists of adjustment groups are shown in tabular form in Appendix-H and I.

Demand adjustments:

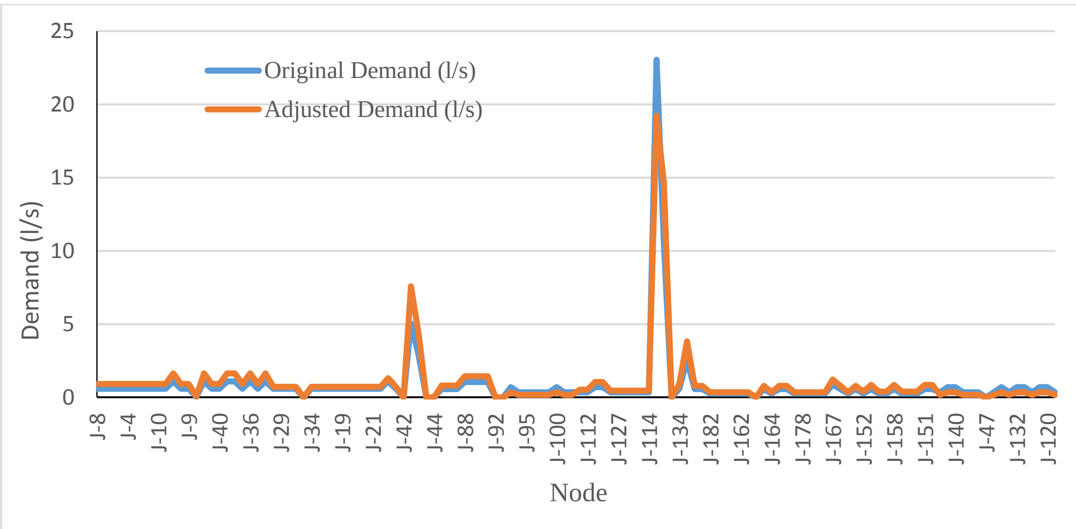

Figure 4.18 Original and Adjusted demands after model calibration

Figure 4.18 above is illustrating plots of original versus adjusted demand values along with minimum and maximum difference between them. The regression model accounts 93% of the variance shows that there is a strong correlation between the original and the adjusted demand values. The minimum and maximum original demand ranges 0 to 23 l/s and the adjusted demand ranges from 0 to 19 l/s as shown in figure 4.18 above. The maximum demand appears in areas where industries (Dashen Beer, Moha Soft Drinks Factory, and Cotton Plant) and modern hotels (Land Mark, Florida, and AG hotels) located.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The average water supply coverage and the city distribution system were evaluated based on the daily per capita consumption and level of connection using the population data of the city. The average water supply coverage of the city is found to be 25.53 liter/capita/day. This average per capita consumption is found lower than that of the standard set by EBCS 9 as a basic need (30 to 60 l/capita/day).

The total average annual water produced and distributed to Gondar Town water supply system in the last ten years was 2,690,785 m^3 while the average annual total water loss was 679,953m^3 which accounts 25.27% (3,984,524.58 birr lost every year in average) of the total water production in the last ten years. So, special attention must be given to overcome this loss.

For the water loss analysis water production and consumption data were taken. Despite the low water supply coverage of the town the total water loss is found to be high enough (up to 38.67%) in the year 2006. The total water loss was computed by subtracting the consumption from the water produced. Three approaches were used to compare the loss among the sub-system (a) the UFW expressed as a percentage, (b) loss per length of pipes and (c) loss per connections. The total water loss expressed as percentage is an important tool to know the extent of the loss within a given environment, comparison of losses from one location to another using the percentage has limitations as the percentage of loss highly depends on the amount of water produced. This is also the experience of many international comparisons as explained by the international water association (IWA) task forces. Depending on the hierarchy of the network system, both the loss per kilometers length of main pipes (m^3/km/day) and loss per connections (liters/connection/day) may be appropriate to measure the loss in the study area.

The water loss per service connection per day for Gondar Town was 279.92 liter/connection/day and water loss per kilometer length of main pipes was 156.12 m^3/km/day.

For the purpose of real loss determination, pursue readings were taken at different elevations and it was found that its magnitude is high in lower elevations. In addition, pressure magnitude was found to be higher during mid-night (between 1:00-4:00PM) at the time of most customers is not using water.

Unauthorized consumption volume of water which comprises of theft illegal connection and others was determined as 1,050m^3/year (2015) which covers 0.03% of the total loss. Non-Revenue Water (25.27% of System Input Volume) has a serious impact on Gondar water service finances as well as on available water resources in a water scarce environment. Especially, in 2006 this non-revenue water was above 38% but now it shows a decreasing tendency.

From the pressure measurement and burst frequency data it can be concluded that greater amount of leakage would occur in higher pressure zones as is proved by many researchers.

The infrastructure leakage index value (5.91) for this system shows that the current annual real losses are assessed as being around six times as high as the unavoidable annual real losses for the system. This value is in average condition in an international comparison context; however it cannot be acceptable based on the current water scarce situation of Gondar Town.

5.2 Recommendations

From the water meter test analysis it can be seen that sample amount of water is lost through meter under registration and customer meter calibration should be made periodically and those meters found nonfunctional and lower performance have to be replaced accordingly.

One main cause of water meter malfunctioning is age, therefore, water meters having service age of greater than 10 years should be replaced by new water meters. On the other hand DCI pipes that exceed 10 years should be replaced by the new ones or HDPE, uPVC, and PVC pipes must be used instead of DCI pipes to overcome corrosion of pipes.

In this study water losses only on the water supply distribution network has been assessed, but one of the main sources of water for the system of Gondar Town is surface water (Angereb Dam), that means there is high evaporation loss on the surface water; so another study must be conducted based on surface evaporation of the water loss on Angereb reservoir.

Leakage detector instruments (Geophones, Sounding Rod) must be full filled to identify the main causes of water loss that means leakage.

The water supply network of Gondar Town should be updated using Geographical Information System (GIS) and this need to be integrated with the Land Information System (LIS) of the town 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 ArcGIS/RS/ICT systems is timely it facilitates the updating of the networks and support to perform related spatial analysis.

The X, Y coordinates as well as elevations of customer water meters must be gathered and recorded to make a model using WaterGEMS with GIS integration/interface software, for more precise and faster way of modeling in demand allocation. Each customer account assigned an x-y coordinate in a GIS. Then, each account can be assigned to a node in the model based on polygons around each node in the GIS. By querying the customer information database, the average demand at each node for any billing period can be determined. The billing data must now be corrected for unaccounted-for water. When working with high-quality GIS data, the modeler can much more precisely assign demands to nodes. An integral part of creating a water distribution model is the accurate allocation of demands to the node elements within the model. The spatial analysis capabilities of GIS make it a logical tool for the automation of the demand allocation process.

Shortage of relevant data for the compilation of literature review, data would not organized in computerized system. A municipality must consider how it would collect, store, organize and evaluate the data to allow it to make the most informed decisions.

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APPENDICES

Appendix-A: Water Production, Consumption and Loss (last 10 years) (Source: GTWSSS Bill Data (2006 to 2015))

Time (Year)	Production (m3/year)	Consumption (m3/year)	Loss (m3/year)	NRW (%)
2006	2,383,933	1,462,071	921,862	38.67
2007	2,240,830	1,746,121	494,709	22.08
2008	2,322,056	1,694,382	627,674	27.03
2009	2,249,541	1,585,166	664,375	29.53
2010	2,426,240	1,824,321	601,919	24.81
2011	2,852,606	2,157,013	695,593	24.38
2012	2,888,175	2073646	814529	28.20
2013	2,980,066	2,368,481	611,585	20.52
2014	3,092,632	2,429,731	662,901	21.43
2015	3,471,767	2,767,383	704,384	20.29
AVG	2,690,785	2,010,832	679,953	25.27
MAX	3,471,767	2767383	814529	38.67
MIN	2,240,830	1,462,071	494,709	20.29

Appendix-B: Sub-cities of Gondar Town (GTWSSS, 2014)

Sub-city	Former Numbers	Population	Total Population	
			2007	2015
Abajale	11+12	12,458+7,498	19,956	28,628
Abiye Izgi	10+17	18,145+6,406	24,551	35,220
Adebabay Eyesus	4+5	9,067+6,281	15,348	22,018
Arbegnoch	1+2	10,088+6,436	16,524	23,705
Azezo Ayermarefia	20+21	15,373+7,256	22,629	32,463
Azezo Demaza	19	17627	17,627	25,287
Cherkos	6+7+8	6,467+8,434+9,480	24,381	34,976
Gebireal	14+15	9,111+6,231	15,342	22,009
Lideta	16	7,348	7,348	10,541
Maraki	18	14,734	14,734	21,137
Medhaniyalem	3+13	11,285+13,760	25,045	35,929
Mehal Arada	9	3,502	3,502	5,024
Total			206,987	296,937

Appendix-C: Missed Data Filling (Survey Data, 2016)

No	Type of Data		Easting	Northing	Elevation	Material Used
1	Junctions	J-1	333,497.33	1,391,589.05	2,082	GPS (GARMIN 72)
		J-2	333,735.54	1,391,878.09	2,086	
		J-3	333,989.67	1,392,253.74	2,100	
		J-4	334,139.91	1,392,650.60	2,097	
		J-5	334,370.86	1,392,849.46	2,089	
		J-6	334,483.61	1,393,036.86	2,068	
		J-7	335,276.32	1,393,808.74	2,089	
		J-8	334,314.22	1,394,795.65	2,238	
		J-9	334,238.09	1,394,805.65	2,237	
		J-10	334,126.32	1,394,771.76	2,203	
		J-11	333,986.84	1,394,947.85	2,194	
		J-12	333,953.20	1,394,819.43	2,196	
		J-13	334,190.51	1,394,518.03	2,198	

		J-14	333,827.59	1,394,269.60	2,196
		J-15	333,779.85	1,394,307.04	2,195
		J-16	333,610.69	1,394,363.58	2,186
		J-17	333,600.24	1,394,503.91	2,187
		J-18	333,304.39	1,394,104.28	2,180
		J-19	333,394.01	1,394,037.34	2,174
2	Tank	Azezo	329,079.16	1,388,555.00	2,018
		Fire Brigade	333,841.00	1,395,079.00	2,198
		Back Wash	335,222.45	1,394,256.62	2,137
3	Reservoir	Dokemit	334,824.73	1,394,628.25	2,298
		Felefelit	333,272.18	1,395,747.85	2,224
		Sanita-1	328,719.03	1,388,832.34	2,030
		Sanita-2	329,018.92	1,390,258.96	2,054
		NW4	334,005.00	1,392,232.00	2,051
		NW5	334,485.00	1,392,662.00	2,066
4	Pump	GTW-7	334,518.19	1,392,971.09	2,067
		TW-5	334,168.25	1,392,604.22	2,060
		TW-6	335,321.37	1,393,752.83	2,088

Appendix-D: Flow Measured at Field Survey (Survey Data, 2016)

Flow Measured by Ultrasonic Flow meter and Mechanical Meter Installed						
No	Date	Sample Area	Duration (min)	Flow Recorded (Ultrasonic Flow meter)	Flow Recorded (Mechanical Flow meter)	Zone
				m^3/h	m^3/h	-
1	7/15/2016	Angereb TP	20	350.26	333.09	-
2	7/15/2016	NW4	5	21.29	22.5	-
3	7/15/2016	NW5	5	50.21	47.88	-
4	7/17/2016	TW5	5	8	7.44	-
5	7/17/2016	TW6	5	15.13	12	-
6	7/17/2016	GTW7	5	29.63	45	-
7	7/18/2016	SR	19	476.34	414.58	1
8	7/18/2016	BSR	31	45.45	43.24	1
9	7/18/2016	SROL	31	525.71	500	1
10	7/20/2016	GoROL	4	6.41	7.61	2
11	7/20/2016	GROL	19	233.89	240	3
12	7/20/2016	StROL	19	61.62	64.86	4
13	7/20/2016	SaROL	19	43.34	72	5
14	7/22/2016	AROL	19	47.66	43.45	6
15	7/22/2016	GUH	9	4.02	5.45	4
16	7/22/2016	GUMC	19	21.41	30	5
17	7/22/2016	DB	5	3.72	6.67	5
18	7/23/2016	CP	10	2.63	2.51	5

Appendix-E: Methods of Supply from Service Reservoirs (GTWSSS, 2014)

SN	Reservoir Name	Supplied From	Supplied To	Method of Supply	
				Pumping	Gravity
1	Azezo	Gebreal Reservoir	Azezo Dimaza & Ayermarefiya		*
2	Debrebirhan Sillassie	Clear Water Reservoir	Arada, Piazza, & All Gravity Reservoirs		*
3	Fire Birgade (Booster)	Debrebirhan Sillassie	Goha Reservoir	*	
4	Gebreal	Debrebirhan Sillassie	Autoparko		*
5	Goha	Fire Birgade (Booster)	Bilko, Weleka		*
6	Samuna Ber	Debrebirhan Sillassie	Samuna Ber, Gondar University, Shenta, & Dashen Brewery		*

7	Stadium	Debrebirhan Sillassie	Stadium, Kebele 18, Fasiledes, Hospital & some part of Lideta		*
8	CWT (Booster)	Angereb Dam& All Borehole's	Debrebirhan Sillasse	*	
9	Back Wash	Clear Water	For cleaning of sand filter & otherpurposes around Treatment Plant		*

Appendix-F: Pipe Table (Extended Period Simulation) (Model Analysis, 2016)

FlexTable: Pipe Table						
Current Time: 7:00 hours						
Label	Diameter (mm)	Material	Length (m)	Velocity (m/s)	Travel Time (hours)	Head loss (Friction) (m)
P-1	80.0	DCI	1,439	0.16	2.537	0.74
P-2	100.0	DCI	349	0.39	0.246	0.76
P-3	80.0	DCI	946	1.05	0.250	16.32
P-4	300.0	DCI	2,000	3.69	0.150	76.03
P-5	200.0	DCI	812	0.39	0.572	0.78
P-6	150.0	PVC	365	0.84	0.121	1.53
P-7	100.0	PVC	95	2.82	0.009	6.04
P-8	100.0	PVC	186	0.42	0.124	0.34
P-9	100.0	PVC	7	0.84	0.002	0.05
P-10	100.0	PVC	65	0.16	0.111	0.02
P-11	80.0	PVC	623	0.05	3.583	0.03
P-12	100.0	PVC	65	0.33	0.054	0.08
P-13	100.0	PVC	75	0.08	0.277	0.01
P-14	100.0	PVC	45	0.67	0.019	0.20
P-15	100.0	PVC	30	0.43	0.019	0.06
P-16	100.0	PVC	40	0.45	0.025	0.09
P-17	100.0	PVC	123	0.02	1.480	0.00
P-18	100.0	PVC	80	0.08	0.286	0.01
P-19	100.0	PVC	145	0.06	0.642	0.01
P-20	100.0	PVC	100	0.10	0.265	0.01
P-21	150.0	PVC	123	0.06	0.594	0.00
P-22	100.0	PVC	16	0.21	0.021	0.01
P-23	100.0	PVC	189	0.10	0.506	0.03
P-24	100.0	PVC	78	0.02	1.097	0.00
P-25	100.0	PVC	102	0.13	0.223	0.02
P-26	100.0	PVC	81	0.52	0.043	0.23
P-27	80.0	PVC	563	0.16	0.954	0.24
P-28	100.0	PVC	80	2.87	0.008	5.28
P-29	100.0	PVC	189	0.41	0.127	0.34
P-30	100.0	PVC	140	0.31	0.125	0.15
P-31	100.0	PVC	65	0.40	0.045	0.11
P-32	100.0	PVC	208	0.22	0.258	0.12
P-33	100.0	PVC	91	0.03	0.726	0.00
P-34	100.0	PVC	201	0.69	0.081	0.93
P-35	80.0	HDPE	26	0.21	0.034	0.02
P-36	100.0	HDPE	86	1.33	0.018	1.36
P-37	100.0	HDPE	259	0.51	0.142	0.69
P-38	100.0	HDPE	86	0.15	0.158	0.02
P-39	100.0	HDPE	165	0.19	0.236	0.07
P-40	100.0	HDPE	410	0.23	0.487	0.26
P-41	100.0	HDPE	302	0.10	0.850	0.04
P-42	100.0	HDPE	68	0.93	0.020	0.55
P-43	100.0	HDPE	190	0.17	0.311	0.07
P-44	100.0	HDPE	33	0.55	0.017	0.10
P-45	100.0	PVC	209	0.15	0.380	0.06
P-46	100.0	PVC	95	0.88	0.030	0.70
P-47	100.0	PVC	78	0.20	0.109	0.04

P-48	100.0	PVC	84	0.01	2.541	0.00
P-49	100.0	PVC	189	0.26	0.203	0.14
P-50	100.0	PVC	19	0.88	0.006	0.14
P-51	100.0	PVC	38	0.42	0.025	0.07
P-52	100.0	PVC	200	0.74	0.075	1.07
P-53	100.0	PVC	189	0.59	0.089	0.67
P-54	100.0	PVC	312	0.26	0.330	0.25
P-55	100.0	PVC	85	3.44	0.007	7.82
P-56	100.0	PVC	321	0.04	2.048	0.01
P-57	80.0	PVC	800	0.07	3.054	0.08
P-58	100.0	PVC	200	0.02	3.493	0.00
P-59	100.0	PVC	369	0.39	0.265	0.59
P-60	100.0	PVC	115	0.18	0.182	0.04
P-61	80.0	PVC	632	0.05	3.586	0.03
P-62	100.0	DCI	296	0.07	1.103	0.03
P-63	100.0	DCI	368	0.26	0.399	0.36
P-64	80.0	DCI	666	0.05	4.007	0.04
P-65	100.0	DCI	165	1.00	0.046	2.00
P-66	100.0	DCI	15	0.55	0.008	0.06
P-67	150.0	DCI	648	0.15	1.235	0.14
P-68	100.0	DCI	185	0.03	1.875	0.00
P-69	100.0	DCI	68	0.41	0.046	0.16
P-70	100.0	DCI	290	0.28	0.285	0.34
P-71	150.0	DCI	454	0.76	0.167	2.05
P-72	100.0	DCI	296	0.07	1.117	0.03
P-73	100.0	DCI	112	0.26	0.118	0.12
P-74	100.0	GI	177	0.17	0.291	0.09
P-75	100.0	GI	46	0.36	0.035	0.10
P-76	100.0	GI	5	1.09	0.001	0.08
P-77	100.0	GI	66	0.03	0.631	0.00
P-78	100.0	GI	139	0.84	0.046	1.42
P-79	100.0	GI	139	0.56	0.069	0.67
P-80	100.0	GI	34	0.66	0.014	0.22
P-81	100.0	DCI	100	0.01	3.225	0.00
P-82	100.0	DCI	356	0.38	0.258	0.73
P-83	100.0	DCI	359	0.31	0.327	0.49
P-84	100.0	PVC	74	0.33	0.062	0.09
P-85	100.0	PVC	82	0.52	0.044	0.22
P-86	100.0	PVC	146	0.90	0.045	1.12
P-87	100.0	PVC	61	0.12	0.145	0.01
P-88	100.0	PVC	65	0.62	0.029	0.25
P-89	100.0	PVC	32	1.56	0.006	0.68
P-90	100.0	PVC	140	0.21	0.186	0.07
P-91	100.0	PVC	125	0.35	0.100	0.17
P-92	100.0	PVC	625	0.07	2.667	0.04
P-93	100.0	PVC	265	0.13	0.561	0.06
P-94	100.0	PVC	364	0.15	0.682	0.10
P-95	150.0	PVC	343	0.59	0.161	0.75
P-96	100.0	PVC	368	0.11	0.931	0.06
P-97	100.0	PVC	60	0.15	0.113	0.02
P-98	150.0	PVC	424	0.72	0.163	1.34
P-99	100.0	PVC	98	1.39	0.020	1.68
P-100	100.0	PVC	127	0.01	2.646	0.00
P-101	100.0	PVC	456	0.29	0.441	0.42
P-102	100.0	PVC	270	0.55	0.137	0.83
P-103	100.0	PVC	96	0.03	0.912	0.00
P-104	100.0	PVC	365	1.31	0.077	5.64
P-105	100.0	PVC	200	0.72	0.077	1.02
P-106	100.0	PVC	99	4.47	0.006	14.81
P-107	100.0	DCI	168	0.01	3.693	0.00

P-108	100.0	DCI	210	0.02	2.937	0.00
P-109	100.0	DCI	146	0.59	0.069	0.67
P-110	100.0	DCI	369	0.17	0.612	0.16
P-111	100.0	GI	230	0.12	0.532	0.06
P-112	100.0	GI	48	1.07	0.012	0.77
P-113	150.0	GI	394	0.67	0.162	1.67
P-114	100.0	GI	132	0.95	0.039	1.69
P-115	150.0	GI	244	0.13	0.521	0.05
P-116	100.0	GI	214	0.62	0.096	1.25
P-117	100.0	GI	156	0.12	0.373	0.04
P-118	100.0	GI	294	0.04	2.059	0.01
P-119	100.0	GI	159	0.17	0.254	0.09
P-120	100.0	GI	162	0.48	0.093	0.60
P-121	100.0	GI	269	0.00	21.088	0.00
P-122	100.0	DCI	53	0.30	0.048	0.07
P-123	100.0	DCI	93	0.85	0.030	0.84
P-124	100.0	DCI	362	0.70	0.144	2.26
P-125	100.0	PVC	125	0.79	0.044	0.75
P-126	100.0	PVC	375	2.05	0.051	13.27
P-127	100.0	PVC	375	0.12	0.902	0.06
P-128	80.0	PVC	2,258	0.21	2.922	1.58
P-129	100.0	PVC	614	1.62	0.105	13.97
P-130	100.0	PVC	166	0.26	0.175	0.13
P-131	100.0	PVC	435	0.14	0.865	0.11
P-132	100.0	PVC	107	0.33	0.091	0.13
P-133	100.0	PVC	75	0.19	0.111	0.03
P-134	100.0	PVC	117	0.25	0.131	0.08
P-135	80.0	PVC	534	0.24	0.607	0.48
P-136	100.0	PVC	150	0.50	0.083	0.39
P-137	80.0	PVC	542	0.07	2.042	0.05
P-138	100.0	PVC	306	0.13	0.636	0.07
P-139	100.0	PVC	49	0.47	0.029	0.11
P-140	100.0	PVC	69	0.46	0.042	0.15
P-141	100.0	PVC	91	0.00	5.767	0.00
P-142	100.0	PVC	369	0.15	0.667	0.11
P-143	100.0	PVC	102	0.61	0.046	0.38
P-144	100.0	PVC	44	0.49	0.025	0.11
P-145	100.0	PVC	196	1.86	0.029	5.81
P-146	100.0	PVC	279	0.27	0.290	0.23
P-147	100.0	PVC	33	0.35	0.026	0.04
P-148	100.0	PVC	236	0.36	0.181	0.34
P-149	100.0	PVC	73	0.28	0.073	0.06
P-150	150.0	PVC	284	0.21	0.384	0.09
P-151	300.0	PVC	94	3.19	0.008	2.08
P-152	80.0	PVC	734	0.01	25.677	0.00
P-153	100.0	PVC	77	0.01	3.067	0.00
P-154	100.0	PVC	269	0.12	0.618	0.05
P-155	80.0	PVC	721	0.07	2.847	0.06
P-156	100.0	PVC	30	0.14	0.060	0.01
P-157	100.0	PVC	39	1.90	0.006	1.20
P-158	100.0	PVC	106	0.40	0.074	0.18
P-159	100.0	DCI	40	0.51	0.022	0.14
P-160	100.0	DCI	236	0.88	0.075	2.26
P-161	100.0	DCI	123	0.80	0.043	1.00
P-162	200.0	GI	510	0.37	0.384	0.51
P-163	100.0	GI	132	0.21	0.175	0.10
P-164	100.0	GI	123	0.05	0.683	0.01
P-165	100.0	GI	200	0.02	2.290	0.00
P-166	100.0	GI	84	0.57	0.041	0.42

P-167	150.0	GI	305	0.86	0.098	2.05
P-168	100.0	GI	59	0.19	0.085	0.04
P-169	100.0	GI	120	0.07	0.461	0.01
P-170	100.0	GI	143	0.00	7.970	0.00
P-171	100.0	GI	451	0.52	0.240	1.90
P-172	100.0	GI	420	0.35	0.333	0.85
P-173	250.0	GI	482	0.60	0.222	0.92
P-174	100.0	GI	216	0.59	0.102	1.14
P-175	100.0	GI	369	0.05	2.129	0.02
P-176	100.0	GI	45	0.30	0.042	0.07
P-177	100.0	GI	28	0.02	0.416	0.00
P-178	100.0	HDPE	210	0.01	4.694	0.00
P-179	100.0	HDPE	150	0.29	0.142	0.14
P-180	100.0	HDPE	210	0.04	1.440	0.01
P-181	100.0	HDPE	42	1.48	0.008	0.81
P-182	100.0	PVC	159	0.69	0.064	0.75
P-183	100.0	PVC	168	0.14	0.336	0.04
P-184	100.0	PVC	189	0.35	0.149	0.25
P-185	100.0	PVC	30	0.00	2.274	0.00
P-186	100.0	PVC	200	0.04	1.490	0.00
P-187	100.0	PVC	201	0.80	0.070	1.23
P-188	100.0	PVC	30	0.68	0.012	0.14
P-189	100.0	PVC	75	0.34	0.061	0.10
P-190	100.0	PVC	20	0.26	0.022	0.02
P-191	100.0	PVC	189	0.30	0.178	0.18
P-192	150.0	PVC	252	1.15	0.061	1.90
P-193	100.0	PVC	19	0.10	0.050	0.00
P-194	100.0	PVC	286	0.90	0.088	2.21
P-195	100.0	PVC	16	1.40	0.003	0.28
P-196	100.0	PVC	125	0.31	0.111	0.14
P-197	200.0	PVC	442	0.92	0.134	1.57
P-198	100.0	PVC	70	1.31	0.015	1.08
P-199	100.0	PVC	90	0.12	0.209	0.02
P-200	150.0	PVC	249	0.87	0.079	1.12
P-201	100.0	PVC	189	0.16	0.336	0.06
P-202	100.0	PVC	89	0.02	1.142	0.00
P-203	100.0	PVC	75	0.03	0.600	0.00
P-204	80.0	PVC	773	0.15	1.440	0.28
P-205	100.0	PVC	200	0.34	0.165	0.25
P-206	100.0	PVC	200	0.21	0.261	0.11
P-207	100.0	PVC	100	0.38	0.074	0.15
P-208	100.0	PVC	65	0.29	0.063	0.06
P-209	100.0	DCI	5	2.25	0.001	0.27
P-210	80.0	DCI	510	1.05	0.135	8.80
P-211	80.0	DCI	511	0.96	0.147	7.53
P-212	80.0	DCI	557	0.96	0.160	8.20
P-213	100.0	DCI	100	0.57	0.049	0.42
P-214	80.0	DCI	508	1.62	0.087	19.64
P-215	80.0	DCI	515	1.62	0.088	19.91
P-216	150.0	DCI	575	0.48	0.334	1.11
P-217	100.0	DCI	4	0.30	0.004	0.01
P-218	100.0	DCI	6	0.30	0.006	0.01
P-219	150.0	DCI	493	0.89	0.153	3.03
P-220	100.0	DCI	6	0.49	0.003	0.02
P-221	100.0	DCI	79	0.49	0.045	0.26
P-222	200.0	DCI	579	0.55	0.292	1.04
P-223	80.0	DCI	508	0.58	0.245	2.89
P-224	80.0	DCI	520	0.58	0.251	2.96
P-225	200.0	DCI	478	0.65	0.206	1.15

P-226	80.0	DCI	511	0.95	0.149	7.32
P-227	80.0	DCI	543	0.95	0.159	7.78
P-228	200.0	PVC	1,273	0.71	0.497	2.82
P-229	300.0	DCI	120	1.94	0.017	1.38
P-230	300.0	DCI	119	2.56	0.013	2.29
P-231	250.0	DCI	280	0.20	0.386	0.06
P-232	250.0	DCI	319	3.58	0.025	14.15
P-233	80.0	DCI	711	0.04	4.721	0.03
P-234	80.0	DCI	866	0.02	14.179	0.01
P-235	80.0	DCI	1,521	0.02	16.994	0.03
P-236	80.0	DCI	1,119	0.01	54.255	0.00
P-237	80.0	DCI	1,137	0.16	2.029	0.57
P-238	80.0	DCI	1,668	0.07	7.095	0.17
P-239	80.0	DCI	603	0.09	1.851	0.11
P-240	100.0	DCI	68	0.24	0.080	0.06
P-241	80.0	DCI	615	0.10	1.667	0.14
P-242	80.0	DCI	513	0.28	0.516	0.75
P-243	80.0	DCI	518	0.18	0.813	0.33
P-244	100.0	DCI	27	1.04	0.007	0.27
P-245	100.0	DCI	30	0.58	0.014	0.10
P-246	80.0	DCI	543	2.53	0.060	47.71
P-247	100.0	DCI	78	0.00	(N/A)	0.00
P-248	100.0	DCI	12	0.04	0.095	0.00
P-249	250.0	DCI	415	4.24	0.027	25.23
P-250	100.0	DCI	98	0.84	0.032	0.87
P-251	250.0	DCI	275	4.38	0.017	17.73
P-252	250.0	DCI	545	4.38	0.035	35.14
P-253	150.0	DCI	233	1.10	0.059	2.10
P-254	150.0	DCI	658	1.10	0.167	5.92
P-255	300.0	DCI	132	0.48	0.076	0.12
P-256	300.0	DCI	132	0.48	0.076	0.12
P-257	300.0	DCI	132	0.48	0.076	0.12
P-258	300.0	DCI	133	0.48	0.076	0.12
P-259	300.0	DCI	100	1.94	0.014	1.15
P-260	300.0	DCI	111	0.48	0.064	0.10
P-261	300.0	DCI	110	0.48	0.063	0.10
P-262	300.0	DCI	111	0.48	0.064	0.10
P-263	300.0	DCI	112	0.48	0.064	0.10
P-264	350.0	DCI	50	1.42	0.010	0.27
P-265	350.0	DCI	560	1.42	0.109	3.04
P-266	300.0	DCI	106	2.56	0.012	2.04
P-267	300.0	DCI	114	2.56	0.012	2.20
P-268	300.0	DCI	786	2.56	0.085	15.14
P-269	250.0	DCI	225	0.00	(N/A)	0.00
P-270	250.0	DCI	227	0.00	(N/A)	0.00
P-271	200.0	DCI	621	0.84	0.206	2.42
P-272	200.0	DCI	387	1.40	0.077	3.91
P-273	100.0	DCI	12	2.25	0.001	0.66
P-274	100.0	DCI	156	0.00	(N/A)	0.00
P-275	150.0	PVC	342	0.68	0.139	0.99
P-276	100.0	PVC	298	0.83	0.100	1.98
P-277	100.0	PVC	90	0.94	0.027	0.75
P-278	100.0	DCI	326	0.39	0.230	0.71
P-279	100.0	PVC	123	0.18	0.195	0.05
P-280	100.0	PVC	101	0.25	0.113	0.07
P-281	100.0	PVC	300	0.06	1.292	0.02
P-282	100.0	PVC	181	0.68	0.074	0.83
P-283	100.0	DCI	151	0.73	0.057	1.03
P-284	100.0	DCI	26	0.42	0.017	0.06

P-285	100.0	PVC	297	0.22	0.381	0.16
P-286	100.0	DI	228	0.27	0.231	0.25
P-287	100.0	PVC	384	0.09	1.175	0.04
P-288	100.0	PVC	75	0.03	0.810	0.00
P-289	100.0	GI	306	0.22	0.386	0.26
P-290	100.0	PVC	241	0.13	0.507	0.05
P-291	100.0	PVC	105	0.56	0.052	0.34
P-292	150.0	PVC	484	0.43	0.309	0.60
P-293	100.0	PVC	185	0.21	0.246	0.10
P-294	100.0	PVC	174	0.16	0.308	0.05
P-295	100.0	PVC	152	0.07	0.601	0.01
P-296	100.0	PVC	166	0.09	0.523	0.02
P-297	250.0	DCI	1,008	1.26	0.223	6.43
P-298	200.0	DCI	629	0.00	(N/A)	0.00
P-299	200.0	PVC	852	0.03	9.097	0.00
P-300	250.0	PVC	678	1.96	0.096	7.58
P-301	250.0	PVC	461	1.98	0.065	5.26
P-302	200.0	PVC	1,114	0.03	9.084	0.01
P-303	200.0	PVC	486	0.00	(N/A)	0.00
P-304	200.0	PVC	551	0.00	(N/A)	0.00
P-305	300.0	DCI	3,250	2.53	0.357	61.25
P-306	150.0	DCI	270	3.32	0.023	18.89
P-307	80.0	DCI	1,000	0.02	14.485	0.01
P-308	100.0	DCI	64	0.26	0.069	0.05
P-309	80.0	PVC	1,150	0.02	14.116	0.01
P-310	100.0	DCI	74	0.06	0.368	0.00
P-311	100.0	DCI	97	0.18	0.152	0.05
P-312	150.0	DCI	293	0.41	0.197	0.43
P-313	250.0	DCI	293	0.20	0.405	0.06
P-314	250.0	DCI	419	0.80	0.145	1.17
P-315	250.0	DCI	672	0.60	0.310	1.10
P-316	250.0	DCI	353	2.15	0.046	6.12
P-317	150.0	DCI	239	2.09	0.032	7.12
P-318	150.0	DCI	366	2.09	0.048	10.91
P-319	150.0	DCI	1,103	1.72	0.178	22.93
P-320	250.0	DCI	305	0.00	(N/A)	0.00
P-321	250.0	DCI	783	0.00	(N/A)	0.00
P-322	150.0	DCI	234	0.62	0.105	0.73
P-323	150.0	DCI	296	0.62	0.133	0.92
P-324	150.0	DCI	722	0.56	0.357	1.88
P-325	250.0	DCI	908	1.87	0.135	12.16

Gondar Town Water Supply Modelling.wtg	Bentley Systems, Inc. Haestad Methods Solution Center	Bentley WaterGEMS V8i (SELECTseries 6) [08.11.06.58]
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Appendix-G: Junction Table (Extended Period Simulation) (Model Analysis, 2016)

Flex Table: Junction Table						
Current Time: 7:00 hours						
Label	X (m)	Y (m)	Elevation (m)	Demand (L/s)	Hydraulic Grade (m)	Pressure (m H2O)
J-1	333,497.33	1,391,589.05	2,082.00	0.83	2,156.65	74.50
J-2	333,735.54	1,391,878.09	2,086.00	0.83	2,156.22	70.08
J-3	333,989.67	1,392,253.74	2,100.00	0.83	2,155.11	55.00
J-4	334,139.91	1,392,650.60	2,097.00	0.83	2,152.08	54.97
J-5	334,370.86	1,392,849.46	2,089.00	0.83	2,151.05	61.92
J-6	334,483.61	1,393,036.86	2,068.00	0.83	2,149.89	81.73
J-7	335,276.32	1,393,808.74	2,089.00	0.83	2,147.07	57.96
J-8	334,490.77	1,394,659.85	2,200.00	0.83	2,203.48	3.48
J-9	334,414.63	1,394,669.85	2,202.00	0.83	2,201.40	-0.60
J-10	334,302.87	1,394,635.96	2,187.00	0.83	2,188.13	1.12
J-11	334,163.39	1,394,812.05	2,177.00	1.49	2,177.04	0.04
J-12	334,129.75	1,394,683.63	2,181.00	0.83	2,182.85	1.84
J-13	334,367.05	1,394,382.23	2,187.00	0.83	2,188.68	1.67
J-14	334,004.13	1,394,133.80	2,179.00	0.83	2,180.86	1.86
J-15	333,956.40	1,394,171.24	2,180.00	0.83	2,180.64	0.64
J-16	333,787.23	1,394,227.77	2,173.00	0.83	2,175.00	1.99
J-17	333,776.79	1,394,368.11	2,169.00	1.49	2,175.06	6.05
J-18	333,304.39	1,394,104.28	2,172.00	0.83	2,173.16	1.16
J-19	333,394.01	1,394,037.34	2,174.00	0.83	2,173.64	-0.36
J-20	333,601.81	1,393,945.98	2,168.00	0.83	2,174.12	6.11
J-21	333,776.34	1,393,912.82	2,170.00	0.83	2,174.82	4.81
J-22	333,746.20	1,393,700.45	2,176.00	0.83	2,173.97	-2.03
J-23	333,853.45	1,393,676.47	2,166.00	1.49	2,174.01	8.00
J-24	333,735.94	1,393,631.26	2,171.00	0.83	2,173.30	2.29
J-25	333,663.03	1,393,472.88	2,171.00	1.49	2,173.26	2.26
J-26	333,492.53	1,393,714.27	2,168.00	0.83	2,172.87	4.86
J-27	333,294.05	1,393,795.25	2,171.00	0.83	2,172.87	1.87
J-28	333,134.74	1,393,865.38	2,171.00	0.83	2,172.14	1.14
J-29	333,077.77	1,393,551.56	2,170.00	0.83	2,171.74	1.73
J-30	333,183.78	1,393,485.27	2,169.00	0.83	2,171.64	2.64
J-31	333,388.23	1,393,332.51	2,171.00	1.49	2,171.57	0.57
J-32	333,102.54	1,393,378.10	2,168.00	0.83	2,170.22	2.21
J-33	333,004.51	1,393,468.46	2,171.00	0.83	2,170.15	-0.84
J-34	332,850.20	1,393,606.15	2,163.00	0.83	2,170.14	7.12
J-35	332,936.49	1,393,210.70	2,170.00	0.83	2,169.97	-0.03
J-36	333,256.03	1,393,028.02	2,169.00	1.49	2,170.86	1.85
J-37	333,374.96	1,393,006.35	2,166.00	1.49	2,170.90	4.89
J-38	333,374.72	1,392,972.42	2,163.00	0.83	2,170.86	7.84
J-39	333,368.15	1,392,736.50	2,162.00	1.49	2,170.85	8.83
J-40	333,231.28	1,392,673.36	2,158.00	0.83	2,170.11	12.09
J-41	333,094.85	1,393,128.10	2,100.00	0.83	2,170.11	69.97
J-42	333,724.89	1,395,484.43	2,269.00	0.00	2,288.63	19.59
J-43	333,756.88	1,395,452.45	2,200.00	0.00	2,288.54	88.37
J-44	333,788.49	1,395,300.93	2,187.00	0.00	2,288.39	101.19
J-45	333,812.35	1,395,447.93	2,249.00	0.00	2,288.25	39.17
J-46	334,481.51	1,395,415.25	2,237.80	0.00	2,288.24	50.34
J-47	331,868.13	1,391,456.15	2,065.61	0.00	2,108.23	42.53
J-48	334,200.84	1,395,984.00	2,267.00	0.00	2,288.21	21.17
J-49	332,699.66	1,393,399.81	2,170.41	0.00	2,169.87	-0.54
J-50	334,303.56	1,396,300.73	2,220.00	0.00	2,288.21	68.07
J-51	334,380.25	1,395,740.36	2,262.00	0.00	2,288.21	26.16
J-52	334,608.19	1,395,674.09	2,245.00	0.00	2,288.21	43.13
J-53	335,011.28	1,394,984.71	2,105.08	0.00	2,144.06	38.90
J-54	333,908.12	1,395,501.08	2,198.00	0.00	2,288.25	90.06

J-55	335,143.85	1,394,260.02	2,132.00	0.00	2,294.66	162.33
J-56	333,829.50	1,395,161.82	2,146.00	0.00	2,288.30	142.01
J-57	335,195.93	1,394,135.16	2,114.85	0.00	2,144.65	29.75
J-58	333,932.86	1,395,244.50	2,245.00	0.00	2,288.26	43.17
J-59	334,047.17	1,395,275.09	2,227.00	0.00	2,288.25	61.13
J-60	334,121.41	1,395,151.27	2,132.00	0.00	2,288.27	155.96
J-61	334,131.29	1,395,074.35	2,241.00	0.00	2,288.27	47.18
J-62	334,515.75	1,394,664.53	2,227.00	0.00	2,288.27	61.15
J-63	334,937.87	1,394,425.27	2,245.00	0.00	2,288.27	43.18
J-64	333,256.64	1,394,831.80	2,099.00	0.79	2,108.36	9.34
J-65	333,203.99	1,394,647.01	2,096.00	0.79	2,107.85	11.83
J-66	333,376.83	1,394,701.17	2,091.00	0.79	2,107.51	16.48
J-67	333,369.32	1,394,431.62	2,069.00	0.79	2,107.44	38.36
J-68	333,213.44	1,394,581.63	2,089.00	0.79	2,107.50	18.46
J-69	333,148.62	1,394,611.19	2,090.00	0.79	2,107.77	17.74
J-70	333,086.16	1,394,595.68	2,080.00	0.79	2,106.66	26.60
J-71	333,145.13	1,394,496.81	2,092.00	0.79	2,107.32	15.29
J-72	333,172.95	1,394,289.54	2,091.00	0.79	2,107.43	16.40
J-73	333,050.65	1,394,179.63	2,086.00	0.79	2,107.45	21.41
J-74	333,011.34	1,394,146.46	2,076.00	0.79	2,107.43	31.36
J-75	332,950.44	1,394,053.66	2,081.00	0.79	2,107.82	26.76
J-76	333,035.46	1,393,875.39	2,096.00	0.79	2,107.80	11.77
J-77	332,873.58	1,393,946.06	2,087.00	0.79	2,107.91	20.87
J-78	332,646.65	1,393,978.31	2,094.00	0.79	2,108.05	14.02
J-79	332,783.80	1,393,789.56	2,091.00	0.79	2,108.14	17.10
J-80	332,890.69	1,393,745.64	2,090.00	0.79	2,108.13	18.09
J-81	332,744.94	1,393,687.37	2,093.00	0.79	2,108.18	15.15
J-82	333,041.21	1,394,605.95	2,094.00	0.79	2,104.97	10.95
J-83	332,831.21	1,394,329.80	2,090.00	1.27	2,104.90	14.87
J-84	332,755.54	1,394,375.83	2,092.00	0.79	2,104.89	12.86
J-85	332,967.52	1,394,617.57	2,091.00	0.79	2,104.89	13.86
J-86	332,868.81	1,394,652.42	2,079.00	0.79	2,104.79	25.74
J-87	332,797.77	1,395,040.63	2,089.00	0.79	2,104.63	15.60
J-88	332,578.95	1,394,933.33	2,070.00	1.43	2,104.63	34.56
J-89	332,650.04	1,395,401.99	2,094.00	1.43	2,104.56	10.54
J-90	332,518.39	1,395,376.79	2,091.00	1.43	2,104.56	13.53
J-91	332,481.51	1,395,364.76	2,092.00	1.43	2,104.55	12.52
J-92	332,529.05	1,395,043.58	2,114.00	0.00	2,121.02	7.01
J-93	332,042.07	1,394,759.88	2,113.00	0.97	2,120.11	7.09
J-94	332,038.31	1,394,561.86	2,112.00	0.48	2,118.06	6.05
J-95	332,115.39	1,394,541.30	2,109.00	0.48	2,118.06	9.04
J-96	332,009.53	1,394,468.77	2,113.00	0.48	2,116.72	3.71
J-97	332,080.21	1,394,064.67	2,098.00	0.48	2,116.85	18.82
J-98	332,067.61	1,394,050.63	2,116.00	0.48	2,115.19	-0.81
J-99	331,959.81	1,394,030.89	2,100.00	0.48	2,115.18	15.15
J-100	331,942.08	1,394,014.94	2,101.00	0.96	2,114.07	13.04
J-101	331,997.22	1,393,712.15	2,088.00	0.48	2,114.44	26.38
J-102	331,823.04	1,393,836.04	2,100.00	0.48	2,114.02	13.99
J-103	331,648.40	1,393,666.50	2,107.00	0.48	2,113.02	6.01
J-104	331,593.50	1,393,641.28	2,105.00	0.96	2,113.08	8.06
J-105	331,789.80	1,393,493.06	2,090.00	0.48	2,112.18	22.14
J-106	331,907.54	1,393,462.89	2,082.00	0.48	2,112.18	30.12
J-107	331,475.94	1,393,529.40	2,110.00	0.96	2,112.00	2.00
J-108	331,435.33	1,393,349.71	2,108.00	0.48	2,111.31	3.30
J-109	331,605.95	1,393,255.35	2,098.00	0.48	2,111.25	13.22
J-110	331,442.81	1,393,216.99	2,101.00	0.48	2,111.24	10.22
J-111	331,373.24	1,393,219.74	2,109.00	0.96	2,111.17	2.17
J-112	331,716.83	1,393,173.29	2,092.00	0.48	2,111.11	19.07
J-113	331,589.34	1,392,988.25	2,092.00	0.96	2,110.43	18.39
J-114	331,602.41	1,392,980.05	2,091.00	0.48	2,110.15	19.11

J-115	332,324.10	1,392,785.22	2,075.00	0.96	2,109.32	34.25
J-116	332,010.06	1,392,635.89	2,083.00	0.48	2,109.22	26.16
J-117	331,929.90	1,392,607.55	2,085.00	0.48	2,109.40	24.35
J-118	331,768.56	1,392,540.33	2,088.00	0.48	2,109.27	21.23
J-119	331,481.94	1,392,426.89	2,102.00	0.96	2,109.39	7.38
J-120	331,615.54	1,392,260.14	2,095.00	0.96	2,108.80	13.77
J-121	331,853.67	1,392,372.36	2,080.00	0.48	2,109.16	29.10
J-122	331,974.64	1,392,092.59	2,074.00	0.96	2,108.74	34.67
J-123	332,114.41	1,392,112.46	2,066.00	0.48	2,109.07	42.99
J-124	332,234.82	1,392,164.44	2,061.00	0.96	2,109.16	48.06
J-125	332,285.80	1,392,035.27	2,057.00	0.96	2,108.40	51.29
J-126	332,054.34	1,391,894.36	2,074.00	0.48	2,108.51	34.44
J-127	332,129.77	1,391,709.74	2,080.00	0.48	2,108.27	28.21
J-128	332,378.75	1,391,805.79	2,062.00	0.48	2,108.27	46.17
J-129	329,075.26	1,387,247.23	2,002.00	0.00	2,030.69	28.64
J-130	332,510.64	1,391,868.30	2,058.00	1.44	2,108.15	50.04
J-131	330,790.72	1,392,213.29	2,039.10	44.06	2,041.78	2.67
J-132	332,465.29	1,391,585.27	2,052.00	0.96	2,108.10	55.99
J-133	332,220.39	1,391,486.06	2,065.00	0.48	2,108.12	43.03
J-134	329,379.41	1,390,964.99	2,000.00	0.82	2,041.15	41.07
J-135	332,506.13	1,391,479.38	2,055.00	0.48	2,108.03	52.92
J-136	329,286.55	1,390,610.84	1,993.00	0.00	2,041.15	48.05
J-137	332,885.25	1,391,315.10	2,042.00	0.96	2,108.00	65.87
J-138	329,933.65	1,390,766.22	2,012.00	3.50	2,041.16	29.10
J-139	332,610.31	1,391,210.09	2,050.00	0.48	2,108.00	57.89
J-140	332,669.35	1,391,069.02	2,038.00	0.96	2,108.00	69.86
J-141	329,427.02	1,389,057.23	2,041.00	0.00	2,048.73	7.71
J-142	332,588.70	1,390,645.71	2,025.00	0.48	2,108.06	82.89
J-143	329,446.54	1,389,277.47	2,023.00	1.07	2,048.73	25.68
J-144	332,216.91	1,390,860.09	2,015.00	0.48	2,108.06	92.87
J-145	329,160.45	1,389,248.70	2,031.00	0.00	2,048.73	17.69
J-146	330,799.91	1,392,347.37	2,020.20	14.36	2,047.89	27.64
J-147	329,049.75	1,388,481.91	2,012.00	0.79	2,033.78	21.73
J-148	329,043.03	1,388,455.28	2,010.00	0.36	2,031.88	21.83
J-149	328,852.63	1,388,457.32	2,009.00	0.78	2,031.68	22.63
J-150	328,678.85	1,388,385.50	1,994.00	0.78	2,031.41	37.34
J-151	328,667.15	1,388,376.02	1,993.00	0.78	2,031.27	38.19
J-152	328,809.47	1,388,328.48	1,997.00	0.36	2,031.42	34.35
J-153	328,887.03	1,388,282.46	1,996.00	0.36	2,031.49	35.42
J-154	328,860.24	1,388,202.79	1,988.00	0.36	2,031.25	43.16
J-155	328,782.22	1,388,241.52	1,988.00	0.36	2,031.31	43.22
J-156	328,640.77	1,388,312.90	1,988.00	0.36	2,031.27	43.18
J-157	328,605.55	1,388,235.45	1,984.00	0.78	2,031.22	47.12
J-158	328,850.44	1,388,157.65	1,984.00	0.78	2,031.11	47.01
J-159	328,930.62	1,388,003.53	2,003.00	0.78	2,030.77	27.72
J-160	329,154.79	1,387,936.48	1,997.00	0.36	2,030.69	33.63
J-161	329,149.00	1,387,990.54	2,000.00	0.36	2,030.69	30.63
J-162	329,135.13	1,388,048.87	2,004.00	0.36	2,030.75	26.70
J-163	329,278.62	1,388,366.25	2,000.00	0.78	2,033.18	33.11
J-164	329,320.79	1,388,343.20	1,998.00	0.36	2,030.92	32.85
J-165	329,362.80	1,388,460.14	1,997.00	0.78	2,030.32	33.26
J-166	333,743.75	1,395,549.42	2,202.00	6.93	2,288.20	86.03
J-167	329,528.33	1,389,117.42	2,000.00	1.20	2,030.23	30.17
J-168	333,814.97	1,395,528.40	2,201.00	3.96	2,288.20	87.02
J-169	329,587.82	1,389,216.62	1,998.00	0.78	2,030.12	32.06
J-170	332,779.12	1,395,401.18	2,132.00	0.00	2,122.12	-9.86
J-171	330,111.11	1,389,313.58	2,001.00	0.78	2,030.11	29.05
J-172	329,955.30	1,389,067.05	2,005.00	0.36	2,030.11	25.06
J-173	329,772.82	1,388,653.89	2,003.00	0.36	2,030.14	27.08
J-174	329,699.98	1,388,545.81	1,995.00	0.36	2,030.20	35.13

J-175	329,498.14	1,388,407.05	2,006.00	0.78	2,030.28	24.23
J-176	329,586.20	1,388,371.97	2,010.00	0.36	2,030.22	20.18
J-177	329,948.13	1,388,382.24	2,008.00	0.36	2,030.17	22.12
J-178	329,873.30	1,388,252.91	2,007.00	0.36	2,030.22	23.17
J-179	329,474.25	1,388,048.44	1,993.00	0.36	2,030.54	37.46
J-180	329,541.42	1,388,038.58	1,990.00	0.36	2,030.50	40.42
J-181	329,789.72	1,387,963.52	1,977.00	0.78	2,030.46	53.35
J-182	329,513.63	1,387,705.98	1,980.00	0.36	2,030.51	50.41
J-183	329,983.01	1,387,574.70	1,964.00	0.78	2,030.48	66.34
J-184	332,689.85	1,395,421.82	2,124.00	0	2,122.06	-1.94
J-185	333,131.73	1,395,299.25	2,122.00	0	2,123.29	1.29
J-186	333,872.50	1,395,119.92	2,149.00	0	2,158.44	9.42
J-187	334,005.40	1,395,043.48	2,176.00	0	2,176.17	0.17

Gondar Town Water Supply Modelling.wtg	Bentley Systems, Inc. Haestad Methods Solution Center	Bentley WaterGEMS V8i (SELECTseries 6) [08.11.06.58]
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Appendix-H: Flow Adjustment Groups after Calibration (Model Calibration, 2016)

Darwin Calibrator (Flow Calibration.wtg): FlowAnalysis-1			
Demand Adjustment Values		**Roughness Adjustment Values**	
Adjustment Group	Demand Adjustment Factor	Adjustment Group	Hazen-Williams C
Angereb - 1junction	0.500	Angereb- 1pipe	0.9
NW4 - 2junction	1.300	NW4 - 2pipe	1.3
NW5 - 3junction	1.500	NW5 - 3pipe	1.5
TW5 - 4junction	1.500	TW5 - 4pipe	1.5
TW6 - 5junction	1.500	TW6 - 5pipe	0.6
GTW7 - 6junction	0.900	GTW7- 6pipe	1.2
BSR-7j	1.500	BSR-7p	1.4
DSBSR-8j	1.300	DSBSR-8p	1.5
OLSR-9j	1.500	OLSR-9p	1.5
GoR-10j	0.700	GoR-10p	1.0
GR-11j	0.600	GR-11p	1.0
StR-12j	1.400	StR-12p	1.5
SbR-13j	1.500	SbR-13p	1.0
AzR-14j	0.900	AzR-14p	0.8
GUH-15j	1.300	GUH-15p	1.5
GUMC-16j	1.500	GUMC-16p	1.5
DB-17j	1.300	DB-17p	1.0
MoSDF-18j	1.500	MoSDF-18p	0.9
Demands			
Adjustment Group	Node	Original Demand (L/s)	Adjusted Demand (L/s)
Angereb - 1junction	J-53	0.00	0.00
Angereb - 1junction	J-8	0.66	0.33
Angereb - 1junction	J-11	1.18	0.59
Angereb - 1junction	J-187	-0.05	0.02
Angereb - 1junction	J-16	0.66	0.33
Angereb - 1junction	J-23	1.18	0.59
Angereb - 1junction	J-49	0.00	0.00
NW4 - 2junction	J-1	0.66	0.85
NW4 - 2junction	J-185	-0.05	0.06
NW4 - 2junction	J-92	0.00	0.00
NW4 - 2junction	J-87	0.62	0.81

NW4 - 2junction	J-91	1.12	1.46
NW4 - 2junction	J-64	0.62	0.81
NW4 - 2junction	J-83	1.00	1.30
NW4 - 2junction	J-84	0.62	0.81
NW5 - 3junction	J-5	0.66	0.98
NW5 - 3junction	J-93	0.76	1.14
NW5 - 3junction	J-95	0.37	0.56
NW5 - 3junction	J-100	0.75	1.13
TW5 - 4junction	J-4	0.66	0.98
TW5 - 4junction	J-122	0.75	1.13
TW5 - 4junction	J-123	0.37	0.56
TW5 - 4junction	J-47	0.00	0.00
TW5 - 4junction	J-132	0.75	1.13
TW6 - 5junction	J-146 (MSDF)	11.31	4.97
TW6 - 5junction	J-131 (Dashen Brewery)	34.71	10.07
TW6 - 5junction	J-138 (Cotton Plant)	2.76	1.14
TW6 - 5junction	J-134	0.64	0.97
TW6 - 5junction	J-143	0.84	1.26
TW6 - 5junction	J-145	0.00	0.00
TW6 - 5junction	J-158	0.61	0.92
TW6 - 5junction	J-156	0.28	0.42
TW6 - 5junction	J-147	0.62	0.93
GTW7 - 6junction	J-6	0.66	0.59
GTW7 - 6junction	J-160	0.28	0.25
GTW7 - 6junction	J-129	0.00	0.00
GTW7 - 6junction	J-182	0.28	0.25
GTW7 - 6junction	J-171	0.61	0.55
StR-12j	J-45	0.00	0.00
StR-12j	J-166 (Land Mark H)	5.46	1.65
SbR-13j	J-52	0.00	0.00
Roughness’s			
Adjustment Group	Link	Original Roughness	Adjusted Roughness
Angereb- 1pipe	P-4	130.00	117.00
Angereb- 1pipe	P-126	150.00	135.00
Angereb- 1pipe	P-111	120.00	108.00
Angereb- 1pipe	P-83	130.00	117.00
NW4 - 2pipe	P-214	130.00	169.00
NW5 - 3pipe	P-71	130.00	195.00
NW5 - 3pipe	P-24	150.00	225.00
NW5 - 3pipe	P-67	130.00	195.00
NW5 - 3pipe	P-95	150.00	225.00
NW5 - 3pipe	P-113	120.00	180.00
NW5 - 3pipe	P-275	150.00	225.00
NW5 - 3pipe	P-166	120.00	180.00
TW5 - 4pipe	P-283	130.00	195.00
TW5 - 4pipe	P-66	130.00	195.00
TW5 - 4pipe	P-148	150.00	225.00
TW5 - 4pipe	P-177	120.00	180.00
TW5 - 4pipe	P-202	150.00	225.00
TW5 - 4pipe	P-62	130.00	195.00
TW5 - 4pipe	P-72	130.00	195.00
TW5 - 4pipe	P-90	150.00	225.00
TW6 - 5pipe	P-272	130.00	120.00
TW6 - 5pipe	P-301	150.00	110.00
TW6 - 5pipe	P-298	130.00	140.00
TW6 - 5pipe	P-289	120.00	115.00
TW6 - 5pipe	P-68	130.00	125.00
GTW7- 6pipe	P-160	130.00	156.00

GTW7- 6pipe	P-64	130.00	156.00
GTW7- 6pipe	P-61	150.00	180.00
BSR-7p	P-254	130.00	182.00
DSBSR-8p	P-323	130.00	195.00
StR-12p	P-308	150.00	225.00
SbR-13p	P-186	150.00	150.00
SbR-13p	P-175	120.00	120.00
SbR-13p	P-234	130.00	130.00
SbR-13p	P-33	150.00	150.00
AzR-14p	P-317	130.00	104.00
GUMC-16p	P-17	150.00	225.00
DB-17p	P-309	150.00	150.00
DB-17p	P-81	130.00	130.00
MoSDF-18p	P-307	150.00	135.00

Statuses

Link	Original Status	Adjusted Status
P-229	Open	Open
P-214	Open	Closed
P-173	Open	Open
P-217	Open	Open
P-226	Open	Open
P-223	Open	Open
P-254	Open	Closed
P-319	Open	Closed
P-322	Open	Closed
P-323	Open	Open
P-150	Open	Closed
P-312	Open	Open
P-140	Open	Open
P-179	Open	Open
P-74	Open	Closed
P-186	Open	Open
P-234	Open	Closed
P-317	Open	Open

Flows

Field Data Snapshot	Pipe	Observed Flow (L/s)	Simulated Flow (L/s)	Difference (L/s)
Flow Test - 1 Angereb	P-265	130.12	143.25	13.13
Flow Test - 2 NW4	P-215	9.00	0.00	-9.00
Flow Test - 3 NW5	P-221	8.26	4.67	-3.59
Flow Test - 4 TW5	P-218	14.00	4.48	-9.52
Flow Test - 5 TW6	P-227	5.00	3.55	-1.45
Flow Test - 6 GTW7	P-224	4.05	3.14	-0.91
Flow Test - 7 BSR	P-230	210.00	233.54	23.54
Flow Test - 8 DSBSR	P-268	214.21	217.35	3.14
Flow Test - 9 OLSR	P-4	250.40	249.93	-0.47
Flow Test - 10 GoR	P-322	1.78	0.00	-1.78
Flow Test - 11 GR	P-305	116.31	113.34	-2.97
Flow Test - 12 StR	P-320	58.14	53.76	-4.38
Flow Test - 13 SbR	P-325	52.51	53.00	0.49
Flow Test - 14 AzR	P-197	16.20	5.01	-11.19
Flow Test - 15 GUH	P-138	3.00	0.98	-2.02
Flow Test - 16 GUMC	P-59	4.95	2.87	-2.08
Flow Test - 17 DB	P-295	1.03	0.39	-0.64
Flow Test - 18 MoSDF	P-162	5.21	8.15	2.94

Flow Calibration.wtg	Bentley Systems, Inc. Haestad Methods Solution Center	Bentley WaterGEMS V8i (SELECTseries 6) [08.11.06.58]

Appendix-I: Pressure Adjustment Groups after Calibration (Model Calibration, 2016)

Darwin Calibrator (Pressure Calibration.wtg): Pressure Analysis 1			
Demand Adjustment Values		**Roughness Adjustment Values**	
Adjustment Group	Demand Adjustment Factor	Adjustment Group	Hazen-Williams C
NDG J-8	1.500	NRG P - 151	1.1
NDG J-40	1.500	NRG P -152	0.6
NDG J-41	1.200	NRG P - 241	0.8
NDG J-42	1.500	NRG P - 150	0.5
NDG J-50	0.600	NRG P - 185	1.2
NDG J-60	1.500	NRG P - 175	0.6
NDG J-64	1.400	NRG P - 162	1.5
NDG J-92	0.500	NRG P - 93	1.5
NDG J-106	1.500	NRG P - 18	0.8
NDG J-144	1.300	NRG P - 173	1.5
NDG J-131	0.600	NRG P - 52	1.2
NDG J-146	1.400	NRG P - 177	1.5
NDG J-136	1.500	NRG P - 297	1.5
NDG J-183	1.400	NRG P - 316	1.5
NDG J-152	1.500	NRG P - 298	1.5
NDG J-139	0.500	NRG P - 296	0.7

Demands			
Adjustment Group	Node	Original Demand (L/s)	Adjusted Demand (L/s)
NDG J-8	J-8	0.60	0.91
NDG J-8	J-53	0.00	0.00
NDG J-8	J-12	0.60	0.91
NDG J-8	J-11	1.09	1.63
NDG J-8	J-13	0.60	0.91
NDG J-40	J-40	0.60	0.91
NDG J-40	J-37	1.09	1.63
NDG J-40	J-38	0.60	0.91
NDG J-40	J-36	1.09	1.63
NDG J-40	J-41	0.60	0.91
NDG J-40	J-31	1.09	1.63
NDG J-41	J-24	0.60	0.73
NDG J-41	J-23	1.09	1.30
NDG J-42	J-166 (Land MH)	5.04	1.65
NDG J-60	J-44	0.00	0.00
NDG J-64	J-87	0.57	0.80
NDG J-64	J-89	1.04	1.45
NDG J-92	J-93	0.70	0.35
NDG J-92	J-99	0.35	0.17
NDG J-92	J-100	0.70	0.35
NDG J-106	J-106	0.35	0.52
NDG J-106	J-112	0.35	0.52
NDG J-106	J-115	0.70	1.04
NDG J-144	J-114	0.35	0.45
NDG J-131	J-131 (Dashen B)	32.04	8.67
NDG J-146	J-146 (MohaSDF)	10.44	4.46
NDG J-136	J-136	0.00	0.00
NDG J-136	J-134	0.59	0.89
NDG J-136	J-138 (Cotton P)	2.55	1.14

NDG J-183	J-183	0.57	0.79
NDG J-183	J-181	0.57	0.79
NDG J-183	J-160	0.26	0.36
NDG J-183	J-129	0.00	0.00
NDG J-183	J-159	0.57	0.79
NDG J-183	J-173	0.26	0.36
NDG J-183	J-167	0.87	1.22
NDG J-183	J-169	0.57	0.79
NDG J-183	J-172	0.26	0.36
NDG J-183	J-171	0.57	0.79
NDG J-152	J-152	0.26	0.39
NDG J-152	J-149	0.57	0.85
NDG J-139	J-139	0.35	0.17
NDG J-139	J-125	0.70	0.35

Roughness

Adjustment Group	Link	Original Roughness	Adjusted Roughness
NRG P - 151	P-151	150.00	165.00
NRG P -152	P-7	150.00	145.00
NRG P - 241	P-241	130.00	104.00
NRG P - 241	P-245	150.00	120.00
NRG P - 241	P-246	130.00	104.00
NRG P - 241	P-244	150.00	120.00
NRG P - 241	P-227	130.00	104.00
NRG P - 241	P-228	150.00	120.00
NRG P - 241	P-317	130.00	104.00
NRG P - 150	P-100	150.00	130.00
NRG P - 150	P-103	150.00	140.00
NRG P - 185	P-185	150.00	180.00
NRG P - 185	P-325	130.00	156.00
NRG P - 175	P-74	120.00	110.00
NRG P - 162	P-75	120.00	180.00
NRG P - 93	P-281	150.00	225.00
NRG P - 93	P-87	150.00	225.00
NRG P - 18	P-18	150.00	120.00
NRG P - 18	P-131	150.00	120.00
NRG P - 173	P-173	120.00	180.00
NRG P - 173	P-166	120.00	180.00
NRG P - 316	P-306	130.00	195.00
NRG P - 316	P-301	150.00	225.00
NRG P - 298	P-298	130.00	195.00
NRG P - 139	P-291	150.00	150.00
NRG P - 139	P-192	150.00	150.00
NRG P - 139	P-139	150.00	150.00
NRG P - 202	P-102	150.00	135.00

Statuses

Link	Original Status	Adjusted Status
P-151	Open	Closed
P-152	Open	Open
P-241	Open	Open
P-150	Open	Closed
P-185	Open	Open
P-175	Open	Closed
P-162	Open	Open
P-93	Open	Open
P-18	Open	Closed
P-173	Open	Open
P-52	Open	Closed
P-177	Open	Open

P-297	Open	Open
P-316	Open	Open
P-298	Open	Open
P-296	Open	Closed
P-139	Open	Open
P-202	Open	Open

Hydraulic Grades

Field Data Snapshot	Junction	Observed Hydraulic Grade (m)	Simulated Hydraulic Grade (m)	Difference (m)
8 AM, J-8	J-8	2,238.97	2,259.74	20.77
9 AM, J-40	J-40	2,188.94	2,139.58	-49.36
10 AM, J-41	J-41	2,142.91	2,145.28	2.37
11 AM, J-42	J-42	2,287.96	2,282.21	-5.75
12 AM, J-50	J-50	2,251.94	2,283.03	31.09
2 PM, J-60	J-60	2,179.90	2,283.61	103.70
3 PM, J-64	J-64	2,118.96	2,099.34	-19.62
4 PM, J-68	J-68	2,123.93	2,098.78	-25.15
5 PM, J-67	J-67	2,120.90	2,097.04	-23.86
6 PM, J-92	J-92	2,134.96	2,128.40	-6.56
8 AM, J-106	J-106	2,117.93	2,125.35	7.42
9, AM, J-144	J-144	2,070.89	2,124.38	53.49
10 AM, J-131	J-131 (DB)	2,063.05	2,033.97	-29.08
11 AM, J-146	J-146 (MSD)	2,050.14	2,040.57	-9.57
12 AM, J-136	J-136	2,037.91	2,041.33	3.42
2 PM, J-183	J-183	2,005.92	2,019.13	13.22
3 PM, J-152	J-152	2,051.89	2,021.28	-30.61
4 PM, J-139	J-139	2,111.88	2,125.11	13.23

Flow Calibration.wtg	Bentley Systems, Inc. Haestad Methods Solution Center	Bentley WaterGEMS V8i (SELECTseries 6) [08.11.06.58]
10/28/2016	27 Siemon Company Drive Suite 200 W Watertown, CT 06795 USA +1-203-755-1666	Page 1 of 1

Appendix-J: Water Balance Analysis (WB-EasyCalc300-V 5.08)

Gondar Town Water Supply and Sewerage Service			Getting Started
			Change Language
The free water balance software Version 5.08 (22 September 2016)	Data Entry	1.)	System Input Volume
		2.)	Billed Consumption
		3.)	Unbilled Consumption
		4.)	Unauthorized Consumption
		5.)	Customer Meter Inaccuracies and Data Handling Errors
Utility Name: GTWSSS; Year: 2016		6.)	Network Data
		7.)	Pressure
The volumes used for this water balance are for a period of: 720 days		8.)	Intermittent Supply
		9.)	Financial Information
		A	Water Balance in m3/year
		B	Water Balance in m3/day
		C	Water Balance for Period
		D	Performance Indicators
By courtesy of Liemberger Partners because the best things in life are free!		E	THE "WHAT IF" TOOL
www.liemberger.cc		F	Historic data

1. System Input Volume		
Water Source	[m^3]	Error Margin [+/- %]
Angereb Surface WTP	2,658,244	4.4%
Borehole: NW-1	64,733	4.5%
Borehole: NW-2	25,204	6.0%
Borehole: NW-3	86,147	2.9%
Borehole: NW-4	55,380	4.4%
Borehole: NW-5	177,216	4.8%
Borehole: TW-5	29,536	5.6%
Borehole: TW-6	39,381	4.5%
Borehole: GTW-7	246,134	4.2%
Springs: Dokemit	28,945	6.4%
Springs: Feliflit	21,858	8.3%
Springs: Sanita-1	13,291	10.0%
Springs: Sanita-2	25,698	7.2%
Error Margin [+/-]:		3.4%
System Input Volume [m^3]		
Minimum	3,353,868	
Maximum	3,589,666	
Best Estimate	3,471,767	

2. Billed Metered Consumption	
Description	[m^3]
JAN	237652
FEB	234110
MAR	265979
APR	262415
MAY	239517
JUN	233124
JUL	197262
AUG	182182
SEP	259880
OCT	205730
NOV	219422
DEC	230108
[m3]	2,767,381

3. Unauthorized Consumption					
Description	Estimated Number	Error Margin [+/- %]	Persons per House	Consumption [liters/person/day]	Total [m^3]
Illegal Connections - domestic	4	5%	8.0	26	588
				Consumption [liters/connection/day]	
Illegal Connections - others	4	6%		82	235
				Consumption [liters/customer/day]	
Meter tampering, bypasses, etc. at registered customers	4	8%		79	227
				Consumption [m3/day]	
Error Margin [+/-]:		6.0%			
Unauthorized Consumption [m^3]					
Minimum					777

Maximum					1,323
Best Estimate					1,050

4. Customer Meter Inaccuracies and Data Handling Errors					
Description	Total [m³]	Meter under-registration		Total [m³]	Error Margin [+/- %]
Enter 1 to use an overall % for meter under-registration or 2 for manual entering of volumes and under-registration of different meter or customer types			1		
Billed Metered Consumption (without Bulk Supply)	2,767,381	5.0%		145,652	10%
Billed Metered Consumption (without Bulk Supply)	Total [m³]	Meter under-registration			
Metered Bulk Supply (Export)	-			-	
Unbilled Metered Consumption (without Bulk Supply)	-			-	
		Estimated % of under-reading			
Corrupt Meter Reading Practices	2,767,381	10%		307,487	50%
Data Handling Errors (Office)				25.0%	25%
Error Margin [+/-]:					34.1%
Customer Meter Inaccuracies and Data Handling Errors					
Minimum				298,707	
Maximum				607,570	
Best Estimate				453,139	

5. Network				
Distribution and Transmission Mains		Service Connections		
Description	Length [km]	Description	Number	Error Margin [+/- %]
150mm	10.7	Number of Customers (active)	26,336	
200mm	9.2			
250mm	8.7			
300mm	11.0	Number of Connections of Registered Customers Note: this figure is most likely (a little bit) less than the number of customers Number of inactive accounts with existing service connection	25,436	2%
350mm	7.6			
			900	3%
		Estimated Number of Illegal Connections	8	5.0%
		Error Margin [+/-]:		2%
		Number of Connections		
		Minimum	25,834	
Total [km]	47.2	Maximum	26,854	

Possible underestimation	5%	Best Estimate	26,344	
Pipe Length [km]		Average Length of Service Connection from Property Boundary to Customer Meter [meter]	37.57	5%
Minimum	47.2			
Maximum	70.8			
Best Estimate	59.0			
		Total Length of Service Connections from Property Boundary to Customer Meter [kilometer]	990	5%

6. Average Pressure		
Area	Approximate Number of Connections	Daily Average Pressure [m]
Sillase	1888	18
	1986	36
	1689	53
Goha	1552	10
	1452	34
	1352	55
Gebreal	1584	36
	1685	51
	1786	60
Stadium	1211	15
	1310	41
	1112	51
Samunaber	838	17
	936	30
	737	42
Azezo	1614	41
	1707	54
	1800	90
Error Margin [+/-]:		10%
Average Pressure [m]		
Minimum		-
Maximum		85.6
Best Estimate		42.8

7. Intermittent Supply			
Area	Approximate Number of Connections	Supply Time [days per week]	Supply Time [hours per day]
Sillase	1888	5	5.5
	1986	5	5.5
	1689	5	5.5
Goha	1552	5	4.2
	1452	5	4.2
	1352	5	4.2
Gebreal	1584	3	5.1
	1685	4	5.1
	1786	4	5.1
Stadium	1211	3	3.5
	1310	4	3.5
	1112	4	3.5
Samunaber	838	5	4.5
	936	5	4.5
	737	5	4.5

Azezo	1614	3	2.8
	1707	3	2.8
	1800	3	2.8
Error Margin [+/-]:			2%
Average Supply Time [h/day]			
Minimum			2.6
Maximum			2.7
Best Estimate			2.6

8. Financial Information

		per m^3	Currency
Average Tariff		6.50	Birr
Variable Production and Distribution Cost (Marginal Cost of Water)		5.86	Birr
NRW Component		Annual Value	
Unbilled Metered Consumption		-	Birr
Unbilled Unmetered Consumption		-	Birr
Commercial Losses		2,952,225	Birr
Customer Meter Inaccuracies and Data Handling Errors		2,945,401	Birr
Unauthorized Consumption		6,824	Birr
Physical Losses		764,051	Birr
Total Volume (m^3/d)	347		
Volume which could be sold to existing or new customers (m^3/d)	89		
Total Value of NRW		3,716,276	Birr
Annual Operating Cost (without Depreciation)		16,326,390	Birr

9. Water Balance in m^3/year

<table>
<tr><td rowspan="6">System Input Volume 3,471,767 m^3/year Error Margin [+/-]: 3.4%</td><td rowspan="4">Authorized Consumption 2,767,381 m^3/year Error Margin [+/-]: 0%</td><td rowspan="2">Billed Authorized Consumption 2,767,381 m^3/year</td><td>Billed Metered Consumption 2,767,381 m^3/year</td><td rowspan="2">Revenue Water 2,767,381 m^3/year</td></tr>
<tr><td>Billed Unmetered Consumption 0 m^3/year</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption 0 m^3/year Error Margin [+/-]: 0%</td><td>Unbilled Metered Consumption 0 m^3/year</td><td rowspan="4">Non-Revenue Water 704,386 m^3/year Error Margin [+/-]: 6.7%</td></tr>
<tr><td>Unbilled Unmetered Consumption 0 m^3/year Error Margin [+/-]: 0%</td></tr>
<tr><td rowspan="2">Water Losses 704,386 m^3/year Error Margin [+/-]: 6.7%</td><td rowspan="2">Commercial Losses 454,188 m^3/year Error Margin [+/-]: 4%</td><td>Unauthorized Consumption 1,050 m^3/year Error Margin [+/-]: 6.0%</td></tr>
<tr><td></td></tr>
</table>

			Customer Meter Inaccuracies and Data Handling Errors 453,139 m^3/year Error Margin [+/-]: 4.1%	
		Physical Losses 250,198 m^3/year Error Margin [+/-]: 7.7%		

Appendix-K: Projected Population

Item	Unit	Year					
		2013	2015	2018	2023	2028	2033
Rate	%	4.553	4.553	4.416	4.253	4.116	3.979
Base Population		2007			206,987		
Projected Population	No	271,633	296,937	338,026	417,583	512,231	624,216

Appendix-L: Projected Water Demands

Item	Unit	Year				
		2013	2018	2023	2028	2033
Population						
Projected Population	No.	271,633	338,026	417,583	512,231	624,216
Domestic Demand						
Percentage of Population Served by Different Modes of Services						
HC	%	12	15.25	18.5	21.75	25
YCS	%	30	33.75	37.5	41.25	45
YCO	%	42	36.5	31	25.5	20
PF	%	16	14.5	13	11.5	10
Population by Modes of Service						
HC	No.	32,596	51,549	77,253	111,410	156,054
YCS	No.	81,490	114,084	156,594	211,295	280,897
YCO	No.	114,086	123,380	129,451	130,619	124,843
PF	No.	43,461	49,014	54,286	58,907	62,422
Per-capita Demand by Mode of Service						
HC	l/cap/day	70	80	90	100	110
YCS	l/cap/day	30	32.5	35	37.5	40
YCO	l/cap/day	25	27.5	30	32.5	35
PF	l/cap/day	15	17.5	20	22.5	25
Water Demand at each Mode of Service						
HC	l/s	26.41	47.73	80.47	128.95	198.68
YCS	l/s	28.3	42.91	63.43	91.71	130.04
YCO	l/s	33.01	39.27	44.95	49.13	50.57
PF	l/s	7.55	9.93	12.57	15.34	18.06
Total Domestic Water Demand	l/s	95.26	139.84	201.42	285.13	397.36
	m^3/day	8,230.48	12,082.33	17,402.79	24,635.13	34,331.87
Socio-economy factor	%	5	5	5	5	5
Adjustment for Socio-economy	l/s	4.76	6.99	10.07	14.26	19.87
	m^3/day	411.52	604.12	870.14	1,231.76	1,716.59
Average Domestic Demand	l/s	100.02	146.84	211.49	299.39	397.36
	m^3/day	8,642.01	12,686.44	18,272.93	25,866.89	30,048.46
Non-domestic Demand (NDD)						

Percentage of NDD	%	50	50	50	50	50
Average NDD	l/s	50.01	73.42	105.75	149.69	208.61
	m^3/day	4,321	6,343.22	9,136.46	12,933.44	18,024.45
Industrial Water Demand (IWD)						
Percentage of IWD	%	3	3	3	3	3
Average IWD	l/s	3	4.41	6.34	8.98	12.52
	m^3/day	259.26	380.59	548.19	776.01	1,081.45
Average Day Demand Excluding UFW	l/s	153.04	224.66	323.58	458.06	638.36
	m^3/day	13,222.27	19,410.26	27,957.58	39,576.34	55,154.15
Unaccounted for Water						
Percentage of UFW	%	40	35	30	25	20
Unaccounted for Water	l/s	61.21	78.63	97.07	114.51	127.67
	m^3/day	5,288.91	6,793.59	8,387.27	9,894.09	11,030.83
Average Day Demand (ADD)						
ADD	l/s	214.25	303.29	420.66	572.57	766.03
	m^3/day	18,511.18	26,203.85	36,344.85	49,470.43	66,184.98
Maximum Day Demand (MDD)						
MDD Peak factor		1.2	1.2	1.2	1.2	1.2
MDD	l/s	257.1	363.94	504.79	687.09	919.24
	m^3/day	22,213.42	31,444.62	43,613.82	59,364.51	79,421.98
Peak Hour Demand (PHD)						
Peak Hour Factor		1.6	1.6	1.6	1.6	1.6
PHD	l/s	342.8	485.26	673.05	916.12	1,225.65
	m^3/day	29,617.89	41,926.16	58,151.76	79,152.68	105,895.97

Appendix-M: Calibration for Pressure Junction (Survey Data, 2016)

Time (hr)	Time	Pressure Junction	X	X_i	Y	Y_i	$X-X_i$	$Y-Y_i$	$(X-X_i)(Y-Y_i)$	$(X-X_i)^2$	$(Y-Y_i)^2$
8:00-12:00	8:00	J-8	49.36	41.94	52.61	45.19	7.42	7.42	55.07	55.06	55.08
	8:14	J-40	23.61	41.94	27.89	45.19	18.33	(17.30)	317.08	335.99	299.24
	8:28	J-41	47.11	41.94	51.69	45.19	5.17	6.50	33.61	26.73	42.27
	8:42	J-42	37.21	41.94	40.68	45.19	(4.73)	(4.51)	21.33	22.37	20.33
	8:56	J-50	31.48	41.94	35.36	45.19	(10.46)	(9.83)	102.81	109.41	96.60
	9:10	J-60	30.41	41.94	32.5	45.19	(11.53)	(12.69)	146.30	132.94	161.00
	9:24	J-64	41.51	41.94	48.65	45.19	(0.43)	3.46	(1.49)	0.18	11.98
	9:38	J-68	30.2	41.94	34.53	45.19	(11.74)	(10.66)	125.13	137.83	113.61
	9:52	J-67	52.12	41.94	47.25	45.19	10.18	2.06	20.98	103.63	4.25
	10:06	J-92	34.08	41.94	29.86	45.19	(7.86)	(15.33)	120.48	61.78	234.97
	10:20	J-106	41.16	41.94	48.18	45.19	(0.78)	2.99	(2.33)	0.61	8.95
	10:34	J-144	46.26	41.94	52.68	45.19	4.32	7.49	32.36	18.66	56.12
	10:48	J-131	21.76	41.94	28.48	45.19	(20.18)	(16.71)	337.18	407.23	279.18
	11:02	J-146	49.86	41.94	44.18	45.19	7.92	(1.01)	(7.99)	62.73	1.02
	11:16	J-136	45.88	41.94	50.24	45.19	3.94	5.05	19.90	15.52	25.52
	11:30	J-183	25.64	41.94	32.74	45.19	(16.30)	(12.45)	202.91	265.69	154.97
	11:44	J-152	48.17	41.94	51.32	45.19	6.23	6.13	38.20	38.81	37.59
	11:58	J-183	63.26	41.94	57.49	45.19	21.32	12.30	262.27	454.54	151.32
2:00-6:00	2:00	J-8	31.67	41.94	37.81	45.19	(10.27)	(7.38)	75.78	105.47	54.44
	2:14	J-40	59.45	41.94	64.18	45.19	17.51	18.99	332.54	306.60	360.67
	2:28	J-41	23.27	41.94	28.94	45.19	(18.67)	(16.25)	303.36	348.57	264.02
	2:42	J-42	48.94	41.94	58.51	45.19	7.00	13.32	93.25	49.00	177.46
	2:56	J-50	29.23	41.94	38.21	45.19	(12.71)	(6.98)	88.70	161.54	48.70
	3:10	J-60	77.92	41.94	72.83	45.19	35.98	27.64	994.54	1294.56	764.05

	3:24	J-64	36.25	41.94	29.94	45.19	(5.69)	(15.25)	86.76	32.38	232.52
	3:38	J-68	54.22	41.94	60.14	45.19	12.28	14.95	183.60	150.80	223.54
	3:52	J-67	38.23	41.94	41.69	45.19	(3.71)	(3.50)	12.98	13.76	12.24
	4:06	J-92	26.21	41.94	29.68	45.19	(15.73)	(15.51)	243.95	247.43	240.52
	4:20	J-106	51.36	41.94	58.49	45.19	9.42	13.30	125.30	88.74	176.93
	4:34	J-144	26	41.94	29	45.19	(15.94)	(16.19)	258.05	254.08	262.07
	4:48	J-131	32.81	41.94	30	45.19	(9.13)	(15.19)	138.67	83.36	230.69
	4:02	J-146	57.4	41.94	67.18	45.19	15.46	21.99	339.99	239.01	483.62
	4:16	J-136	38.65	41.94	44.12	45.19	(3.29)	(1.07)	3.52	10.82	1.14
	4:30	J-183	29.2	41.94	33.39	45.19	(12.74)	(11.80)	150.31	162.31	139.21
	5:44	J-152	42.31	41.94	44.5	45.19	0.37	(0.69)	(0.25)	0.14	0.47
	5:58	J-183	56	41.94	58	45.19	14.06	12.81	180.13	197.68	164.13
8:00-12:00	8:00	J-8	45.62	41.94	49	45.19	3.68	3.81	14.03	13.54	14.53
	8:14	J-40	31.51	41.94	36.32	45.19	(10.43)	(8.87)	92.50	108.78	78.65
	8:28	J-41	26.37	41.94	20.32	45.19	(15.57)	(24.87)	387.20	242.42	618.45
	8:42	J-42	44.6	41.94	39.25	45.19	2.66	(5.94)	(15.80)	7.08	35.27
	8:56	J-50	45.91	41.94	52.37	45.19	3.97	7.18	28.51	15.76	51.57
	9:10	J-60	45.56	41.94	38.1	45.19	3.62	(7.09)	(25.66)	13.10	50.25
	9:24	J-64	22.62	41.94	29.22	45.19	(19.32)	(15.97)	308.51	373.26	255.00
	9:38	J-68	63.18	41.94	51.36	45.19	21.24	6.17	131.08	451.14	38.09
	9:52	J-67	60.01	41.94	64.21	45.19	18.07	19.02	343.72	326.52	361.81
	10:06	J-92	27.11	41.94	35.18	45.19	(14.83)	(10.01)	148.43	219.93	100.17
	10:20	J-106	46.65	41.94	48	45.19	4.71	2.81	13.24	22.18	7.90
	10:34	J-144	59.14	41.94	62.31	45.19	17.20	17.12	294.49	295.84	293.14
	10:48	J-131	40.32	41.94	46.36	45.19	(1.62)	1.17	(1.90)	2.62	1.37
	11:02	J-146	27.56	41.94	31.28	45.19	(14.38)	(13.91)	200.01	206.78	193.45
	11:16	J-136	34.52	41.94	37.45	45.19	(7.42)	(7.74)	57.42	55.06	59.89
	11:30	J-183	49.23	41.94	52.3	45.19	7.29	7.11	51.84	53.14	50.57
	11:44	J-152	35.21	41.94	39.34	45.19	(6.73)	(5.85)	39.36	45.29	34.21
	11:58	J-183	52.7	41.94	57.8	45.19	10.76	12.61	135.70	115.78	159.05
2:00-4:00	2:00	J-8	41.38	41.94	43.65	45.19	(0.56)	(1.54)	0.86	0.31	2.37
	2:07	J-40	36.52	41.94	39.21	45.19	(5.42)	(5.98)	32.40	29.38	35.74
	2:14	J-41	49.8	41.94	54.21	45.19	7.86	9.02	70.91	61.78	81.39
	2:21	J-42	58.63	41.94	62.3	45.19	16.69	17.11	285.59	278.56	292.80
	2:28	J-50	37.05	41.94	41.25	45.19	(4.89)	(3.94)	19.26	23.91	15.51
	2:35	J-60	47	41.94	43.56	45.19	5.06	(1.63)	(8.24)	25.60	2.65
	2:42	J-64	58.96	41.94	52.41	45.19	17.02	7.22	122.91	289.68	52.15
	2:49	J-68	26	41.94	32.1	45.19	(15.94)	(13.09)	208.63	254.08	171.31
	2:56	J-67	48.96	41.94	59.62	45.19	7.02	14.43	101.31	49.28	208.26
	3:03	J-92	32.47	41.94	36.25	45.19	(9.47)	(8.94)	84.65	89.68	79.90
	3:10	J-106	65.87	41.94	69.81	45.19	23.93	24.62	589.19	572.64	606.21
	3:17	J-144	43.56	41.94	55.36	45.19	1.62	10.17	16.48	2.62	103.46
	3:24	J-131	36.56	41.94	42.68	45.19	(5.38)	(2.51)	13.50	28.94	6.29
	3:31	J-146	61.07	41.94	66.21	45.19	19.13	21.02	402.14	365.96	441.9
	3:38	J-136	29.8	41.94	36.5	45.19	(12.14)	(8.69)	105.48	147.38	75.49
	3:45	J-183	34.36	41.94	37.8	45.19	(7.58)	(7.39)	56.01	57.46	54.59
	3:52	J-152	49.85	41.94	56.32	45.19	7.91	11.13	88.05	62.57	123.91
	3:59	J-183	30.14	41.94	41.23	45.19	(11.80)	(3.96)	46.71	139.24	15.67
Total									9873	11043	10363

$$R^2 = \left[\frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2(y-\bar{y})^2}} \right]^2 = 0.85$$

Appendix-N: Input Parameters for Model Analysis

Pipe Data														
Label	Length (m)	Diameter (mm)	Material	Hazen-Williams C	Label	Length (m)	Diameter (mm)	Material	Hazen-Williams C	Label	Length (m)	Diameter (mm)	Material	Hazen-Williams C
P-1	1,439	80	DCI	130	P-33	91	100	PVC	150	P-65	165	100	DCI	130.
P-2	349	100	DCI	130	P-34	201	100	PVC	150	P-66	15	100	DCI	130
P-3	946	80	DCI	130	P-35	26	80	HDPE	150	P-67	648	150	DCI	130
P-4	2,000	300	DCI	130	P-36	86	100	HDPE	150	P-68	185	100	DCI	130
P-5	812	200	DCI	130	P-37	259	100	HDPE	150	P-69	68	100	DCI	130
P-6	365	150	PVC	150	P-38	86	100	HDPE	150	P-70	290	100	DCI	130
P-7	95	100	PVC	150	P-39	165	100	HDPE	150	P-71	454	150	DCI	130
P-8	186	100	PVC	150	P-40	410	100	HDPE	150	P-72	296	100	DCI	130
P-9	7	100	PVC	150	P-41	302	100	HDPE	150	P-73	112	100	DCI	130
P-10	65	100	PVC	150	P-42	68	100	HDPE	150	P-74	177	100	GI	120
P-11	623	80	PVC	150	P-43	190	100	HDPE	150	P-75	46	100	GI	120
P-12	65	100	PVC	150	P-44	33	100	HDPE	150	P-76	5	100	GI	120
P-13	75	100	PVC	150	P-45	209	100	PVC	150	P-77	66	100	GI	120
P-14	45	100	PVC	150	P-46	95	100	PVC	150	P-78	139	100	GI	120
P-15	30	100	PVC	150	P-47	78	100	PVC	150	P-79	139	100	GI	120
P-16	40	100	PVC	150	P-48	84	100	PVC	150	P-80	34	100	GI	120
P-17	123	100	PVC	150	P-49	189	100	PVC	150	P-81	100	100	DCI	130
P-18	80	100	PVC	150	P-50	19	100	PVC	150	P-82	356	100	DCI	130
P-19	145	100	PVC	150	P-51	38	100	PVC	150	P-83	359	100	DCI	130
P-20	100	100	PVC	150	P-52	200	100	PVC	150	P-84	74	100	PVC	150
P-21	123	150	PVC	150	P-53	189	100	PVC	150	P-85	82	100	PVC	150
P-22	16	100	PVC	150	P-54	312	100	PVC	150	P-86	146	100	PVC	150
P-23	189	100	PVC	150	P-55	85	100	PVC	150	P-87	61	100	PVC	150
P-24	78	100	PVC	150	P-56	321	100	PVC	150	P-88	65	100	PVC	150
P-25	102	100	PVC	150	P-57	800	80	PVC	150	P-89	32	100	PVC	150
P-26	81	100	PVC	150	P-58	200	100	PVC	150	P-90	140	100	PVC	150
P-27	563	80	PVC	150	P-59	369	100	PVC	150	P-91	125	100	PVC	150
P-28	80	100	PVC	150	P-60	115	100	PVC	150	P-92	625	100	PVC	150
P-29	189	100	PVC	150	P-61	632	80	PVC	150	P-93	265	100	PVC	150
P-30	140	100	PVC	150	P-62	296	100	DCI	130	P-94	364	100	PVC	150
P-31	65	100	PVC	150	P-63	368	100	DCI	130	P-95	343	150	PVC	150
P-32	208	100	PVC	150	P-64	666	80	DCI	130	P-96	368	100	PVC	150
P-97	60	100	PVC	150	P-129	614	100	PVC	150	P-161	123	100	DCI	130
P-98	424	150	PVC	150	P-130	166	100	PVC	150	P-162	510	200	GI	120
P-99	98	100	PVC	150	P-131	435	100	PVC	150	P-163	132	100	GI	120
P-100	127	100	PVC	150	P-132	107	100	PVC	150	P-164	123	100	GI	120
P-101	456	100	PVC	150	P-133	75	100	PVC	150	P-165	200	100	GI	120
P-102	270	100	PVC	150	P-134	117	100	PVC	150	P-166	84	100	GI	120
P-103	96	100	PVC	150	P-135	534	80	PVC	150	P-167	305	150	GI	120
P-104	365	100	PVC	150	P-136	150	100	PVC	150	P-168	59	100	GI	120
P-105	200	100	PVC	150	P-137	542	80	PVC	150	P-169	120	100	GI	120
P-106	99	100	PVC	150	P-138	306	100	PVC	150	P-170	143	100	GI	120
P-107	168	100	DCI	130	P-139	49	100	PVC	150	P-171	451	100	GI	120
P-108	210	100	DCI	130	P-140	69	100	PVC	150	P-172	420	100	GI	120
P-109	146	100	DCI	130	P-141	91	100	PVC	150	P-173	482	250	GI	120
P-110	369	100	DCI	130	P-142	369	100	PVC	150	P-174	216	100	GI	120
P-111	230	100	GI	120	P-143	102	100	PVC	150	P-175	369	100	GI	120
P-112	48	100	GI	120	P-144	44	100	PVC	150	P-176	45	100	GI	120
P-113	394	150	GI	120	P-145	196	100	PVC	150	P-177	28	100	GI	120
P-114	132	100	GI	120	P-146	279	100	PVC	150	P-178	210	100	HDPE	150
P-115	244	150	GI	120	P-147	33	100	PVC	150	P-179	150	100	HDPE	150
P-116	214	100	GI	120	P-148	236	100	PVC	150	P-180	210	100	HDPE	150
P-117	156	100	GI	120	P-149	73	100	PVC	150	P-181	42	100	HDPE	150
P-118	294	100	GI	120	P-150	284	150	PVC	150	P-182	159	100	PVC	150
P-119	159	100	GI	120	P-151	94	300	PVC	150	P-183	168	100	PVC	150
P-120	162	100	GI	120	P-152	734	80	PVC	150	P-184	189	100	PVC	150
P-121	269	100	GI	120	P-153	77	100	PVC	150	P-185	30	100	PVC	150
P-122	53	100	DCI	130	P-154	269	100	PVC	150	P-186	200	100	PVC	150
P-123	93	100	DCI	130	P-155	721	80	PVC	150	P-187	201	100	PVC	150
P-124	362	100	DCI	130	P-156	30	100	PVC	150	P-188	30	100	PVC	150
P-125	125	100	PVC	150	P-157	39	100	PVC	150	P-189	75	100	PVC	150
P-126	375	100	PVC	150	P-158	106	100	PVC	150	P-190	20	100	PVC	150
P-127	375	100	PVC	150	P-159	40	100	DCI	130	P-191	189	100	PVC	150
P-128	2,258	80	PVC	150	P-160	236	100	DCI	130	P-192	252	150	PVC	150
P-193	19	100	PVC	150	P-225	478	200	DCI	130	P-257	132	300	DCI	130
P-194	286	100	PVC	150	P-226	511	80	DCI	130	P-258	133	300	DCI	130
P-195	16	100	PVC	150	P-227	543	80	DCI	130	P-259	100	300	DCI	130

P-196	125	100	PVC	150	P-228	1,273	200	PVC	150	P-260	111	300	DCI	130
P-197	442	200	PVC	150	P-229	120	300	DCI	130	P-261	110	300	DCI	130
P-198	70	100	PVC	150	P-230	119	300	DCI	130	P-262	111	300	DCI	130
P-199	90	100	PVC	150	P-231	280	250	DCI	130	P-263	112	300	DCI	130
P-200	249	150	PVC	150	P-232	319	250	DCI	130	P-264	50	350	DCI	130
P-201	189	100	PVC	150	P-233	711	80	DCI	130	P-265	560	350	DCI	130
P-202	89	100	PVC	150	P-234	866	80	DCI	130	P-266	106	300	DCI	130
P-203	75	100	PVC	150	P-235	1,521	80	DCI	130	P-267	114	300	DCI	130
P-204	773	80	PVC	150	P-236	1,119	80	DCI	130	P-268	786	300	DCI	130
P-205	200	100	PVC	150	P-237	1,137	80	DCI	130	P-269	225	250	DCI	130
P-206	200	100	PVC	150	P-238	1,668	80	DCI	130	P-270	227	250	DCI	130
P-207	100	100	PVC	150	P-239	603	80	DCI	130	P-271	621	200	DCI	130
P-208	65	100	PVC	150	P-240	68	100	DCI	130	P-272	387	200	DCI	130
P-209	5	100	DCI	130	P-241	615	80	DCI	130	P-273	12	100	DCI	130
P-210	510	80	DCI	130	P-242	513	80	DCI	130	P-274	156	100	DCI	130
P-211	511	80	DCI	130	P-243	518	80	DCI	130	P-275	342	150	PVC	150
P-212	557	80	DCI	130	P-244	27	100	DCI	150	P-276	298	100	PVC	150
P-213	100	100	DCI	130	P-245	30	100	DCI	150	P-277	90	100	PVC	150
P-214	508	80	DCI	130	P-246	543	80	DCI	130	P-278	326	100	DCI	130
P-215	515	80	DCI	130	P-247	78	100	DCI	150	P-279	123	100	PVC	150
P-216	575	150	DCI	130	P-248	12	100	DCI	130	P-280	101	100	PVC	150
P-217	4	100	DCI	130	P-249	415	250	DCI	130	P-281	300	100	PVC	150
P-218	6	100	DCI	130	P-250	98	100	DCI	130	P-282	181	100	PVC	150
P-219	493	150	DCI	130	P-251	275	250	DCI	130	P-283	151	100	DCI	130
P-220	6	100	DCI	130	P-252	545	250	DCI	130	P-284	26	100	DCI	130
P-221	79	100	DCI	130	P-253	233	150	DCI	130	P-285	297	100	PVC	150
P-222	579	200	DCI	130	P-254	658	150	DCI	130	P-286	228	100	DI	130
P-223	508	80	DCI	130	P-255	132	300	DCI	130	P-287	384	100	PVC	150
P-224	520	80	DCI	130	P-256	132	300	DCI	130	P-288	75	100	PVC	150
P-289	306	100	GI	120	P-321	783	250	DCI	130	P-310	74	100	DCI	130
P-290	241	100	PVC	150	P-322	234	150	DCI	130	P-311	97	100	DCI	130
P-291	105	100	PVC	150	P-323	296	150	DCI	130	P-312	293	150	DCI	130
P-292	484	150	PVC	150	P-324	722	150	DCI	130	P-313	293	250	DCI	130
P-293	185	100	PVC	150	P-325	908	250	DCI	130	P-314	419	250	DCI	130
P-294	174	100	PVC	150	P-300	678	250	PVC	150	P-315	672	250	DCI	130
P-295	152	100	PVC	150	P-301	461	250	PVC	150	P-316	353	250	DCI	130
P-296	166	100	PVC	150	P-302	1,114	200	PVC	150	P-317	239	150	DCI	130
P-297	1,008	250	DCI	130	P-303	486	200	PVC	150	P-318	366	150	DCI	130
P-298	629	200	DCI	130	P-304	551	200	PVC	150	P-319	1,103	150	DCI	130
P-299	852	200	PVC	150	P-305	3,250	300	DCI	130	P-320	305	250	DCI	130
P-306	270	150	DCI	130	P-307	1,000	80	DCI	150	P-308	64	100	DCI	150

Junction Data

Label	X (m)	Y (m)	Elevation (m)	Demand (L/s)	Label	X (m)	Y (m)	Elevation (m)	Demand (L/s)
J-1	333,497.33	1,391,589.05	2,082.00	0.23	J-95	332,115.39	1,394,541.30	2,109.00	0.13
J-2	333,735.54	1,391,878.09	2,086.00	0.23	J-96	332,009.53	1,394,468.77	2,113.00	0.13
J-3	333,989.67	1,392,253.74	2,100.00	0.23	J-97	332,080.21	1,394,064.67	2,098.00	0.13
J-4	334,139.91	1,392,650.60	2,097.00	0.23	J-98	332,067.61	1,394,050.63	2,116.00	0.13
J-5	334,370.86	1,392,849.46	2,089.00	0.23	J-99	331,959.81	1,394,030.89	2,100.00	0.13
J-6	334,483.61	1,393,036.86	2,068.00	0.23	J-100	331,942.08	1,394,014.94	2,101.00	0.26
J-7	335,276.32	1,393,808.74	2,089.00	0.23	J-101	331,997.22	1,393,712.15	2,088.00	0.13
J-8	334,490.77	1,394,659.85	2,222.00	0.23	J-102	331,823.04	1,393,836.04	2,100.00	0.13
J-9	334,414.63	1,394,669.85	2,215.00	0.23	J-103	331,648.40	1,393,666.50	2,107.00	0.13
J-10	334,302.87	1,394,635.96	2,203.00	0.23	J-104	331,593.50	1,393,641.28	2,105.00	0.26
J-11	334,163.39	1,394,812.05	2,194.00	0.41	J-105	331,789.80	1,393,493.06	2,090.00	0.13
J-12	334,129.75	1,394,683.63	2,196.00	0.23	J-106	331,907.54	1,393,462.89	2,082.00	0.13
J-13	334,367.05	1,394,382.23	2,198.00	0.23	J-107	331,475.94	1,393,529.40	2,110.00	0.26
J-14	334,004.13	1,394,133.80	2,196.00	0.23	J-108	331,435.33	1,393,349.71	2,108.00	0.13
J-15	333,956.40	1,394,171.24	2,195.00	0.23	J-109	331,605.95	1,393,255.35	2,098.00	0.13
J-16	333,787.23	1,394,227.77	2,186.00	0.23	J-110	331,442.81	1,393,216.99	2,101.00	0.13
J-17	333,776.79	1,394,368.11	2,187.00	0.41	J-111	331,373.24	1,393,219.74	2,109.00	0.26
J-18	333,304.39	1,394,104.28	2,180.00	0.23	J-112	331,716.83	1,393,173.29	2,092.00	0.13
J-19	333,394.01	1,394,037.34	2,174.00	0.23	J-113	331,589.34	1,392,988.25	2,092.00	0.26
J-20	333,601.81	1,393,945.98	2,168.00	0.23	J-114	331,602.41	1,392,980.05	2,091.00	0.13
J-21	333,776.34	1,393,912.82	2,170.00	0.23	J-115	332,324.10	1,392,785.22	2,075.00	0.26
J-22	333,746.20	1,393,700.45	2,176.00	0.23	J-116	332,010.06	1,392,635.89	2,083.00	0.13
J-23	333,853.45	1,393,676.47	2,166.00	0.41	J-117	331,929.90	1,392,607.55	2,085.00	0.13
J-24	333,735.94	1,393,631.26	2,171.00	0.23	J-118	331,768.56	1,392,540.33	2,088.00	0.13
J-25	333,663.03	1,393,472.88	2,171.00	0.41	J-119	331,481.94	1,392,426.89	2,102.00	0.26
J-26	333,492.53	1,393,714.27	2,168.00	0.23	J-120	331,615.54	1,392,260.14	2,095.00	0.26
J-27	333,294.05	1,393,795.25	2,178.00	0.23	J-121	331,853.67	1,392,372.36	2,080.00	0.13

J-28	333,134.74	1,393,865.38	2,171.00	0.23	J-122	331,974.64	1,392,092.59	2,074.00	0.26
J-29	333,077.77	1,393,551.56	2,175.00	0.23	J-123	332,114.41	1,392,112.46	2,066.00	0.13
J-30	333,183.78	1,393,485.27	2,176.00	0.23	J-124	332,234.82	1,392,164.44	2,061.00	0.26
J-31	333,388.23	1,393,332.51	2,171.00	0.41	J-125	332,285.80	1,392,035.27	2,057.00	0.26
J-32	333,102.54	1,393,378.10	2,174.00	0.23	J-126	332,054.34	1,391,894.36	2,074.00	0.13
J-33	333,004.51	1,393,468.46	2,171.00	0.23	J-127	332,129.77	1,391,709.74	2,080.00	0.13
J-34	332,850.20	1,393,606.15	2,163.00	0.23	J-128	332,378.75	1,391,805.79	2,062.00	0.13
J-35	332,936.49	1,393,210.70	2,170.00	0.23	J-129	329,075.26	1,387,247.23	2,002.00	0.00
J-36	333,256.03	1,393,028.02	2,169.00	0.41	J-130	332,510.64	1,391,868.30	2,058.00	0.39
J-37	333,374.96	1,393,006.35	2,166.00	0.41	J-131	330,790.72	1,392,213.29	2,039.10	12.02
J-38	333,374.72	1,392,972.42	2,163.00	0.23	J-132	332,465.29	1,391,585.27	2,052.00	0.26
J-39	333,368.15	1,392,736.50	2,162.00	0.41	J-133	332,220.39	1,391,486.06	2,065.00	0.13
J-40	333,231.28	1,392,673.36	2,158.00	0.23	J-134	329,379.41	1,390,964.99	2,000.00	0.22
J-41	333,094.85	1,393,128.10	2,100.00	0.23	J-135	332,506.13	1,391,479.38	2,055.00	0.13
J-42	333,724.89	1,395,484.43	2,269.00	0.00	J-136	329,286.55	1,390,610.84	1,993.00	0.00
J-43	333,756.88	1,395,452.45	2,200.00	0.00	J-137	332,885.25	1,391,315.10	2,042.00	0.26
J-44	333,788.49	1,395,300.93	2,187.00	0.00	J-138	329,933.65	1,390,766.22	2,012.00	0.96
J-45	333,812.35	1,395,447.93	2,249.00	0.00	J-139	332,610.31	1,391,210.09	2,050.00	0.13
J-46	334,481.51	1,395,415.25	2,237.80	0.00	J-140	332,669.35	1,391,069.02	2,038.00	0.26
J-47	331,868.13	1,391,456.15	2,065.61	0.00	J-141	329,427.02	1,389,057.23	2,041.00	0.00
J-48	334,200.84	1,395,984.00	2,267.00	0.00	J-142	332,588.70	1,390,645.71	2,025.00	0.13
J-49	332,699.66	1,393,399.81	2,170.41	0.00	J-143	329,446.54	1,389,277.47	2,023.00	0.29
J-50	334,303.56	1,396,300.73	2,220.00	0.00	J-144	332,216.91	1,390,860.09	2,015.00	0.13
J-51	334,380.25	1,395,740.36	2,262.00	0.00	J-145	329,160.45	1,389,248.70	2,031.00	0.00
J-52	334,608.19	1,395,674.09	2,245.00	0.00	J-146	330,799.91	1,392,347.37	2,020.20	3.92
J-53	335,011.28	1,394,984.71	2,105.08	0.00	J-147	329,049.75	1,388,481.91	2,012.00	0.21
J-54	333,908.12	1,395,501.08	2,198.00	0.00	J-148	329,043.03	1,388,455.28	2,010.00	0.10
J-55	335,143.85	1,394,260.02	2,132.00	0.00	J-149	328,852.63	1,388,457.32	2,009.00	0.21
J-56	333,829.50	1,395,161.82	2,146.00	0.00	J-150	328,678.85	1,388,385.50	1,994.00	0.21
J-57	335,195.93	1,394,135.16	2,114.85	0.00	J-151	328,667.15	1,388,376.02	1,993.00	0.21
J-58	333,932.86	1,395,244.50	2,245.00	0.00	J-152	328,809.47	1,388,328.48	1,997.00	0.10
J-59	334,047.17	1,395,275.09	2,227.00	0.00	J-153	328,887.03	1,388,282.46	1,996.00	0.10
J-60	334,121.41	1,395,151.27	2,132.00	0.00	J-154	328,860.24	1,388,202.79	1,988.00	0.10
J-61	334,131.29	1,395,074.35	2,241.00	0.00	J-155	328,782.22	1,388,241.52	1,988.00	0.10
J-62	334,515.75	1,394,664.53	2,227.00	0.00	J-156	328,640.77	1,388,312.90	1,988.00	0.10
J-63	334,937.87	1,394,425.27	2,245.00	0.00	J-157	328,605.55	1,388,235.45	1,984.00	0.21
J-64	333,256.64	1,394,831.80	2,099.00	0.21	J-158	328,850.44	1,388,157.65	1,984.00	0.21
J-65	333,203.99	1,394,647.01	2,096.00	0.21	J-159	328,930.62	1,388,003.53	2,003.00	0.21
J-66	333,376.83	1,394,701.17	2,091.00	0.21	J-160	329,154.79	1,387,936.48	1,997.00	0.10
J-67	333,369.32	1,394,431.62	2,069.00	0.21	J-161	329,149.00	1,387,990.54	2,000.00	0.10
J-68	333,213.44	1,394,581.63	2,089.00	0.21	J-162	329,135.13	1,388,048.87	2,004.00	0.10
J-69	333,148.62	1,394,611.19	2,090.00	0.21	J-163	329,278.62	1,388,366.25	2,000.00	0.21
J-70	333,086.16	1,394,595.68	2,080.00	0.21	J-164	329,320.79	1,388,343.20	1,998.00	0.10
J-71	333,145.13	1,394,496.81	2,092.00	0.21	J-165	329,362.80	1,388,460.14	1,997.00	0.21
J-72	333,172.95	1,394,289.54	2,091.00	0.21	J-166	333,743.75	1,395,549.42	2,202.00	1.89
J-73	333,050.65	1,394,179.63	2,086.00	0.21	J-167	329,528.33	1,389,117.42	2,000.00	0.33
J-74	333,011.34	1,394,146.46	2,076.00	0.21	J-168	333,814.97	1,395,528.40	2,201.00	1.08
J-75	332,950.44	1,394,053.66	2,081.00	0.21	J-169	329,587.82	1,389,216.62	1,998.00	0.21
J-76	333,035.46	1,393,875.39	2,096.00	0.21	J-170	332,779.12	1,395,401.18	2,132.00	0.00
J-77	332,873.58	1,393,946.06	2,087.00	0.21	J-171	330,111.11	1,389,313.58	2,001.00	0.21
J-78	332,646.65	1,393,978.31	2,094.00	0.21	J-172	329,955.30	1,389,067.05	2,005.00	0.10
J-79	332,783.80	1,393,789.56	2,091.00	0.21	J-173	329,772.82	1,388,653.89	2,003.00	0.10
J-80	332,890.69	1,393,745.64	2,090.00	0.21	J-174	329,699.98	1,388,545.81	1,995.00	0.10
J-81	332,744.94	1,393,687.37	2,093.00	0.21	J-175	329,498.14	1,388,407.05	2,006.00	0.21
J-82	333,041.21	1,394,605.95	2,094.00	0.21	J-176	329,586.20	1,388,371.97	2,010.00	0.10
J-83	332,831.21	1,394,329.80	2,090.00	0.35	J-177	329,948.13	1,388,382.24	2,008.00	0.10
J-84	332,755.54	1,394,375.83	2,092.00	0.21	J-178	329,873.30	1,388,252.91	2,007.00	0.10
J-85	332,967.52	1,394,617.57	2,091.00	0.21	J-179	329,474.25	1,388,048.44	1,993.00	0.10
J-86	332,868.81	1,394,652.42	2,079.00	0.21	J-180	329,541.42	1,388,038.58	1,990.00	0.10
J-87	332,797.77	1,395,040.63	2,089.00	0.21	J-181	329,789.72	1,387,963.52	1,977.00	0.21
J-88	332,578.95	1,394,933.33	2,070.00	0.39	J-182	329,513.63	1,387,705.98	1,980.00	0.10
J-89	332,650.04	1,395,401.99	2,094.00	0.39	J-183	329,983.01	1,387,574.70	1,964.00	0.21
J-90	332,518.39	1,395,376.79	2,091.00	0.39	J-184	332,689.85	1,395,421.82	2,130.00	0.02
J-91	332,481.51	1,395,364.76	2,092.00	0.39	J-185	333,131.73	1,395,299.25	2,129.00	0.02
J-92	332,529.05	1,395,043.58	2,114.00	0.00	J-186	333,872.50	1,395,119.92	2,149.00	0.02
J-93	332,042.07	1,394,759.88	2,113.00	0.26	J-187	334,005.40	1,395,043.48	2,200.00	0.02
J-94	332,038.31	1,394,561.86	2,112.00	0.13					

Reservoir Data				**Pump Data**					
Label	Elevation (m)	X (m)	Y (m)	Label	X (m)	Y (m)	Elevation (m)	Pump Head (m)	Flow (Design) (l/s)
AngerebR	2,132.00	335,264.42	1,395,004.36	Esat A Pum	333,823.36	1,395,087.75	2,116.00	93.11	18.00

GTW-7R	2,069.00	334,540.00	1,392,928.00	GTW-7	334,518.19	1,392,971.09	2,067.00	85.86	13.00
NW-1R	2,019.00	335,274.02	1,394,079.48	NW-1	335,232.65	1,394,106.58	2,018.00	122.22	18.00
NW-2-R	2,039.00	333,561.00	1,391,522.00	NW-2	333,553.26	1,391,531.34	2,034.00	142.80	12.00
NW-3-R	2,046.00	333,854.00	1,391,779.00	NW-3	333,842.27	1,391,789.22	2,043.00	126.01	11.00
NW-4-R	2,050.50	334,005.00	1,392,232.00	NW-4	333,995.88	1,392,245.56	2,048.00	144.13	14.00
NW-5-R	2,066.00	334,485.00	1,392,662.00	NW-5	334,437.61	1,392,738.66	2,064.00	84.19	16.00
TW-5-R	2,065.00	334,203.00	1,392,539.00	TW-5	334,168.25	1,392,604.22	2,060.00	86.26	16.00
TW-6-R	2,092.00	335,364.00	1,393,699.00	TW-6	335,321.37	1,393,752.83	2,088.00	68.27	4.00
Dokemit	2,297.55	334,824.73	1,394,628.25	Angereb-P	335,214.14	1,394,998.19	2,104.00	31.04	90.00
Felefelit	2,224.00	333,272.18	1,395,747.85	C.Water-P	335,237.28	1,394,203.05	2,125.00	131.73	150.00
Sanita-1	2,030.00	328,719.03	1,388,832.34						
Sanita-2	2,054.00	329,018.92	1,390,258.96						

Tank Data

Label	X (m)	Y (m)	Elevation (Base) (m)	Elevation (Maximum)	Diameter (m)
Azezo	329,079	1,388,555.	2,018	2,047	8.00
Gebreal	332,986	1,395,096	2,089	2,170	4.00
Goha	333,663	1,395,536	2,271	2,298	6.00
Stadium	332,694	1,395,361	2,120	2,144	5.38
BW	335,222	1,394,256	2,137	2,140	3.50
CWT	335,281	1,394,174	2,130	2,164	6.17
DB ST	334,834	1,394,473	2,278	2,298	11.43
Esat AT	333,841	1,395,079	2,198	2,224	3.84
Sam.T	330,777	1,392,385	2,018	2,048	5.80

Valves

1. PRV data				
Label	Elevation (m)	X (m)	Y (m)	Diameter (mm)
PRV1	2,105	335,028	1,394,895	350
PRV2	2,130	335,187	1,394,233	300
PRV3	2,137	335,185	1,394,297	250
PRV4	2,295	334,825	1,394,570	150
PRV5	2,270	333,675	1,395,524	150
2. FCV				
FCV1	2,104	335,166	1,394,991	300
FCV2	2,119	332,650	1,395,355	250
3. Air Valve				
AV-1	2,012	329,330	1,390,117	250

Hydrant Data

Label	Elevation (m)	X (m)	Y (m)
H-1	2,088	332,235	1,393,320.13
H-2	2,125	332,646	1,393,396

Turbine Data

Label	Elevation (m)	X (m)	Y (m)	Efficiency (%)
TBN-1	2,134	335,115	1,394,981	90

Turbine Data

Label	Elevation (m)	X (m)	Y (m)	Efficiency (%)
TBN-2	2,134	335,113	1,395,005	90
TBN-3	2,134	335,116	1,394,955	90
TBN-4	2,134	335,113	1,395,030	90

Appendix-O: List of Questionnaires

Hello! My name is _________. I am assisting an on-going research by Gebrie Semagn in partial fulfillment for his Master's degree at Jimma University. We are talking to selected sample households in Gondar town about the water supply distribution and water loss management of the town. The information that will be collected from this questionnaires survey will be used for research purpose only. Please be frank and open-minded in your evaluations and opinions. All information obtained will be kept strictly confidential. Your kind cooperation is highly appreciated.

Questionnaire No: ___________Name of Interviewer: ________Date of interview: __________

1. Name of Sub-City: _________________
2. House No: ________________________
3. Sex: (a) Male (b) Female
4. Age: (a) Under 14 years (b) 15-39 years (c) 40-64years (d) above 65 years
5. Educational background: (a) None (b) Read-Write (c) Elementary school (d) Secondary school (e) High School (f) College (g) Graduated (h) Higher education (i) Others_____
6. Occupation: a. Government Sector b. Retired c. Private Sector d. Housekeeper e. other (specify) _______________________
7. How many persons live in your household? (a) Infants (less than 1 year old) (b) Children (1-18 years old (c) Adults (more than 18 year old) (d) Total
8. House holding: (a) Private Rent (b) Government (c) Private (d) Other (specify)
9. How long have you been living in this area? __________Years
10. Monthly income (Birr/month): (a) <700 (b) 701-1000 (c) 1001-2500 (d) >2500
11. Are you satisfied with the quality of main water source available in your household? (a) Yes (b) No
12. If there are water supply interruptions, do you suggest the main reasons? (a) Water source problem (b) Pipe break (c) Reservoir fails (d) Electric failure (e) Pump failure (f) Other/specify
13. If pipes break, when do you think it happens so? (a) During road construction (b) During telephone line installation (c) During electric line installation (d) During building construction (e) When it gets old (f) Other (specify) ________________________
14. Why do you think the water supply system is not performing as intended? (a) Poor planning (b) Poor Design (c) Poor construction (d) Poor maintenance (e) Poor management (f) I don't know
15. What time does your household usually obtain the water from the water distribution pipe? (On average): (a) 04 – 08 AM (b) 09-12 AM (c) 01 – 04 PM (d) 05-08 PM (e) 09 -12 PM (f) Other (specify) ____________________
16. For how long does the water system working in a day? (On average): (a) Less than 2 hr. (b) 2-8 hr. (c) 8-12 hr. (d) All the time (e) Other (specify) ________________
17. Is there any leakage in the water supply system? (a) Yes (b) No

18. If ‘yes’ what are the main causes of leaks?
19. Do you think an importance for taking care of running water away unused through leaks or wastage? (a) Yes (b) No
20. If yes, why? (Please select one or more): (a) Water is an important resources and should not be waste unnecessarily (b) Water is expensive for me and I cannot afford to pay for wastage (b) It takes a lot of effort to get (fetching, carrying, etc.) (c) Others (specify)___
21. If No, why? (Please select one or more): (a) Water can easily get and sufficient available in my house (b) Water does not cost much money (c) Other reason (specify) _________
22. Do you want (willing) to participate for preventing water running away through leaks or wastage near your house? (a) Yes (b) No
23. If water leakage problem is in or near your household, how do you act for this problem? (Please select one or more): (a) Immediately repair the fault by ourselves (b) Immediately inform to Gondar town water supply staff for repair the fault (c) Immediately call the private plumber for repair the fault (d) Leave the leak because water is not cost too much (e) Leave the leak because the cost of repairs is too much (f) Leave the leak because difficult to call to Gondar town water supply staff for repair the fault and too much cost (g) Other (specify) _________________________
24. In case, if there is leakage problem, the Average duration in hours or days that leakage existed: (a) To identify (detect) _______ (b) From identified to report ______, and (c) From reported to repaired _________
25. Is there any leakage at your water meter? (a) Yes (b) No (c) If yes, -- liter, or---- m^3
26. How much water in m^3 do you consume in this month? (Check in your water bill (m^3)
27. How much do you pay for $1m^3$ of water as a tariff currently? Birr _________________
28. Are you willing to participate on the water loss management for the improvement of the town water supply service? (a) Yes (c) No
29. Do you know current laws, regulations and penalties for water users that obligated by GTWSSS on water management? (a) Yes (b) No
30. Have you encountered illegal connections or illegal water users in your locality? (a) Yes (b) No
31. Which way do you want to participate on proactive water loss management? (select one or more): (a) Paying water tariff regularly, to enhance O&M (b) Taking care of running water away unused through leaks or wastage (b) Obey laws and regulations related with water and environmental concerns (c) Reporting leaks quickly for the town water supply enterprise (d) Sharing information and knowledge about water to neighbors and others (e) Others (Please specify) _____________________
32. What do you expect from GTWSSS on proactive water loss management? ___________