ASSESSMENT OF WATER DISTRIBUTION NETWORK OF ADOLA WAYOU TOWN WATER DISTRIBUTION SYSTEM

MSC THESIS

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This is to certify that research study entitled as "The Assessment of Water Distribution Network of Adola Wayou Town Water Distribution System located in Oromia region of Ethiopia" and submitted in partial fulfillment of the requirement for degree Master of Science (Water Resource Engineering and Management) the graduate program of Department of Water Resource and Irrigation Engineering and has been performed by Solomon Seyoum ID.no GPWREMR 0015/2012 under my supervision. Therefore, we recommended that the student has fulfilled the requirement and hereby can submit the thesis to department.   .

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We undersigned, the member of board of examiners of the final MSC open defense by Solomon Seyoum Damisse have read and evaluate his/her thesis entitled “The Assessment of Water Distribution Network of Adola Wayou Town Water Distribution System Located in Oromia region of Ethiopia” and examined the candidate.

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DEDICATION

I dedicate this thesis manuscript to all my family members for nurturing me with care and love and, for their dedicated partnership in the success of my life.

STATEMENT OF AUTHOR

By signature below, I declare and affirm that this thesis is my own work. I have followed all ethical and technical principles of scholarship in the preparation, data collection, data analysis and compilation of the thesis. Any scholarly matter that is included in the thesis has been given recognition through citation.

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ABSTRACT

Water distribution systems are designed to fulfill all requirements of water demand needed for decades. Initial system designs frequently consider any anticipated changes likely to happen. However, as times elapsed they slowly begin to fail to satisfy customer' requirement; both in quantity and quality. This research was conducted by aiming to undertake the assessment of water distribution network of Adola Wayou Town for existing water distribution system which is located southern Oromia region of Ethiopia. The main objective of this research study was to investigate the states of the existing water distribution system by assessing water demand, and water production, hydraulic parameter analysis and water loss and the cause in the distribution system. The research depend on the secondary and primary data which was collected from design document, literature, journals and reports, field observation, interviews and discussion with water utility office to analysis water loss and the cause and water service coverage. The town water distribution network had been analyzed using computer model Water GEMs connected edition under both steady-state and extended period simulation for the present population scenarios. The simulation result of the model for maximum and minimum pressure and velocity was used as the base to analysis the hydraulic performance of the water network during peak hour consumption times and low consumption times. From the analysis result about 11.62% of the nodes have the negative pressure. Additionally, the model output results indicate that about 63 pipe in water network system has the velocity below minimum requirement of 0.6m/s during peak hour consumption time. The total domestic and non-domestic water demand of town was 3421.12m^3/day. From the water produced from the treatment source the non-revenue water in the town water system was considered as 31.93% of distributed water in distribution system. The actual/real water loss share large volume that accounts about, 312,545.2m^3/year whereas the apparent loss 60,412.79m^3/year. The finding of the study showed that the service coverage and average connection per family of the town were estimated in the order of 62.65% and 41% respectively. In general the result of the research study of water distribution network system indicates that Adola Wayou Town water utility office under current situation was inefficient. Accordingly it's required to provide efficient and more reliable water system through pressure zoning, improving pipe size, and planning another water distribution system, giving more attention to water loss reduction police and strategies to reduce the waste actual/real and apparent loss.

Key word: pressure, velocity, water distribution network, water demand, water loss, simulation, water gems, Adola Wayou Town

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LIST OF ABBREVIATIONS AND ACRONYMS

ACWA	Actual Consumed Water Amount
ADD	Adjusted Domestic Demand
AWWA	America Water Work Association
AM	After Meridian
CSA	Central Static Agency
DCI	Ductile Iron
DN	Nominal Diameter of Pipe
E	East
EPA	Environmental Protection Agency
EPS	Extended -Period Simulation
GC	Gregorian Calendar
GIS	Geographic Information System
HC	House Connection
HCU	House Connection User
ILI	Infrastructure Leakage Index
IWA	International Water Association
Km	Kilometer
ℓ/c/day	Liter per capita per day
ℓ/s	Liter per second
mm	Millimeter
m/s	Meter per second
m^3	Meter cubic
m^3/hr	Meter cubic per hour
m^3/day	Meter cubic per day
MMD	Maximum Daily Demand
MDF	Maximum Day Factor
MHD	Maximum Hourly Demand
MoWR	Ministry of Water Resource
NP	Nominal Diameter of the Pipe
N	North

NDWD	Non-Domestic Water Demand
NRC	National Research Council
NRW	Non-Revenue Water
OWREB	Oromia Water Resource & Energy Bureau
OWWDSE	Oromia Water Work Design & Supervision Enterprise
PHF	Peak Hour Factor
PHD	Peak Hour Demand
PRV	Pressure Reducing Valves
PT	Public Tap
PTU	Public Tap User
PVC	Polyvinyl Chloride Pipe
PM	Post Meridian
SC	Service Coverage
RC	Reinforced Concrete
RMSE	Root Mean Square Error
R square	Correlation Coefficient
sq.km	Square kilometer
TDW	Total Water Demand
TMWD	Theoretical Minimum Water Demand
UARL	Unavoidable Annual Real Loss
UFW	Unaccounted of Water
UNICEF	United National Child Fund
UTM	Universal Transfer Mercator
WHO	World Health Organization
YCU	Yard Connection User
YSC	Yard shared User

1. INTRODUCTION

1.1. Background of the study

For every living thing in the universe water is one of the essential elements required to full fill the need. Human being needs sufficient amount of water for various uses such as for food preparation, swimming, washing, drinking, industry and the like. But from available water only 2.5% of water is used for this purpose all over the world (Ciobanu J & Natalia K, 2013). The rest of water 97.25% existed as salt water in the ocean.

The availability of potable water is important for high living standard of the community, but now a day meaningful number of populations do not have access to safe and sufficient water supply from water system in developing countries. About two and half population of the world mainly shared by Asia and Africa do not have access to safe and sufficient water (Salunke M, 2018: Pravinkumar S, 2019). Due to this water cries increase every year, especially in urban area of developing countries in line to population increase, expansion of urbanization and the like.

In Ethiopia, urbanization increase at high rate every year, above 17% percent of population migrate from rural to urban area based on the data of Ethiopia Central statistical (CSA, 2007). According to UNICEF joint monitoring programmer 2014 report, in Ethiopia nearly about (43%) of the total population of the countries are lack accesses to safe and sufficient water.

The provision of safe and sufficient water distribution for the population can eradicate poverty, health living and provide good environment for sustainable economic development of the society (Zewdu, 2014). However, due to low hydraulic performance of urban water supply system of Ethiopia including Addis Ababa has faced the challenges in terms of water distribution, quality and reliability and, it was among lowest countries (Shimesles, 2012).

Water distribution system is hydraulic infrastructure that contains different element like pipe, valve, pump and reservoir. The primary use of water distribution system was to deliver safe and sufficient water after the treatment source (Rameshwari D & Bhoyar I, 2017). The good water distribution system needs to meet the basic requirement through providing expected quantity and quality of water supply during life for expected demand loading condition with desired residual pressure (Misirdali L, 2003). This water system has the category of loop and branch system. In branch system, the pipe discharge is unique and can be obtained simply by applying discharge continuity equation at node. But, in the case of loop system, the numbers of pipes are too many to find the discharge of the node by applying discharge continuity equations.

In ancient city of the early civilization, the appearances of water distribution system were not complex system. They were a system of single line or very few lines. However as the population increase in the town every decade the need to develop complex water supply infrastructure increase.

Currently, one of the main problems towards supplying safe and sufficient water supply to the consumer from water supply system in urban area of Ethiopia is the limitation of financial resource. It can be the main reason for providing limited expansion, rehabilitation of the existing aged pipe and the development of water supply system source which may hinder the service coverage of the hydraulic system. One more key problem which may hinder the hydraulic of the existing system was the limited institutional capacity and, water loss from the distribution system which may account 50% of water produced of the treatment source (Dighade et al., 2014). Water loss from the distribution system component happened for various reasons including leakage loss, pipe burst, overflow from service reservoir, illegal connection and unmetered water connection. The magnitude of leakage from the distribution system may account large volumes of water loss than the rest of water loss factor, but this is not all the case. Moreover managing water loss from distribution system requires a lot of effort from water utility office and concerned body.

Generally, because of many factor that affect the hydraulic performance of the existing water distribution network, the total water required for consumption purpose for all types of water demand including of domestic and non-domestic water demand in water utility exceed the available water production of the treatment source. During field survey of the town water office the town population used the traditional water source (like protected well/ spring, unprotected spring/ well to meet the domestic water consumption in their day to day activity. Therefore, the study was conducted to identify the main problems of water distribution network of Adola Wayou Town located in Oromia region of Ethiopia. The goal of the study was to conduct the analysis of the hydraulic performance of existing water distribution network of the town on the base of the assessment of the water distribution network using hydraulic simulation software. Water GEMs connected edition is selected since it has the capability to wide regimes of analysis hydraulic and water quality and also manage cost and energy. Additionally it has its own calibrators that differ from the other computer hydraulic model to use it for the purpose of calibration.

1.2. Statement of the problem

Access to safe and sufficient water supply is prerequisite for health and development of the community and, it is also taken as the basic human right, but several millions of people relying on unsafe drinking water source in Africa including Ethiopia. This due to intermittent nature of the distribution system caused from insufficient water supply, irregular pressure and water loss or wastage. Population increment and social and economic changes also contribute for water demand increase. For this reason the existing water distribution system in Ethiopia did not satisfy the requirement both in quantity and quality for tremendously increasing populations (Bereket, 2006).

The water utility of the town, Local Government & Regional Water Resource & Energy Bureau has made significant contribution in redressing the imbalance of water demand and water supply of the town. But still now there is the situation for the town water once every fortnight for a few hours which is in adequate for domestic water consumption occur due insufficient water distribution, inequality of service among customer, high level of actual and apparent loss from water distribution system which display the poor performance of water supply system in conveying sufficient water supply to consumer place of life. So the population of the town uses unprotected spring and well which are far away from their house to meet the water consumption for domestic purpose. As result of the above mentioned problem existed in the town water distribution system, it is necessary to evaluated the currents status of water demand in the existing water distribution network of Adola Wayou Town water distribution system using hydraulic simulation software Water GEMs connected edition to increase the efficiency of the water distribution networks and to avoid inequality among consumer of water supply in service provision from water system.

1.3. Research objective

1.3.1. Main objective

The objective of this research study was to evaluate the performance of the existing water distribution network using hydraulic simulation software Water GEMs connected edition and recommend the possible improvements method of Adola Wayou Town water network system.

1.3.2. Specific objectives

- ☞ To estimate the current and future water demand of the town water distribution system,
- ☞ To evaluate the hydraulic performance of the existing water distribution network,
- ☞ To estimate the level of water loss in the water distribution network,
- ☞ To assess the causes of water loss in the town distribution network,
- ☞ To assess the current situation of the existing water distribution.

1.4. Research questions

The main and specific objective of the research study was achieved by the way of seeking the answer to the following question.

- ☞ What are the present water demand and future water need of the population?
- ☞ What is the hydraulic performance of the existing water distribution network?
- ☞ How much water is lost from water distribution system when compared with the water produced of the source?
- ☞ What is the factor contributing to water loss in the town water distribution system?
- ☞ What is the current situation of the town water distribution?

1.5. Significance of the study

From this study it was expected to identify the deficiencies of the town water distribution network through examining the hydraulic performance of the existing water distribution network, water demand analysis, the actual and apparent loss in the town water network including the main factor contributing for water loss is well known. The finding of the research study can be used for planning of new water distribution system, to improve the knowledge gap and initiates another researcher for the further study of similar urban water system.

1.6. The scope of the study

In this study the hydraulic performance assessment of the existing water distribution network is analyzed under different scenarios based on the hydraulic condition. The peak hour consumption times and low consumption times scenarios are used to analysis the hydraulic parameter of the water distribution network. The water conveyed in the distribution network is considered as potable water. The reason for excluding water quality analysis was due to the financial resource problem faced me to undertake the water quality analysis because I am self-sponsored student which pay for all activity including for education and for thesis work.

1.7. Limitation of the study

This research study was restricted to analysis water distribution network from service reservoir to the water distribution end of the customer. There is no funding for this research study for carrying out field data and design document data collection for the entire water network. The testing of water meter was costly and the required data were collected by reviewing different design document available in the town.

1.7. Organization of the study

The entire of the research study were summarized and representing the result to analysis in suitable manner.

Section one: introduction part: contains statement of the problem which is important to establish the specific and general objective, significance of the study and research question.

Section two: the review of relevant theories and studies related to the specific objective were included.

Section three: it describe the method used for data collection and analysis for each specific objective including description of the study area.

Section four: data analysis, presentation and interpretation, discussion of the finding were included in this section as per study objective in the form of table and graph.

Section five: contains conclusion and recommendation part of the study.

2. LITERATURE REVIEW

2.1. Introduction

In developing countries the challenges in providing safe and sufficient water supply to the rapidly growing population of the town increase in alarming rate in the recent times. Therefore, most of the existing water distribution system is unable to meet the domestic, non-domestic and industrial demand of water. Beside to this, infrastructure ageing problem, illegal connection, poor management of existing system component, and low capacity of the institution was the main problems of the water supply system. So most of the water system is often unable to satisfy existing and the future water demand of consumer. In addition to water supply shortage or the inefficiency of the system, many towns are faced a problem in distributing the available water impartially among the resident. Beside, to water supply shortage, water loss in urban water supply system share large volume of water supply that mainly arise from leakage of pipe, joint, and valves, over flowing service reservoirs and wastage of water through illegal connection and unmetered house connection. Poor management of the existing infrastructure also increases the level of water loss in the distribution system (Melaku, 2015). As this research deal with assessment of water distribution network, the issues related to the water demand of the population, hydraulic performance evaluation, water losses and factor causing water loss, water distribution were identified and reviewed in this chapter.

2.2. Types of water network system

The element of water network system includes valves, appurtenance, hydrant, pipes and reservoir. Pipes are one of the main elements of the distribution system used to transport water to use for consumption purpose and, it was available in the market with different type of material and size. The water network system classification was the branched and loop types system (Tomas et al., 2003).

Branching type of water network system

These types of water network system were commonly designed and constructed in developing countries since the system need low cost to design water supply system and for construction of the system when compared with loop types of water system. In this water system, the new branch follows that development and the new dead will be produced. Branching system has some disadvantage since the maintenance and operation brought the interruption of the whole area of the system.

Loop type of water network system

Loop system is the another types water network system which have the capacity to provide reliable water over the dead end types of water network system, since in this system the water was circulated freely over the entire system. The system has sufficient valves located properly to avoid the inconvenient during the repair and maintenance activity to minimize the interruption of the area of the loop system.

The analysis of a loop network consists of the determination of pipe discharges and the nodal heads based hardy cross methodology using the principle of continuity equation and the conservation of energy theory (Prabhata & Ashok, 2008). The continuity equation implies that the algebraic sum of the flow rates in the pipes meeting at a node together with any external flows is zero. This was shown as in the equation below.

$Q_1 + Q_2 = D + Q_3$ … 2.1

$D = Q_1 + Q_2 + Q_3$ … 2.2

Where Q is the flowed in or out of the node and D is the demand at the node or nodal demand.

The conservation energy implies that the algebraic sum of head loss around the loop is zero. For all paths around closed loops and between fixed grade nodes, the accumulated energy loss including minor losses minus any energy gain or heads generated must be zero as shown in the figure below.

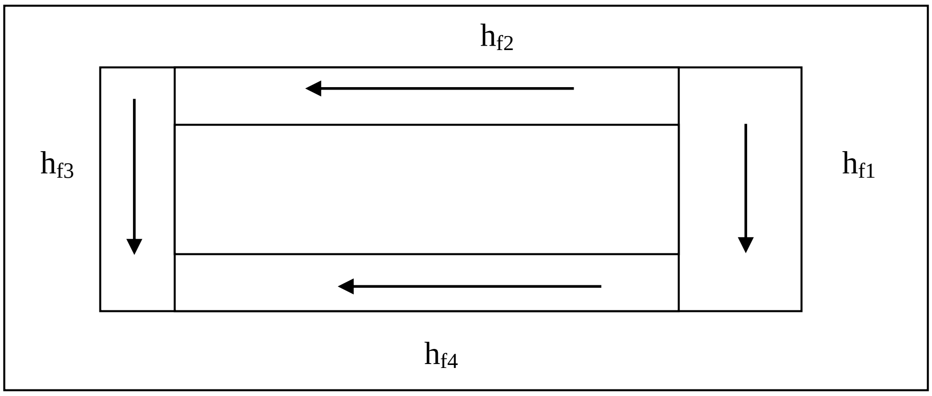

Figure 2.1 The illustration of conservation of energy in loop system

Given that total head loss for each link as hf and assuming counterclockwise flow direction to be positive, then.

$$h_{f2} + h_{f3} - h_{f4} - h_{f1} = 0 \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 3.3$$

The loop data do not constitute information independent of link –node information, and theoretically it is possible to generate loop data from this information and, the information about the loop forming pipes can be developed by combining flow paths. This path are the set of pipe connecting a demand (withdrawals) node to the supply (input) node can be identified by moving opposite to the directions of flow in pipe (Sharma, 2008). Unlike branch systems, the flow direction in the loop network is not unique and depends upon a number of factors, mainly topography and nodal demand. The Adola Wayou Town water system layout consists of loop system and branch system.

2.3. Method of water distribution

Different method of water distribution can be used to deliver water in the distribution system by having sufficient pressure at consumer tap. Selecting one method of water distribution depend on the different factor such as the topography of the area and elevation with respect to the site of the treatment (Singh G, 2003). The method of water distribution can be gravity method, distribution by pumping and distribution by pumping with storage. From the three method of water distribution, gravity method was the most preferable method of water distribution for it is the most econonmical value, becouse it avoid the cost fual or electricity for delivering water

2.4. Water demand

The volume of safe water requested by users to satisfy their need was estimated based on a simple per capita water demand taking into consideration to determine demand of the projected need of the population, industrial, commercial and another water use responsible to supply by the water utilities (Trifunovic N, 2008). Water demand for the town population may be estimated using population growth rate, land use information and the past water production data (Sharma S, 2014). On the other hand, water demand depends on several factors such as: climatic condition, size and types of settlement, different standard of living, water supply quantities, pressure along the distribution system, supply regime (intermittent or continuous), water costs and tariff, environmental issue and etc. Therefore, for the increasing demand new water resource development was required to meet the increasing water demand at present and future. According to Sharma (2014), urban water demand consist of domestic, non-domestic, commercial and industrial, public use, miscellaneous (system cleaning losses, fire demand) components.

2.4.1. Domestic water demand

The quantity of water needed for actual house hold activity is taken as domestic water demand (WHO, 2000). It includes the water used for various purposes including for cooking, drinking, bathing, toilet and the like. The water used for house hold consumption depends on many factors such as climatic condition, mode of service and accessibility of service. According to Ministry of Water Resource (2006) in Ethiopia the actual water demand expected to be greater than the water consumption.

2.4.2. Non-domestic water demand

Non-domestic water demand includes the various water demand categories such as light, industrial demand, commercial and institutional demand (public demand) and unaccounted water demand. Generally these types of water demand include all water demand that is not considered as a part of domestic water demand and usually expressed as the percentage of domestic water demand (MoWR, 2011).

Public water demand: the quantity of water needed for the use of school, restaurant, public office, commercial and military camp, light industry and the like, usually recommended by taking about 30% of the domestic water demand.

Industrial water demand: the volume of water adjusted based on the availability of the industrial development that may consume the water similarly as the population of the resident.

Animal demand: the quantity of water used for animal consumption and allocated if there is no water source in the proximity of the town or city that may serve the animal demand.

Firefighting demand: the amount of water allocated for one fire incident and stored in service reservoir.

Unaccounted water demand: is the water loss on the water distribution network which may include illegal connection, overflow from the service reservoir and improper meter reading was considered as unaccounted water demand.

2.4.3. Baseline demand

Demand allocation is the task performed in water distribution network modeling for assigning the water demand. One of the most common methods of allocating baseline demand is point loading method (Tomas et al., 2003). It is one of the demands loading method that require detail house hold survey. This method involves counting the number of customers (hectares of a given land use, number of fixture unit, or number of equivalent dwelling unity) that contribute to the demand at certain nodes, and then multiplying that number by unity demand (liter per capita per day). Average day demand is used to estimate baseline demand and other demand in the water distribution system including unaccounted for water (Bhadbhade N, 2009). Hence, most modelers determine the water demand analysis of a given town by applying baseline demand to variety of peaking factors and demand multipliers.

2.4.4. Demand diurnal pattern and multipliers factors

The variation in water usage for water supply system typically follows a 24-hour cycle. However, in reality, water demand varies overtimes and for extended period simulation to reflect the dynamics of the real system and, these demand fluctuation must be incorporated into the model and it requires both baseline demand data and information on how demands vary overtimes. These demands can be determined by applying a multiplication factors or peak factor. According to (Tomas et al., 2003) these factor are system- specific, so it must be determined based on the demand character of the system. Therefore, when more than one demand types is served by particular junction, the total demand for a junction at any given times is equal to the sum of each baseline demand times with it respective pattern multiplier, and it used in most software packages to assign a different pattern to the different component of the composite demand.

2.5. Hydraulic performance of the distribution system

The purpose of water distribution was to convey water to individual users in a sufficient amount and at an acceptable pressure. It should be capable of delivering the maximum instantaneous design flow at a satisfactory pressure. The water distribution networks should meet all types of water demands. If designed correctly, the network of interconnected pipe, storage tanks, pumps, and regulating valves, provide sufficient pressure, adequate supply, and good water quality throughout the system (Haested press, 1999). If incorrectly designed, some areas may have low pressure, poor fire protection, and even health risks.

The water distribution system, which is typically the most expensive component of water supply system, which was continuously subjected to environmental and operational, stresses which lead to its deterioration(Kleiner W & Adams B, 2001). Increase operational and maintenance cost, reduction in the quality of service and reduction in the quality of water are typical outcomes of this deterioration.

2.5.1. Principal of pipe network hydraulic

In the network of interconnected hydraulic element, every element, is influenced by each of its neighbors, the entire system is enter related in such a way that the condition of one element is in constituent with the condition of the other entire element. This condition can be governed by the law of conservation mass and the law of the conservation of energy (Walski et al., 2003).

2.5.1.1. Conservation of mass

The principal conservation of mass dictates that there is no fluid mass created or destroyed in the hydraulic system. The fluid mass entering the pipe network match with the fluid mass leaving the system, but in the distribution system the out flow is divided into small piece or taken at nodal demand. According to Walski (2003) the mathematical method to express the principal of conservation of mass was:

$$\sum Q_i \Delta T - \sum Q_0 \Delta T - \Delta Vs = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(2.4)$$

Where:

$\sum Q_i$ = Total inflow (volume /time)

$\sum Q_0$ = Total outflow (volume /time)

ΔVs = Change in storage volume

ΔT = Change in time

The withdraw water from the storage tank bring the storage of water in some area of the distribution system during extended period simulation.

2.5.1.2. Conservation of energy

The principal conservation of energy is the energy equation which contains the pressure head, velocity head and elevation head and sometimes called Bernoulli's equation.

$$Z_1 + \frac{(P_1)}{\gamma} + \frac{(V_1)^2}{2g} = Z_2 + \frac{(P_2)}{\gamma} + \frac{(V_2)^2}{2g} + hl \dots\dots\dots\dots\dots\dots\dots\dots.\dots\dots\dots. (2.5)$$

Where

$\mathrm{Z} = \mathrm{Elevation\ (m)}$

$\mathrm{P} = \mathrm{Pressure\ (Ib/ft^2\ or\ N/m^2)}$

$\gamma = \mathrm{specific\ weight\ of\ the\ fluid\ \ (Ib/ft^3\ or\ N/m^3)}$

$\mathrm{g} = \mathrm{gravitational\ acceleration\ constant\ (ft/s^2 or\ m/s^2)}$

$\mathrm{hl} = \mathrm{head\ loss\ in\ the\ pipe\ head\ H(L)}$

$\mathrm{V} = \mathrm{Fluid\ velocity\ (ft/s\ or\ m/s)}$

The energy can be added to the system from the pump and removed from the system due to friction force in which the difference in energy between two points is the head loss or head gain (Walski et.a.,2003).

2.5.2. Water distribution system network component

Service reservoir

Service reservoir was provided in the water distribution system to store excess water during low consumption times in order to meet the fluctuation of water demand in water supply system, to reserve water for firefighting demand and to stabilize pressure in water distribution system or my close to it as much as possible, if any place was available. The service reservoir was constructed above the service area to provide the correct hydraulic grade line (Jeffrey A & Gilbert P, 2012). In the area where is the topographic problem to permit surface reservoir, the elevated tank was required to be constructed. The mass diagram is one method used for determining the service reservoir capacity in the water distribution network system.

Accessary equipment

Accessary equipment in water distribution system of the pipe line can be categorized as valves, hydrant, fitting, and drainage facilities, flow meter and etc. According to Bhadbhade N (2009) the accessary equipment is installed at place where needed to correct the network of pipes, for controlling and management of the system and for maintenance during failure occurred.

Pipe

In water distribution system, pipes was one the essential component used to link all of water distribution network system element that was categorized as transmission main, distribution main and service pipe. In ancient times pipe is available in limited types and size, but nowadays the pipe produced from different material with different types and size were used for resident and commercial water supply network application (Kay chamber, 2004).

2.5. 3. Head loss

Head loss is the energy loss in the hydraulic structure of water distribution system, due to the friction along the length of the pipe network and those due to fitting, valves and other system considered as the minor loss (Walski et al, 2003). The energy loss can be estimated using the expression in terms of the equation as in below. (Zyoud S 2003).

$$\mathrm{hL} = (\mathrm{CfLQ}^{1.852}/\mathrm{C}^{1.852}\mathrm{D}^{4.87}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.6)$$

Where:

$\mathrm{hL} = \text{Head loss due to friction } (\mathrm{m}, \mathrm{ft})$

$\mathrm{L} = \text{Length of the pipe} (\mathrm{ft}, \mathrm{m})$

$\mathrm{C} = \text{Hazen} - \text{Williams friction factor}$

$\mathrm{D} = \text{Pipe internal diameter } (\mathrm{ft}, \mathrm{m})$

$\mathrm{Q} = \text{Flow rate in the pipes } (\mathrm{cfs}, \mathrm{cms})$

$\mathrm{Cf} = \text{unit conservation factor}$

2.5.4. Hydraulic parameter

2.5.4.1. Pressure

In the hydraulic analysis, pressure is the main parameter which depends on the adopted guide lines for maximum and minimum pressure and, can be varies based on the topographic circumstance and the size of the network within the water network system. The maximum pressure constraint result from service performance requirement such fire need or the pressure bearing capacity of the pipe and limit the leakage in the distribution system. The minimum pressure should be maintained to avoid water column separation to ensure sufficient water supply for the consumer. According to MoWR, 2006 the normal working pressure in water supply system will vary between 15m to 70m.

2.5.4.2. Flow rate

A flow rate is the volume of water that passes in certain amount of time through certain cross section. It is directly proportional to the velocity of the flow and low velocity affect the proper supply and will be undesirable for hygienic reason.

2.5.4.3. Velocity

The optimum velocity in water distribution network was between 0.6m/s and 2m/s to prevent sedimentation for low velocity and prevent of high head loss occurred for high velocity (MoWR, 2006). The velocity in water distribution system is inversely proportional to the diameter of the pipe in which as the pipe diameter increase the velocity decrease and vise verse. According to Jeffery and Gilbert, 2012 proper size of the pipe diameter was required to meet the demand during high consumption times while maintaining an adequate dynamic pressure in water system.

2.5.5. Water distribution network simulation

The simulation can be defined as the process of imitating the behavior of one system through the function of another. It is mainly used to predict the system response to event under wide range of condition without disturbing the actual system. The problem can be predicted using simulation in the proposed and existing system and can be evaluated before times; money and material are invested in real world project (Tomas et al., 2003). The basic types of simulation were steady- state and extended-period simulation.

Steady state simulation: represent the particular view of point in times and can be used to determine the operating behavior of the system under static condition. It can be computed the hydraulic parameter including pressure, flow, pump operating character and velocity by assuming the demand and boundary condition is constant with change in times (Tomas et al., 2003). The steady-state simulation can be used during worst condition such as at time of peak water demand, firefighting demand and during distribution system failure in which the effect of time are not particularly important.

Extended period simulation (EPS): is used to determine the dynamic behavior of the system and computing the state of system as series of the steady- state simulation. It is also used to evaluate the system performance over the times and allows the user to model pressure, flow rate changing, tank filling and draining and valves opening and closing throughout the system in response to demand varying condition by modular. The model simulation analysis the existing condition of the system to provide valuable information that helps the engineer to make decision (Tomas et al., 2003).

2.5.5.1. Model calibration

Model calibration can be expressed as the process of approximating the model output result such as pressure and velocity with filled measured values under different condition. It can be carried out by trial and error through adjusting of internal pipe roughness or estimated of nodal demand until the required acceptable ranges was reached. It is used to understand the physical changes that may occur in the distribution system due to the aging and another condition. The main advantage of the model calibration is to have better confidence of the water distribution system modeling, to identify and understand of the error made during model building process (Tomas et al., 2003).

2.5.5.2. Acceptable level of calibration

There is the performance criteria needed for modeling of water distribution system, but there is no universally accepted standard to model water distribution system (Japan Water Work Association, 1990). The performance criterion for pressure through extended period simulation has been expressed as follows:

Pressure

a. 85% of field test measurement should be within ±0.5 m or ±5% of maximum head loss across the system, which ever greater.
b. 95% of the field test measurement should be within ±0.75 m or ±7.5 % maximum head loss across the system, whichever greater.
c. 100% of field measured should within ±2 m or ±15 % of the maximum head loss across the system which ever greater.

2.5.6 Comparison of hydraulic model

The commercial and public domain software application are available for design and modeling of water distribution network that differ from each other in various aspect, including their functionality and compatibility to different computational system. The selection of the computer model for modeling of water distribution system depends on the availability of data, applicability and over preview of the project (NitinP S & MandarG J, 2015). Some of the commonly used computer model for analysis of water distribution network was EPANET, Water CAD and Water GEMs(Tomas, 2003).

EPANET: is one of the public domain software package developed by U.S. Environmental Protection Agency, originally and primarily for use as an evaluation tool concerned with distribution system water quality.

Epanet is the hydraulic model which has the capability to provide variety of analysis including extended- period simulation, water quality analysis, residual chlorine calculation for disinfection and the like. When it is compared to Water CAD, Epanet has the limitation to use text editor for input data and also lack of graphical input capabilities. In general Epanet is the free software capable for predicting head loss, pressure and water quality analysis in the distribution network.

Water CAD: is the commercial software produced and marketed by Haested Method of Waterbury, standalone hydraulic simulation software containing its own graphical editor and strong modeling capabilities when compared to Epanet. Water Cad performs hydraulic and water quality analysis, steady- state and extended period simulation, strong data arrangement along with Auto CAD and GIS integration. When compared to Epanet, Water CAD is a simplified model building with geospatial model and tool like LoadBuilder and Trex, fire flow analysis, optimization and scenario management.

Water GEMs: is compressive and easy use water distribution system modeling software. It is the super set of Epanet and Water CAD water distribution system modeling; for having everything in the water CAD and Epanet, plus more in Water GEMs. It is the only hydraulic simulation software performs automated design, automated calibration, pump scheduling and pipe renewal planning. It makes the special from the other application by having six modules, skelebrator and pipe renewal planner.

Pipe renewal planner: is the asset management tool that rank pipe based on the performance to choose which pipes are the critical to screen for repair.

Darwin designer: with automated design, genetic algorithm methodology wills analysis many of the design and rehabilitation of water distribution network based on the cost minimization, benefit maximization or multi objective. The automate design feature calibrator is only available with water GEMs, but the adjustment of the model parameter is done manually through guess work and trial and error.

Darwin calibrator: finding the optimum values for the model parameter such as pipe roughness, nodal demand, and link operation status to have the best match the real- life situation in your hydraulic system. It is effective for predicting the mostly likely area of hidden leakage.

SCADAconnect: connecting of SCADA data is directly to the model to easily calibrate unlimited number of signal based upon the real world condition. SCADAconnect is the only available feature in Water GEMs as it is needed to perform calibration study.

Skelebrator: is used for automated removes of the network complexity, while maintaining connectivity, hydraulic equivalence and reallocation assigned demand.

2.6. Water loss from water distribution system

Water loss from water distribution system is the difference in volume between the water delivered to the water distribution network and that was consumed by user of water obtained from billed data of water utilities office (Richard G et al., 2000). It is well known problem happened in water distribution system which is now day the common challenges specially for water utilities developing counties irrespective of the magnitude which may varies from one water supply system to another water system. High level of water loss from the distribution system indicates inefficiency of the system to convey water for the urban resident and, it was the basic measure to indicate the level of underperformance water distribution network system.

Understanding and managing of water loss or wastage in water distribution network was performed by analysis of the network atmosphere and operating practice, determining the magnitude of water loss and use the appropriate mechanism to suggest the possible solution for the problem (Sharma S, 2008). According to Bogale (2016) in the water utilities of developing countries more than 40% of the treated water is lost in the distribution system. For the well maintained water distribution system the volume of annual water loss was reduced up to 3% to 7% of the total volume of water delivered to the system as well as in the poor maintained distribution system the volume of water loss may reach 50% of the total volume supplied to the system (Lambert A, 2002).

Both apparent and actual categories of water loss were available in urban water supply system. The actual water loss represent the magnitude of water loss mainly from leakage, pipe burst, overflow from service reservoir and service connection up to the individual consumer whereas apparent loss represent the volume of water loss as result of illegal connection, meter under registration, inaccuracy metering and billing faulty.

Apparent losses

Apparent losses in water supply networks are often holding a very high percentage of water supplied into the network. According Seago C, Bhagwa J & McKenzie, 2004 the study performed in South Africa on benchmarking leakage from water reticulation system, the apparent loss was extended up to 20% of water loss from the distribution system. In line to Lambert A, Taylor R, 2010 on water loss guide line in the New Zealand, the magnitude of apparent loss may extend up to 30% to 40% of the total water loss in some water distribution system. Therefore the reduction of the volume of apparent loss from the water supply network system to increase the system performance which in turn increase water system profit by extending electro- mechanical of the water system (McKenzie R & Seago C, 2005).

Actual loss/real loss

Actual loss increase the water supply system water production expense and water source because the produced water does not reach the consumer due to the losses in water distribution system. According to Tabesh M & Asadian Y, 2005 on the conference proceeding on non-revenue water calculation using software tool in urban water supply system, actual water loss include the water loss from the reported and unreported burst, reservoir leakage and overflow and leakage from connection.

Leakage loss

Leakage is one of the main causes for excessive failure of the main component of water distribution system especially in the transmission main, distribution main which contains large volume of water loss in the system. It is the volume of water loss existed due to aged pipe, high pressure, and poor quality of material and poor workmanship. The main factor that increases the leakage loss from water distribution system was the aged pipe of system (Shcouten M, 2011). Additionally this factor contributes for the pressure reduction in the water distribution system and then brought intermittent water supply of the water distribution system (Dighade et al, 2014).

2.6.1. Water loss measuring approach

Top-down and bottom-up approach of leakage detection method were used to assess water loss in which the top-down based on the annual water balance method and bottom-up were based on the minimum night flow analysis (Dighade et al, 2014). The most commanly used water loss analysis method in water utilites of developing countries was the top-down annual water balance due to the avaliable data problem. The weakness of top-down water loss measuring method was it's difficult to dictacte the actual volume of water loss from the water distribution system. Bottum-up approch is better to dictacte the existance of leakage in the town water system (Twort A.C.et.al.,1994). However in the developing countries the assessment of water loss by bottom-up approach does not give good result, because intermittent water supply consumer always keep the tap open to fill the tank during minimum night flow burst.

2.6.2. Water loss management in developing countries

In water utility of developing countries water loss management program is not commonly practiced when compared to the increasing severity of the problem occurred in water distribution network (EPA, 2010). Some of the component of water loss management program commonly used was water auditing and intervation.

Water Auduiting: the assessment of all activities of water ditribution system perform to determine the amount of water loss and where it occur in the water supply network by considering all issue concerning the public water network system face.

Intervention:it is the process that puts the option selected into action. In action selection process more than one action can be selected and it can be based on the budget constraint, public benefit and priority of the other scheduling capital investiment. According to EPA, 2010 intervation includes, metering assessment testing or meter replacement, detecting and locating leakage, repairing and replacing pipe, operating and maintenance program and changes, administrative process or policy changes and evaluation. Evaluation includes the portion of the method part consist of identifying the success of audit and intervention.

2.7. Urban water supply coverage

Urban water coverage provides the situation of water distribution of the city or town which is used to compare the one city or town with one another in terms of service coverage. The percentage of the population with and without pipe water connection is relevant indicator to compare the coverage of water supply in urban area. Although the water supply coverage is better in urban areas while compared with rural, the actual water supply coverage in cities of developing countries in general and Africa cities in particular is very low (Jalal M, 2008). According to the global water supply and sanitation assessment 2000 report, the African capital cities are having the lower house connection or yard tap and served by public and most of the population has un-served by public (WHO, 2000). According to Un-habitat, 2003 the average water consumption should be sufficient at affordable price, if it is greater than the minimum per capita water demand adopted by ministry of water resource and available to consumer without extreme specially to women and children.

2.8. Factor causing the loss of hydraulic integrity in the distribution network

In practice in the majority developing countries, the design of water supply system is based on the assumption of direct supply, although most of these systems are characterized by intermittent systems which result in severe supply, insufficient pressure in the distribution system (pressure losses in several areas in the network), and inequitable distribution of the available water and very short duration of supply' (Hussni and Zyoud, 2003). The main advantage of hydraulic integrity in water supply system is to supply water at optimum pressure and flow. But the most common factors for intermittent water supply and loss of hydraulic integrity of water distribution system are water demand increase, low pressure, and high pressure during low water demand condition, poor infrastructures and etc. (chamber et al., 2003, NRC, 2006 & Hickey, 2008).

2.8.1. Demand increase

The increasing water demand in the water system as result of population growth and urbanization has the direct effect on the availability and reliability of existing water distribution system. Therefore, water demands need to be assessed on the basis of considering the year and date supplying water through the distribution system. If there are deficiencies in meeting current or future goals because of population growth, this needs to be identified for the areas of the community where there may be inadequate flows to meet customers consumption during peak hour water demand of the day' (Hickey, 2008).

2.8.2. Poor infrastructures

Currently in most of the developing countries the water supply system was characterized by aged pipe network which is laid many years ago without replacement. With aging problem there is considerable reduction in carrying capacity of the pipelines. Although, most of the distribution pipeline were get corroded and leakage were occur, since resulting in loss of water and pressure reduction. Therefore to suffer pipe material from degradation, preventive maintenance of distribution system assures and providing condition for adequate flow through the pipelines (Hickey M, 2008). If there are deficiencies in meeting current or future goals because of population growth, this needs to be identified for the area of the community where there may be inadequate flows to meet customer's consumption during peak hour water demand of the day.

2.8.3. Negative pressure

The condition that gives rise to negative pressure was due to corrosion of the pipe material, remotes properties at the end of the long length of pipe, the position of ground surface or elevation and etc. This situation that may give rise to negative pressure should always be avoided. Faecal organisms and cultivable human viruses may be present in groundwater adjacent to a pipeline and drawn into a pipe during transient low or negative pressures (Mosisa, 2008). Hydraulic models can be used to identify where, when and how negative pressure may occur. Preventative measures such as system reinforcement may then be identified and implemented. Until such measure are effective, staff responsible for the daily operation of the network should be informed of these situation and hence where, when and how contamination of the network may occur.

3. RESEARCH METHODOLOGY

3.1. Description of the study

Adola Wayou Town is located in the east Guji administrative zone of Oromia national regional states. It is far 470 kilometer from Addis Ababa and 125 kilometer from the zonal capital Negelle town. It is one of the largest towns' in Adola Redde woreda administrative. The town is located at $5^0$51'.0-$5^0$55'.0'N Latitude and $38^0$56'30'-$39^0$20.0'E longitude and having the area of 27.373sq.km. According to the National Metrological Agency of Ethiopia the minimum and maximum temperature of the town was 18^0c to 24^0c and mean annual rainfall is 1490mm. The town is accessible by asphalt road from Addis Ababa to Negelle Town. The location of the study area is shown in the figure 3.1 below.

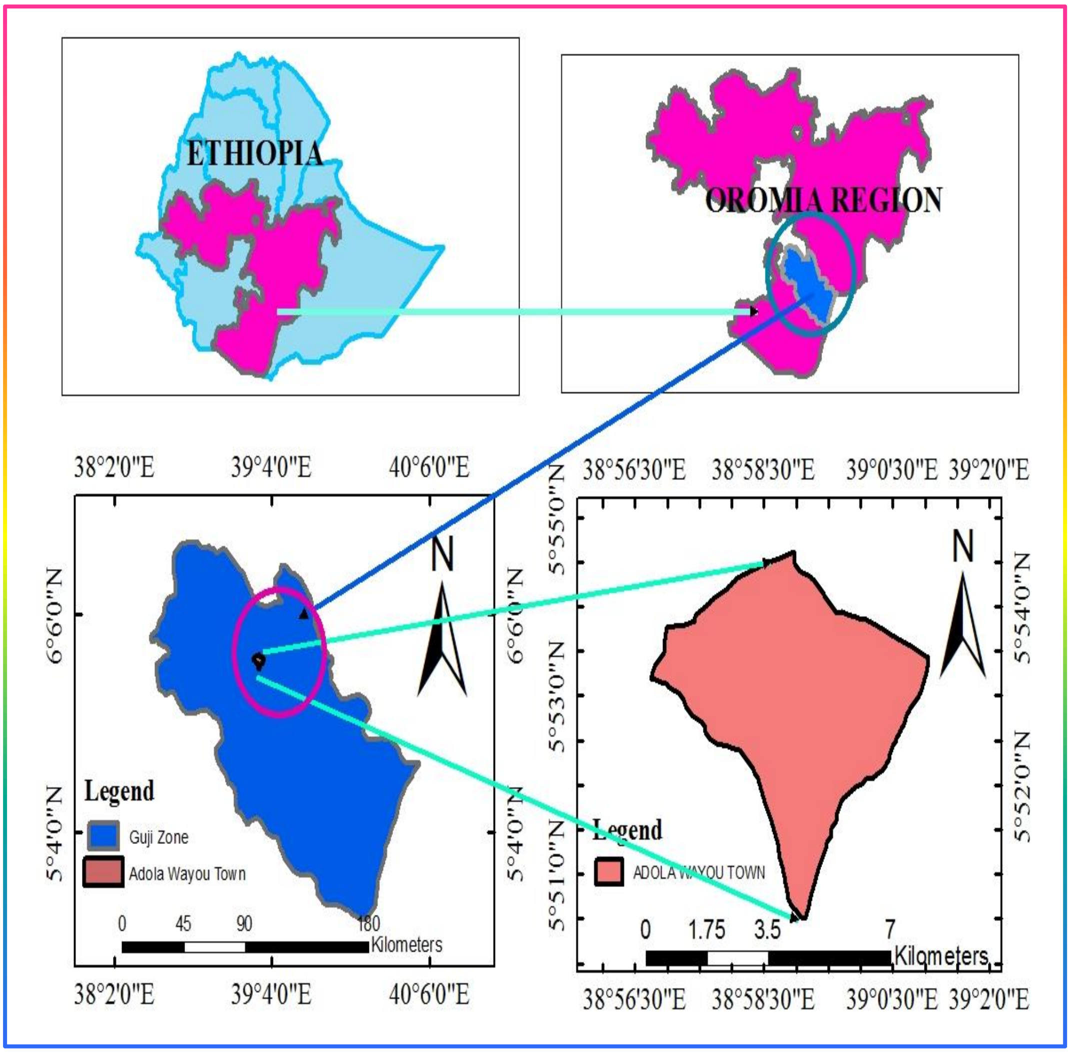

Figure 3.1 Location of the Adola Wayou Town

Population: according to the Ethiopia CSA and using town the structure figures the base population of Adola Wayou Town was 32,381 using geometric method of population forecasting method.

Topography: the town is characterized is moderately rugged with rise and fall and disconnecting micro relief. Based on the report of 2021 Adola Redde woreda agricultural office, the topography of the town is characterized by 60% plain, 20% undulating, 15% valley and remains 10% was mountain.

3.2. Existing water supply system of the town

For both water supply of Adola Wayou and Shakiso Town, the source of water supply were collected from Hawata River through river side intake into well via 350mm DCI inlet pipe located in Shakiso woreda of Guji zone in Oromia region of Ethiopia. From 280m^3 raw water wet well, water is pumped to the tray aerator to removes the element iron from raw water which is the first phase of the component of the treatment plant in water system. Then from tray aerator of the water supply system raw water is delivered to the balancing tank available in water supply system of the treatment plant part. After pre sedimentation of the particle has been finished in the balancing tank it is conveyed through the pipe to the rest of the treatment plant such as flocculation tank, sedimentation tank, rapid sand filter and disinfection tank. After treatment process has been completed in the treatment plant; the treated water is pumped by clear water pump to 150m^3 elevated water tanks and delivered to service reservoir and to consumer living area by gravity method of water distribution. Generally, water supply system of Adola Wayou Town consist of river side intake, raw water pumping station, for bay, tray aerator, balancing tank, clear water pump station, sedimentation tank, service reservoir, rapid sand filter, raw water wet well, elevated water tank and distribution network.

3.3. Research methodology

Research design is sometimes taken as master plan, blue print and even as sequence of research task. For this study the research methodology used for this study were presented in the diagram below.

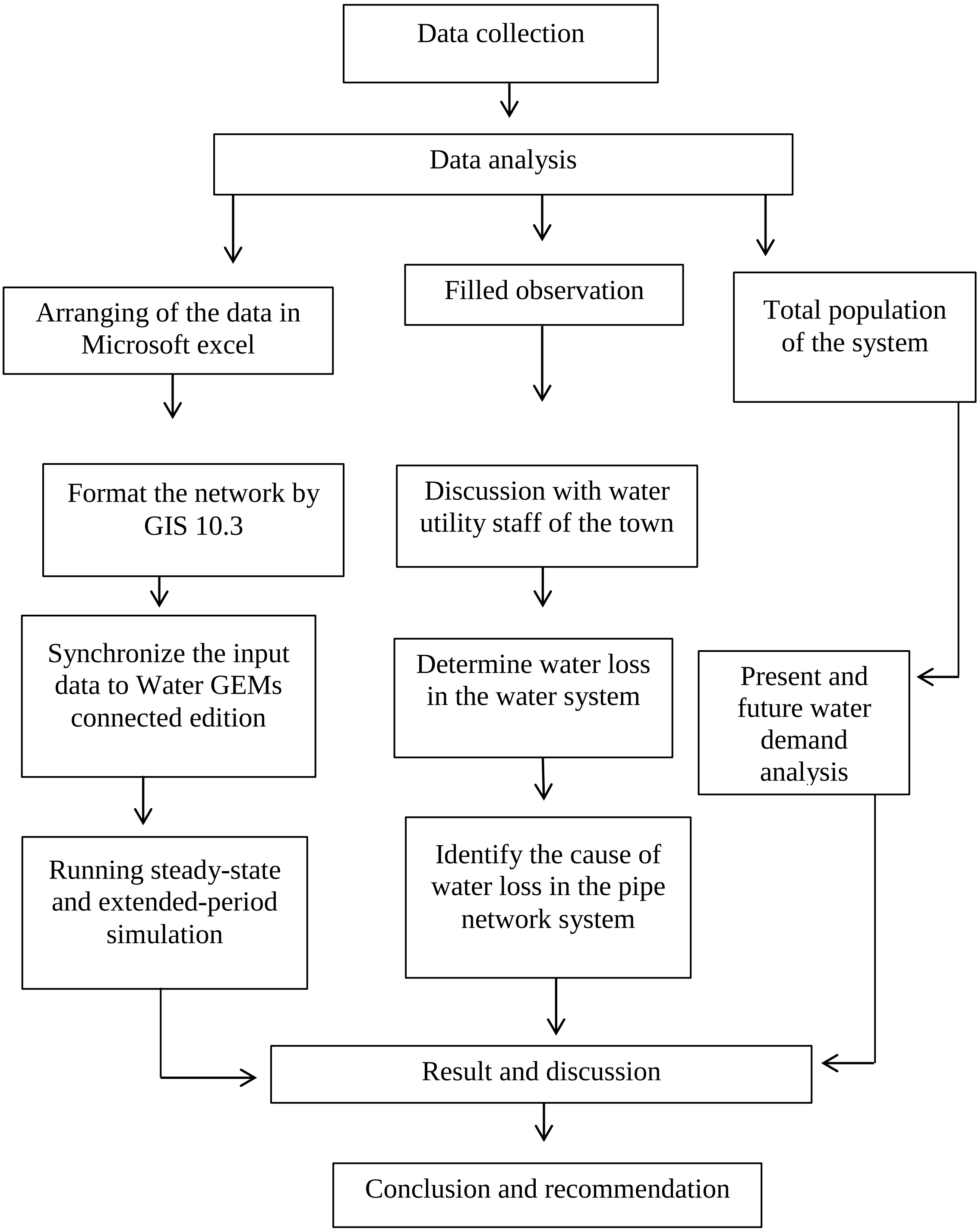

Figure 3.2 Research flow diagrams for methodology

3.4. Material

To study any thesis weather it is the Master of Science or Master of Art, different types of material and equipment were collected based on the necessity of material to use in research study. To do this thesis the material and equipment listed in the table below was used for data collection, processing and evaluation.

Table 3.1 Material used for the research study

No	Types of material or equipment	The use of equipment/ material
1	Water GEMs	Used to analysis hydraulic parameter such as pressure, velocity and head loss and another parameter to underline, the performance of the system.
2	Arc GIS 10.3	To delineate the study area and format the network to export to water GEMs.
3	Global mapper and Google earth pro	Used to check the elevation of the network
4	Pressure Gauges	Used to measure the pressure at the selected location in the water distribution network system.
5	GPS	Used to collect elevation data during pressure and flow rate measuring activity in the distribution network.
6	Endnote	Used as personal data base to gather and store citation record.
7	Microsoft excel	Used for elevation data arrangement, nodal base water demand estimation and for manual validation work.

3.5. Data collection

3.5.1. Estimating the current and future water demand

Water demand is the volume of water required for domestic and non-domestic purpose; in which different adjustment factor would be applied to estimate the present water demand and forecasting the future water demand of the study area. Secondary data such as population data, different literature review, and design document and etc. were obtained from water utility office of Adola Wayou Town, to analysis the present and future water demand.

3.5.1.1. Population data of the town

Population data is obtained from Adola Wayou Town Finance and Economic Development Office using the CSA (2007) data. From the existing population forecasting method geometric method of population forecasting method was selected to estimate the population of the town in the year 2021 using CSA (2007) data as the base for Adola Wayou Town. The reason for the selection of this method of population forecasting was it’s applicable for the growing town and city having vast scope of expansion.

Field observation: it is another technique that supports to undertake research activity. At the times of field visit private connection, public tap and the site infrastructure were visited to collect relevant information and to record the data that support to undertake research study.

3.5.2. Evaluating the hydraulic performance of the existing distribution network

In order to effectively utilize water distribution network system, assessing of the system component performance using computer model Water GEMs plays the great role for the improvement of the performance the system. System component can be assessed in term of pressure, velocity and head loss based on the urban water supply system design criteria to use as guide line provided by (MoWR, 2006). The source of data used to analysis the hydraulic performance of the distribution system was the primary and secondary data. The primary data is collected through filled survey and whereas the secondary data collected from the design document and other data available in water utility office.

Pressure measurement: - is taken at different area in water distribution network using pressure measuring instrument. The measurement is taken in selecting critical times while pressure gauge taken at the location of systematic selected by random sample method in the area of different hydraulic character to use for the purpose of calibration and validation work with observed and simulated values**.** These critical times were fixed based on the demand rates of the user 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).

3.5.2.1. Water distribution network of the town

The existing water distribution networks of the town and, its character such as pipe length and diameter, types of material and service reservoir and its cross section were collected from Adola Wayou Town water office. The collected pipe network comprises the main pipe and secondary pipe that cover the major part of the town resident. As built drawing of the town were collected from water utility office.

3.5.2.2. Transmission

Transmission main, although it may have a small number of service connection on it, but in case of the Adola Wayou Town there is no service connection in the main and it's used to convey water from the treatment source and storage facilities to the water distribution network system where the majority of the service connection are located. Based on the design document of Adola Wayou Town water supply project, the entire length of the transmission main was 17.9km with having DN300mmDCI pipes material and DN350mm uPVC pipe material.

3.5.2.3. Distribution network

The distribution network of the town operates with single pressure zone having the pipe diameter ranging from ND50mm to ND300mm. The types of pipe material used were UPVC with having the length of entire network 30.394km until the accomplishment of this base line data. Based on the water utility report the extent of the distribution network does not cover the whole area of the town.

3.5.2.4. Service reservoir

Reservoir is the component of water distribution system used to balance the gap between water supply and demand. The service reservoir of the town is circular RC types of reservoir with the storage capacity of 1500m^3. It is located at UTM498446.7E and 651194.8N and elevation of 1755m.

3.5.2.5. Elevation data

Setting elevation is one of the requirements to simulate the hydraulic character of the water distribution network system. The elevation data is collected from the design document of Adola Wayou Town water supply project available in water utility office and the expansion elevation is also collected from the town water office.

3.5.3. Determining water loss on the distribution system

The water loss from distribution system can be determined using the treated water from the treatment source and the consumed water aggregated from the billed water data, most of the time available on the monthly base in water office. Secondary data such as water production and consumption which is used to analysis water loss from the water distribution network is obtained from water utility office.

Interview: to get additional information, unstructured interview questioners' were conducted for the concerned body of water utility office staff including the manager of the water utility office concerning the factor that cause water loss in the water distribution system and the like.

3.5.3.1. Water production

The existing source for water supply, to water supply system for water utility office was the three bore hole and the Hawata River which is the source of water supply for both Adola Wayou and Shakiso Town. But at present the only source of water supply for Adola Wayou Town was the Hawata River, because the drilled three bore hole was non-functional due to it is low yield. As per information obtained from water utility office the source is designed to have the production capacity 59.1 liter per second or 3830.33m^3/day for only Adola Wayou Town water utility office, but currently 47.50 liter per second or 3077.93m^3 per day is pumped with 18 average working hours per day for the town water distribution system.

3.5.3.2. Water consumption

The billed water data is used to evaluate water loss on the water supply system and, it was collected from water utility office of the town commonly available on the monthly base. The monthly collected water billed data were converted to the annual water consumption base for the purpose of analysis. The customer data can be collected from water billed data available on the monthly base.

3.5.4. Evaluating of the current situation of the existing water distribution

Under this objective, the current situation of existing water distribution system can be evaluated based on the per capita water consumption, and level of connection per family. The source of data involved under this objective was the secondary data and it is obtained from Adola Wayou Town Water Supply and Sewerage Enterprise Office.

3.6. Analysis method

3.6.1. Estimating water demand for the town

Water demand estimation is one of the basic inputs to select source of water supply and to find the amount of water required to fill the gap between supply and demand of the system. It is also required to design water supply system applicable to size the pump equipment, transmission and distribution lines and storage facilities. Additionally it requires the consideration of different factor including climate, economic and social factor.

3.6.2. Population forecasting

Population estimating method which is used for evaluating the current and future population size, several methods are used to estimate the population size of the given study area. The selection, of the best method to estimate the populations of Adola Wayou Town consider the availability of the data for calculation, the oldness and the incremental situation of the town. By considering the above geometric increase method of the population forecasting method was selected.

Table 3.2 Growth rate of the population of the town (Source: OWRDEB, 2012)

Year (GC)	2007- 2011	2011-2016	2016- 2021	2021-2026	2026-2031
Growth rate (%)	4.4	4.2	4.1	4	3.7

The growth rate of the population of the Adola Wayou town was decrease from time to time due to more education/ awareness among the people and increased the use of family planning device and increased planning of resource which contributes for the birth rate decrease. In addition to this, liberations of woman has increased their success to education, work and other outdoor activities leading to delayed child bearing or fewer children bearing born per women in the town. The population of the town can projected using the following formula as given in the below.

$$P_n=P_0(1+r)^n \qquad (3.1)$$

Where:

$P_n =$ design population after n year

$P_0 =$ present population

$r = $ annual population growth rate, $n = $ design period in the year

3.6.3. Per capita water demand by mode of service

Per capita water demand requirement for various water demand categories varies depending on the size of the town, level of development, socioeconomic condition and climatic condition. The initial value of per capita water demand is adopted from MoWR and it is used as the base for estimating the domestic water demand of the study area. The values in the table 3.3 shows the initial values of per capita water demand used for water demand estimation.

Table 3.3 Water demand by mode of service (Source: MoWR, 2006)

Mode of Service	Per capita water demand (ℓ/c/day)
House Connection(HC)	70
Yard Connection (HC)	45
Yard Shared Connection (YSC)	25
Public Tap (PT)	20

3.6.4. Domestic water demand analysis

Domestic water demand (DWD) is the portion of municipal water supply required for the actual house hold activities. The amount of domestic water demand depends on the social, economic and climatic condition. Based on the available data obtained from Adola Wayou Water Supply and Sewerage Enterprise office, four mode of service is identified for domestic consumption. It includes the House Connection (HC or HTU), Yard Connection -private (YC), Yard Connection- shared (YSC) and public tap (PT or PTU). The following formula is used to quantify domestic water demand.

$$\mathrm{DWD} = \mathrm{Population} * \mathrm{Per\ capita\ water\ demand} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\,.\ldots\ldots. (3.2)$$

3.6.5. Domestic water demand adjustment factor

i. Adjustment to climate

The quantity of water consumption is directly related to the climatic condition. The city or town with high temperature needs large quantity of water whereas the city or town with low temperature needs low water. Therefore it needs the adjustment toward temperature changes which is in the given in the table 3.4 below.

Table 3.4 Climate factors (Source: data compilation and analysis project, 1997)

Mean annual Temperature (^{0}C)	Description	Altitude	Factor
<10	Cool	>3300	0.8
10-15	Cool temperate	2300-3300	0.9
15-20	Temperate	1500-2300	1
20-25	Warm temperate	500-1500	1.3
Above 25	Hot	<500	1.5

ii. Socio economic condition

The town with high economic activities requires large amount of water for various demand and the town with lower economic activities requires lower amount of water for different use. For this reason domestic water demand is estimated based on the socio economic adjustment factor by grouping and adjustment factor corresponding to each group as indicated in the table 3.5 below under normal Ethiopia condition.

Table 3.5 Socio economic adjustment factors (Source: MoWR, 2006)

Group	Description	Factor
A	Town enjoy high living standard with very high potential of development.	1.1
B	Towns having a very high potential for development, but lower living standard at present.	1.05
C	Town under normal Ethiopian condition	1
D	Advanced rural	0.9

3.6.6. Non- domestic water demand

Public water demand: it is a part of water demand adjusted from domestic water demand for public use usually in the ranges of 10-30% of the domestic water demand (World Bank Operation, 1972). Public demand is the portion of water demand required for school, hospital, restaurant, public office, commerce and Public Park.

Firefighting demand: is the quantity of water used to extinguish fire and, required in small amount annually, but during period of need the demand may be exceeding largely. These types of demand assessed based on the existence of equipment and, the capacity of any firefighting service. Based on the MoWR, 2006 the design criteria for urban water supply, the firefighting demand is taken off 10% of the reservoir capacity for the moderately sized town.

Livestock water demand: is the volume water required for animal consumption and it is allocated when perennial surface water source is unavailable near proximity of the town, inclusion of livestock water demand analysis is necessary for benefit of the society. Based on the record of data collected from Adola Redde Agricultural Office, the number of livestock figure and their per capita water demand are listed as shown in the table 3.6 below.

Table 3.6 Livestock population and per capita water demand

No	Types of livestock	No of livestock	Per capita water demand
1	Donkey	123	50l/head/day
2	Horse	102	50l/head/day
3	Cattle	2903	50l/head/day
4	Sheep	1967	10l/head/day
5	Goat	1345	10l/head/day
Total		6440	

Source: Adola Redde Agricultural Office, 2020

Unaccounted water (UFW): it is the volume of water loss in the water supply system and expressed as percentage of the total water produced of the source. Different factor can contribute for water loss appearance on the water distribution system that may differ from one water supply system to another. As it is observed from computation of the past record of water production and consumption, unaccounted for water on the water supply system gradually decline.

In general non-domestic water demand is the summation of all types of water demand excluding domestic water demand. These types of water demand are determined as in the equation below.

$$\text{NDWD} = \text{Public demand} + \text{firefighting demand} + \text{livestock demand} + \text{UFW} \ldots\ldots(3.3)$$

3.6.7. Average daily water demand

The average daily demand is the total annual water demand distributed over 365 days. It is determined by simply summing up the domestic and non-domestic. It is used as the base to calculate the maximum day demand or the peak hour demand. For an average day demand, 20 to 24 hours of pumping are suggested. The most common means of forecasting average daily water demand is estimating per capita water demand, and multiply this by the projected population figure since non-domestic water demand is the percentage of domestic demand by using the formula in the given below.

$$\text{Average daily water demand} = \text{domestic} + \text{non} - \text{domestic demand} \dots\dots\dots (3.4)$$

3.6.8. Water demand variation

The rate of water consumption varies from day to day, on hourly, yearly and seasonal base. Therefore to meet the required variation of demand, the average day demand was scaled up by the factor to satisfy the maximum day demand of given study area. It is used to determine the pump size, transmission main, distribution main line and storage facilities.

Maximum day demand (MDD): is considered to meet the water consumption during 24-hour period over specific year. Based on the design criteria of urban water supply provided by Ministry of Water Resource, 2006 the maximum day factor is 1.3 to 1.2 but, for this research study 1.2 adopted.

Peak hour demand (PHD): occur particularly when all tap are opened any hour over the maximum day**.** Peak hour factors (PHF) is utilized to calculate the peak hour demand and greatly influenced by the size of the town, mode of service and social activity pattern. Since the population of Adola Wayou Town was above 50001 the peak hour factor adopted was 1.9, 1.7 and 1.6 in the year 2021, 2026 and 2031 respectively.

Table 3.7 Peak hour factors (Source: MoWR, 2006)

Total population	Peak Hour Factor (PHF)
0-20000	2
20001-50000	1.9
50001 above	1.7

3.7. Water supply coverage analysis

Water supply coverage is usually evaluated based on the quantity, quality, paying capacity of the people and the distance, but the intension of this research is not to evaluate all these but related to the quantity of supply and level of connection that are related to water loss. In thesis part of analysis, the number of domestic connection per family and the average daily per capita water consumption are used to analyze the domestic water supply coverage for the entire water distribution system. Access to water supply may be evaluated using the amount of water consumed and the level of connection.

3.7.1. Domestic water consumption

To evaluate the amount of water consumption, the total annual water consumption is converted to average daily per capita water consumption using the population data of the town (Desalegn, 2005). The following formula was applied for the determination of per capita water consumption (liter/person/day), nominal present water supply coverage and service coverage.

$$\text{Per capita consumption (L/p/d)} = \frac{\text{Annual consumption}^{*}\text{m}^{3}\,10001/\text{m}^{3}}{\text{Population number}^{*}365} \ldots\ldots\ldots(3.5)$$

$$\text{Nominal present water supply coverage} = \frac{\text{Annual consumption} * 100\%}{\text{Annual production}} \ldots\ldots(3.6)$$

$$\text{Service Coverage (SC)} = \frac{\text{Actual consumped water amount(ACWA)} * 100\%}{\text{Theoretical minimum water demand(TMWD)}} \ldots(3.7)$$

3.7.2. Level of connection per family

In order to compare the distribution of the water connection in the town, the total number of connection is converted to connection per family using the population data of the town by the following expression.

$$\text{Level of connection per family} = \frac{\text{Total number of connection in the town}}{\text{Total population /average family size}} \ldots(3.8)$$

3.8. Water loss analysis

Water loss from leakage on the distribution main may occur at pipe line, valves and joint was the major cause of water loss. The method is used to evaluate water loss in the distribution main can be top down annual water balance method and based on the minimum night flow analysis. The top down water balance method is used to analysis water loss in the developing countries as per IWA, 2000 recommended and it is used to analysis water loss in the system in this study. The total water produced and distributed to the distribution system, the billed water aggregated from individual customer meter reading were used to analysis water loss in the distribution system (EPA, 2010).

$$\mathrm{NRW}(\%) = \frac{(\text{Water produced} - \text{Billed water} \quad) * 100}{\text{Water produced}} \ldots\ldots (3.9)$$

There was the problem of recorded data to average leak flow, the number of the repeated burst and average duration in water utility office. Therefore, physical loss in the water main was evaluated based on the existing data, and it was adopted by considering the minimum achievable annual physical loss (Unavoidable Annual Real Loss) in the system (Fairley et al., 2008).

$\mathrm{UARL(liter/day)} = (18 * L_m + 0.8 * N_C + 21 * L_P)P \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.10)$ Where:

$L_m =$ main length (km)

$N_C =$ number of service connection

$L_p =$ Total length of private pipe, property boundary of customer meter (km)

$P =$ average pressure (m)

The most important performance indicator related to water losses Infrastructure Leakage Index-ILI, and the following formula is used to estimate infrastructure leakage index (Alegre H, 2006).

$$\text{Infrastructure Leakage Index} = \frac{\mathrm{CARL}}{\mathrm{UARL(liter/day)}} \ldots\ldots\ldots\ldots\ldots\ldots (3.11)$$

3.9. Nodal demand

Determining the base demand to service node is one of the basic requirement to determine the hydraulic performance of the existing water distribution system. To estimate the base demand to each node in water supply system, it was necessary to perform the following activity.

a) The present population of Adola Wayou Town is estimated based on the geometric method of population forecasting method.
b) Determining the number of population served from each node. To estimating the number of people at each node the image of the town was overlapped with the distribution network of supply system and the number of house were counted from the image for each node by considering the real situation of the town.

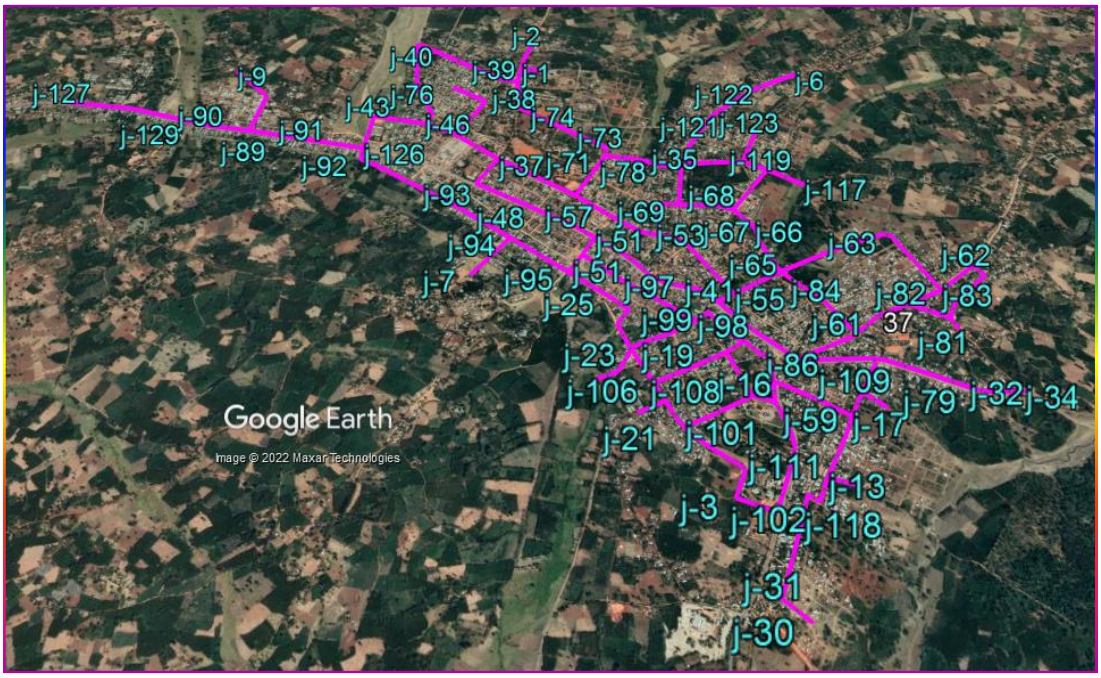

Figure 3.3 The overlapped image of the town with water distribution system

c) Determine the number of people in each house in order to verify the people at each node in the distribution system. From the town population estimation report the average family was 5.7 therefore by multiplying the number house around each node by this average family size total population for each node could gained.

d) Estimating the average daily demand for the town by summing up of domestic, non-domestic and NRW.

e) Estimating the water demand at each node**.** According to Bhadbhade, 2009 the water demand at each node in the water distribution system can be determined by the following formula.

$$\text{Nodal water demand} = \frac{\text{Population by the node} * \text{ADD}}{\text{Total population of the town}} \dots\dots.\dots\dots..(3.12)$$

f) The commercial, institutional and industrial water consumption was 275.93m^3/day. To assign nodal demand for commercial and institutional and industrial water demand the following formula was used.

$$C\text{WD} = \frac{\text{Number of insitution served by the node} * \text{consumed water demand}}{\text{Total number of costumer in the institutions}}..(3.13)$$

The estimated base demand was manually assigned into each node. The table appendance III shows the simple mathematically calculation to determine the base demands to each node.

3.10. Sample location

Selecting sample measurement location is typically a compromise between selecting measurement location that provide the greatest amount of information and measurement location that are the most amenable to sample. The measurement location should be spread throughout the study area and should reflect a variety of situation of interest, such as distribution main, high pressure zone and low pressure.

Nine representative sample measurement locations have been selected by systematic random sampling method used for calibration purpose. The measurement is taken at location near to water supply main node of the home faucet rather than the direct connection to water main based on the availability of the size of pressure gauging instrument in water utility office of the town. This measurement is taken to examine the level of accuracy between the model and actual physical network. The field test location for this research study is to identify through process known as the sample design problem which essentially defines the limiting criteria that delineated the test-location sample space (Walski, 2003).

3.10.1. Sample size

According to the United State Environmental Protection Agency, 2005 the international proposed guide line stipulated for model calibration criteria guideline for modeling pressure and flow for medium to highly detailed water supply system modeling, the following limit should be adopted as mention below.

- ☞ The number of pressure reading (10%-5%) of the junction and the accuracy of the pressure reading ± 2psi (1.4).
- ☞ The number of flow reading in the pipe network is 2% of the pipe and the accuracy of the flow reading ±5%.

From the total 129 number of junction, 7% of the total junction is taken as the sample size which gives approximately nine number of junction selected and it is located in the distribution network according to sample location criteria at higher and lower pressure, service reservoir, and public tap and consumer tap having different hydraulic character. The junction indicated in the red color as shown in the figure 3.3 of the distribution network model representation indicate the location of sample and the sample size pressure, field test on the distribution network for calibration purpose.

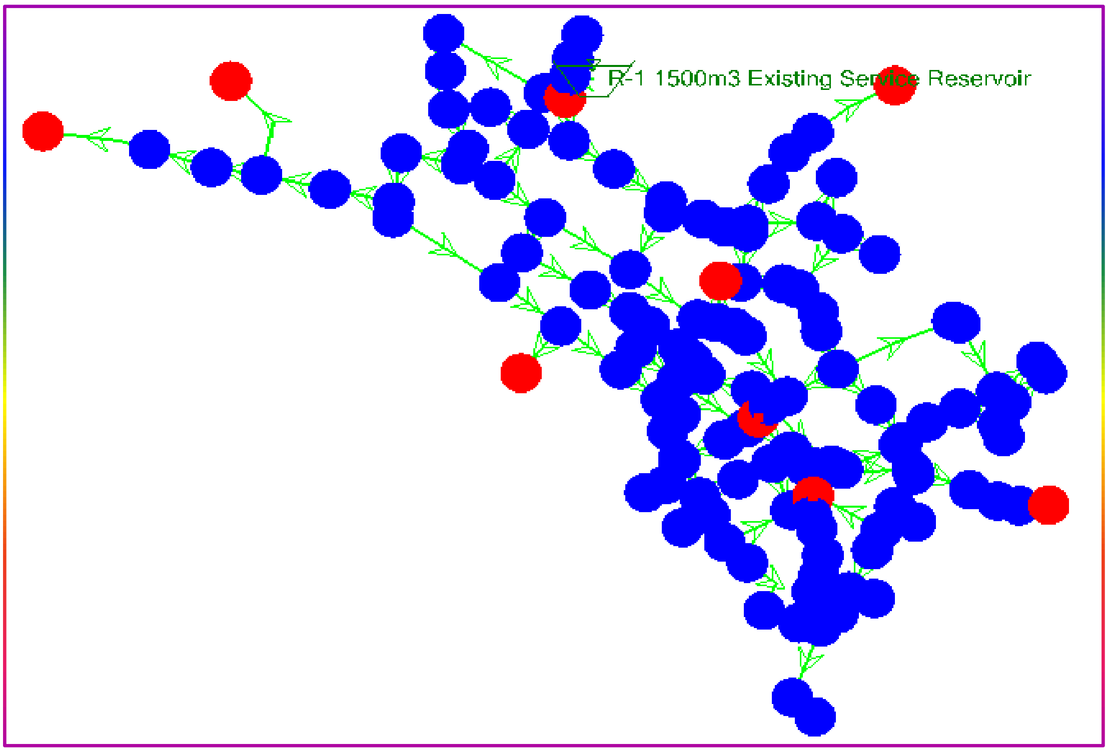

Figure 3.4 The locations of sample and sample size in the distribution network

3.11. Water distribution system modeling

3.11.1. Hydraulic modeling software

Water GEMs connected edition software is one of the computers model developed by Bentley and the primary use in the modeling and analysis of hydraulic and water quality modeling application of water distribution system. It is required to analysis the hydraulic parameter such as pressure and velocity and nodal demand in the system by feeding the diameter, elevation, and types of material to the software for better understanding of the pipe network operation. After running the analysis the result can be viewed on color coded network map, contour plot, times serious graph and table.

Water GEMs perform varieties of function, including steady- state and extended period simulation of pressure network with pump, storage tank, pipe, nodes and control valve. The other capabilities of the software are it can solve for different frictional head loss using Hazen Williams, Darcy Weisbach or manning's method. It can also perform model calibration using Darwin calibrator.

In order to analysis water distribution network system the available data of distribution network were reviewed. The modeling process was started with input data collection, model building and data entries and model test and problem analysis. The input parameter needed for water GEMs is pipe character, pipe length, nodal water demand, junction elevation, reservoir elevation and size, pump character whereas the output data contains velocity at the pipe, junction pressure and changes in reservoir elevation during 24 hours in one hours interval.

Table 3.8 The common network modeling element

Element	Type	Primary modeling purpose
Reservoir	Node	Provide water to system.
Tank	Node	Store excess water within system and release that water at high usage.
Junction	Node	Removes (demand) or add(inflow) water from/ to system
Pipe	Link	Convey water from one node to other.
Pump	link or node	Raise the hydraulic grade to overcome elevation difference and friction force.
Control valve	link or node	Control flow or pressure in system based on the specific criteria.

3.11.2. Model calibration and validation

Hydraulic model calibration was carried out by adjusting of model parameter in order to establish the necessary level of accuracy of the hydraulic model whenever it is necessary to perform adjustment. According to Tomas, et al., 2003 the calibration process was performed by adjusting sensitivities parameter related with flow, pipe roughness coefficient, water demand and operation status of the pipe and valves until it was become within the acceptable limit of 85 % of the field measurement should be within ± 0.5m or ±5% the maximum head loss across the system, which ever greater. Root mean square error (RMS) is used for calibration check whereas correlation coefficient is used for validation check of the water system. Therefore, each efficiency criteria is computed using the proceeding equation in the model, where RMSE is used to indicate error index.

$$\text{Root Mean Square Error (RMSE)} = \sqrt{\frac{\sum_{i=1}^{n}(P_{Obs,i} - P_{Model.i})^2}{n}} \dots\dots\dots\dots\dots\dots..\dots\dots (3.14)$$

$P_{Obs,i} =$ observed pressure at the time step i

$P_{Model.i} =$ the simulated pressure at the time step i in (m)

$n =$ number of observation

It was generally validated using correlation coefficient R square method using Microsoft excel.

$$\text{R square} = \frac{\text{Sum of }(\text{X} - \text{X}_{\text{mean}})(\text{Y} - \text{Y}_{\text{mean}})}{\text{square}(\text{sum}(\text{X} - \text{X}_{\text{mean}})^2 \text{x } (\text{sum}(\text{Y} - \text{Y}_{\text{mean}})^2} \dots\dots\dots\dots\dots..(3.15)$$

Whenever R square is the correlation coefficient, X and Y are the measured and simulated values; the X mean and Y mean are the average values of measured and simulated data respectively.

3.12. Data analysis

Both quantitative and qualitative method was used to analysis the data collected from different source. The data were analyzed and presented by means of descriptive statistical method like percentage, graph and cross tabulation in order to come up with appropriate result. The field survey data was evaluated by using computer model water GEMs connected edition software. The method of analysis can be based on the velocity and nodal pressure in which it was determined based on MoWR, 2006 water supply design criteria which are in the range of maximum 70m and minimum15m pressure to identify the higher and the lower pressure zone area. The value which was under normal values was taken as acceptable, whenever it was above and below was unacceptable.

4. RESULTS AND DISCUSSIONS

4.1. The current and future water demand of the town

4.1.1. Population projection

Population projection provide the information on the future size, configuration of the town which is the fundamental in planning new water resource development to satisfy the need of water for population of the study area. Based on the Ethiopia CSA report the base population of the town is 32382 in the year 2007. The population of Adola Wayou Town in 2021 is 60310 with growth rates 4.10% and the population at the end of 2031 as per CSA final result of 2007 by applying geometric method of population forecasting method as shown in the table 4.1 below.

Table 4.1 Adola Wayou Town population projection

Year (GC)	2007	2011	2016	2021	2026	2031
Growth rate (%)		4.4	4.2	4.1	4	3.7
Projected population	32381	40160	49332	60310	73376	87993

Source CSA, 2007

4.1.2. Population distribution by mode of service

The population to be served from each mode of service will vary from time to time. The variation is caused due to the change in living standard, service level, the expansion capability of water supply system and the change in standard of supply. Four mode of service such as (House Connection), Yard Connection (YC), Yard Shared Connection (YSC) and Public Tap (PT) for domestic water consumption was identified during filled survey of water utility office in the year 2021. According to the town water utility office the customer which obtain water from water distribution system were HC, YC, YSC, and PT are 5.06%, 40.98%, 20.52% and 21.44% respectively. It is used as the base to determine the population distribution by mode of service as shown in the table 4.2 below.

Table 4.2 Population percentage distribution by mode of service

Mode of service	Unit	Population percentage distribution by mode of service		
		2021	2026	2031
House Connection (HC)	%	5.06	8.48	11.7
Yard Connection (YC)	`%	40.98	44.05	47.36
Yard Shared Connection (YSC)	%	20.52	22.78	25.57
Public Tap (PT)	%	21.44	16.35	11.91

Source Adola Wayou Town Water Utility Office, 2021

To estimate the future population in each mode of service, the factor that affects the growth rates of mode of service including institutional capacity and affordability level for community is taken into consideration.

4.1.3. Per capita domestic water demand by mode of service

Estimating the quantity of water required for different water demand categories is one of the basic inputs to select the source of water supply required for different water demand categories and to find the amount of water required to fill the gap between the water supply and demand from the subsystem. According to the working standard established by MoWR, 2006 for urban water supply design, the initial figure of domestic per capita water demand of Adola Wayou Town were 70ℓ/p/day,45 ℓ/p/day, 25 ℓ/p/day and 20 ℓ/p/day for house connection, yard connection, yard shared connection and public tap as indicated in the table 4.3 below.

Table 4.3 Per capita water demand by mode of service

Mode of service	2016	2021	2026	2031
House connection (ℓ/c/day)	70	77	85	90
Yard connection (ℓ/c/day)	45	49	52	56.67
Yard shared connection (ℓ/c/day)	25	29	33	36
Public tap(ℓ/c/day)	20	23	26	29

Source MoWR, 2006

The estimated per capita water demands by mode of service were used as the base to calculate domestic water demand in each mode of service including non-revenue water for the projected year. The average per capita domestic water demand is computed by combining water demand in each mode of service through the design period as indicated in the table 4.4 below.

Table 4.4 Domestic water demand estimation

Year (GC)	2016	2021	2026	2031
Growth rate (%)		4.10%	4.00%	3.70%
Projected population		60310	73376	87993
Population percentage by mode of service				
House connection (%)		5.06	8.48	11.70
Yard connection (%)		40.98	44.05	47.36
Yard shared connection (%)		20.52	22.78	25.57
Public tap (%)		21.44	16.35	11.91
Population served by mode of service				
House connection(HC)		3052	6219	10292
Yard connection (YC)		24715	32325	41671
Yard shared connection (YSC)		12376	16713	22498
Public tap (PT)		12930	11996	10480
Per capital demand by mode of service				
House connection (ℓ/c/day)	70.00	77.00	85.00	90.00
Yard connection (ℓ/c/day)	45.00	49.00	52.00	56.67
Yard shared connection (ℓ/c/day)	25.00	29.00	33.00	36.00
Public tap(ℓ/c/day)	20.00	23.00	26.00	29.00
Domestic water demand by mode of service				
House connection (m^3/day)		234.98	528.62	926.25
Yard connection (m^3/day)		1211.04	1680.85	2361.72
Yard shared connection (m^3/day)		358.89	551.56	809.81
Public tap (m^3/day)		279.40	311.93	303.96
Total domestic water demand	m^3/day	2102.31	3072.97	4401.73
	ℓ/s	24.33	35.57	50.95

As shown in the above table the domestic water demand by mode of service in the year 2021 is 2102.31m^3/day and the total domestic water demand at the ends of the design period in the year 2031was 4401.73m3/day.

4.1.4. Climate and socio economic adjustment factors

Socio-economic factor determine the degree of development. Therefore, socio-economic condition of the study area plays a role in determining the water consumption of the population. Its adjustment factor is determined based on the degree of development of particular town. Adola Wayou Town is taken as the town of very high potential of development and considered as it is under group B. Depending on the potential of development of the town, the socio economic factor of the town was taken as it 1.05. Besides to socio economic adjustment factor, the mean annual temperature of the town taken into consideration as it exists in the ranges of 1500m-2300m above sea levels. Therefore the climate adjustment factor of Adola Wayou Town considered as one.

Table 4.5 Adjusted domestic water demand

Year (GC)	Unit	2021	2026	2031
Total domestic water	m^3/day	2102.31	3072.97	4401.73
	ℓ/s	24.33	35.57	50.95
Socio economic factor	Unitless	1.05	1.05	1.05
Climate factor	Unitless	1	1	1
Adjusted Domestic water Demand (ADD)	m^3/day	2207.43	3226.61	4621.82
	ℓ/s	25.55	37.53	53.49

Depending on the above table 4.5 the domestic water demand of the town in water supply system was 2207.43m^3/day in the year 2021 and 4621.82m^3/day at the end design period in phase one which is 2031. The total water demand of the town in water distribution system can be estimated by summing up the adjusted domestic water demand with non-domestic water demand including non-revenue water. According to MoWR, 2006 non-domestic water demand can be expressed by the percentage of domestic water demand. Therefore after projecting domestic water demand the rest of demand was computed to analysis the total water demand of the town.

4.1.5. Non-domestic water demand

Commercial and institutional water demand: in practice most commonly, commercial and institution water demand has been adjusted from domestic water demand and it was taken as 30% of the domestic water demand. But in the case of this research study the estimation of commercial and institutional water demand is carried out by considering the past trend of character of this demand in the town water distribution system.

Industrial water demand: as per information obtained from water utility office, the town has the potential for small scale industry which require to allocated water for these types of demand. But according to Ministry of Water Resource (2006) for small scale industry water demand will not be allocated individually and should be contained in allowance for commercial and institutional water demand.

Non-revenue water demand: is the volume water allocated to meet the water loss water demand categories in water distribution system and universally expressed as the percentage of domestic water demand. As per information obtained from past history record of water production and consumption of water utility office, non-revenue water demand of the town gradually decrease in some extent and reach 31.93% of domestic water demand in the year 2021.

Livestock water demand: is quantity of water demanded to meet the requirement of livestock watering and it can be allocated based on the specific demand of each livestock adopted by MoWR, 2006 on liter per head per day. But for this thesis domestic water demand allocation is done as other types of non-domestic water demand estimation performed by percentage of domestic water demand. The livestock watering demand was adjusted by 5% of domestic water demand.

Table 4.6 Average day demand

Description	Unit	2021	2026	2031
Adjusted Domestic Water Demand (ADD)	m^3/day	2207.43	3226.61	4621.82
	ℓ/s	25.55	37.35	53.49
Non-Domestic Water Demand (NDWD)				
Commercial, institutional & industrial water demand (12.5% of ADD)	m^3/day	275.93	403.33	577.73
	ℓ/s	3.19	4.67	6.69
Livestock water demand (5% of ADD)	m^3/day	110.37	161.33	231.09
	l/s	1.28	1.87	2.67
Total water demand(TWD)	m^3/day	2593.73	3791.27	5430.63
	ℓ/s	30.02	43.88	62.85
Non-revenue water demand (15-25% of TWD)	%	31.93	31	30.5
Non-revenue water demand (15-25% of TWD)	m^3/day	828.18	1175.29	1656.34
	ℓ/s	9.59	13.6	19.17
Average day demand	m^3/day	3421.91	4966.57	7086.98
	ℓ/s	39.61	57.48	82.03

4.1.6. Peak hour and maximum day factor

Peak hour factors are one of the methods used to adjust the average daily demand to respond to the fluctuation of demand in water system. The peak hour factor used in design of urban water system to meet the fluctuation of water demands varies depending on the population to be served. Peak hour water demand estimation can be performed by multiplying average day demand with peak hour factor.

The maximum day demand was the deviation of water consumption from average daily demand and it can be estimated by computing with maximum day factor. The value adopted for design of each individual water supply system shall be selected according to judicious observance of the habits of consumers and the knowledge of the community. As per urban water supply design criteria of Ethiopia the maximum day demand factor is adopted as indicated in the table 4.7 below.

Table 4.7 Peak hours and maximum day demand of the town

Description	Unit	2021	2026	2031
Average day demand	m^3/day	3421.91	4966.57	7086.98
	ℓ/s	39.61	57.48	82.03
Maximum day factor	Unitless	1.2	1.2	1.2
Maximum day demand	m^3/day	4106.29	5959.88	8504.37
	ℓ/s	47.53	68.98	98.43
	m^3/hr.	171.10	24833	3554.35
Peak hour factor	Unitless	1.9	1.7	1.6
Peak hour demand	m^3/day	6501.63	8443.17	11339.17
	ℓ/s	75.25	97.72	131.25
	m^3/hr.	270.92	351.80	472.47

Based on the above table 4.7 the maximum day demand of the town was 4106.29m^3/day in the year 2021and 8504.37m^3/day in the year 2031 or at the end of the first phase of the design. The design production capacity of water supply source was 3830.33m^3/day, but the average water production of water source was 3077.93m^3/day indicating that the variation between them was 752m^3/day and annually 274626m^3/year. This variation occurs due to the various reasons which may include the shortage of power, pump failures and lack of the timely maintenance. For this reason at present time the gap between water supply and demand reach 1028.38m^3/day. Based on this result the gap can be increased to 5426.44m^3/day in the year 2031 indicating the need for new water supply system planning for the town to meet the gap between water supply and water demand.

Table 4.8 Summary of water demand analysis

Year (GC)	2016	2021	2026	2031
Growth rate (%)		4.10%	4.00%	3.70%
Projected population		60310	73376	87993
Population percentage by mode of service				
House Connection (%)		5.06	8.48	11.7
Yard Connection (%)		40.98	44.05	47.36
Yard Shared Connection (%)		20.52	22.78	25.57
Public Tap (%)		21.44	16.35	111.91
Population served by mode of service				
House Connection (HC)		3052	6219	10292
Yard Connection (YC)		24715	32325	41671
Yard Shared Connection (YSC)		12376	16713	22498
Public Tap (PT)		12930	11996	10480
Per capital demand by mode of service				
House Connection (ℓ/c/day)	70	77	85	90
Yard Connection (ℓ/c/day)	45	49	52	56.67
Yard Shared Connection(ℓ/c/day)	25	29	33	36
Public Tap (ℓ/c/day)	20	23	26	29
Domestic Water Demand by Mode of Service				
House Connection (m^3/day)		234.98	528.62	926.25
Yard Connection (m^3/day)		1211.04	1680.85	2361.72
Yard Shared Connection (m^3/day)		358.89	551.56	809.81 1
Public Tap (m^3/day)		297.4	311.93	303.96

Total domestic water demand	m^3/day	2102.31	3072.97	4401.73
	ℓ/s	24.33	35.57	50.95
Socio-economic factor	Unitless	1.05	1.05	1.05
Climatic Factor	Unitless	1	1	1
Adjusted domestic water demand (ADD)	m^3/day	2207.43	3226.61	4621.82
	ℓ/s	25.55	37.35	53.49
Non-Domestic Water Demand (NDWD)				
Commercial, institutional & industrial water demand (12.5% of ADD)	m^3/day	275.93	403.33	577.73
	ℓ/s	3.19	4.67	6.69
Livestock water demand (5% of ADD)	m^3/day	110.37	161.33	231.09
	ℓ/s	1.28	1.87	2.67
Total demand	m^3/day	2593.73	3791.27	5430.63
	ℓ/s	30.02	43.88	62.85
Non-revenue water demand (15-25% of TWD)		31.93	31	30.50
Non-revenue water demand (15 -25% 0f TWD)	m^3/day	828.18	1175.29	1656.3
	ℓ/s	9.59	13.6	19.17
Average day demand	m^3/day	3421.91	4966.57	7086.98
	ℓ/s	39.61	57.48	82.03
Maximum day factor		1.2	1.2	1.2
Maximum day demand	m^3/day	4106.29	5959.88	8504.37
	ℓ/s	47.53	68.98	98.43
	m^3/hr.	171.10	248.33	354.35
Peak hour factor	Unitless	1.9	1.7	1.6
Peak hour demand	m^3/day	6501.62	8443.17	11339.17
	ℓ/s	75.25	97.72	131.25
	m^3/hr.	270.9	351.80	472.47

4.1.7. Water distribution network analysis

Water distribution network system analysis includes different system element available in the transmission main and distribution main of the pipe network. Using the computer model output result the water distribution network of Adola Wayou Town water supply system compromise the water network system of main with total length of 30.394km having PVC types of pipe material with the diameter that range from 50mm to 300mm. The pipe network of the town water distribution system according to the size and types of pipe material were described in the table 4.9 below.

Table 4.9 Pipe inventory of the distribution networks

Diameter(mm)	Length (PVC) (m)	Length (All material) (m)	Volume (m^3)	Percentage
50	8,309	8,309	16.31	27%
80	8,646	8,646	43.46	28%
100	5,081	5,081	39.91	17%
150	5,163	5,163	91.23	17%
200	2,222	2,222	69.81	7%
300	973	973	68.77	3%
All diameters	30,394	30,394	329.49	100%

Depending on the above table 4.9 the 80mm diameter PVC pipe material covers the major part of the of the pipe network of the water supply system indicating about 28% while 300mm pipe network were in smallest quantity used in the network of the town water distribution system.

4.1.7.1. Existing Reservoir capacity

Reservoir is one of system element in water supply system responsible to balance the fluctuation in water demand to meet peak hour demand in water supply system. Therefore the storage volume of reservoir is large enough to accommodate the difference between water supply and water demand from system. According to the MoWR, 2006 the water supply design manual, there are different method used to determine the reservoir storage capacity. The most appropriate and economical approach of determining storage volume of reservoir is the 24 hour supply and demand simulation mass curves. Accordingly the reservoir capacity determination is estimated using mass curve method as indicated in the table 4.10 below.

Table 4.10 Reservoir capacity determination

Maximum Daily Demand	8,504.37(m^3/day)
Average hourly Demand	354.35(m^3/hr)
Pumping Hour (Supply)	24(hr)
Average hourly supply (Pumping rate)	354.35(m^3/hr)
	0.0984 (m^3/s)
	98.4302 (l/s)

Reservoir Analysis

Time	Hourly demand variation	Supply (m^3/hr)	Demand (m^3/hr)	Storage (m^3)	Cumulative Storage (m^3/hr)	Cumulative Supply (m^3/hr)	Cumulative Demand (m^3/hr)
00_01	0.3	354.35	106.3	248.04	248.04	354.35	106.3
01_02	0.3	354.35	106.3	248.04	496.09	708.7	212.61
02_03	0.4	354.35	141.74	212.61	708.7	1063.05	354.35
03_04	0.4	354.35	141.74	212.61	921.31	1417.4	496.09
04_05	0.4	354.35	141.74	212.61	1133.92	1771.74	637.83
05_06	0.7	354.35	248.04	106.3	1240.22	2126.09	885.87
06_07	1.2	354.35	425.22	-70.87	1169.35	2480.44	1,311.09
07_08	1.8	354.35	637.83	-283.48	885.87	2834.79	1,948.92
08_09	1.6	354.35	566.96	-212.61	673.26	3189.14	2,515.88
09_10	1.5	354.35	531.52	-177.17	496.09	3543.49	3,047.40
10_11	1.5	354.35	531.52	-177.17	318.91	3897.84	3,578.92

11_12	1.4	354.35	496.09	-141.74	177.17	4252.19	4,075.01
12_13	1.4	354.35	496.09	-141.74	35.43	4606.53	4,571.10
13-14	1.4	354.35	496.09	-141.74	-106.3	4960.88	5,067.19
14-15	1.3	354.35	460.65	-106.3	-212.61	5315.23	5,527.84
15-16	1.4	354.35	496.09	-141.74	-354.35	5669.58	6,023.93
16-17	1.5	354.35	531.52	-177.17	-531.52	6023.93	6,555.45
17-18	1.5	354.35	531.52	-177.17	-708.7	6378.28	7,086.98
18-19	1.2	354.35	425.22	-70.87	-779.57	6732.63	7,512.19
19-20	1.1	354.35	389.78	-35.43	-815	7086.98	7,901.98
20-21	1	354.35	354.35	0	-815	7441.32	8,256.33
21-22	0.6	354.35	212.61	141.74	-673.26	7795.67	8,468.94
22-23	0.4	354.35	141.74	212.61	-460.65	8150.02	8,610.67
23-24	0.3	354.35	106.3	248.04	-212.61	8504.37	8,716.98
Maximum Positive Storage					1240.22		
Maximum Negative Storage					-815		
Balancing vol.(m3)					2055.22		
Reserve for fire demand 10% (m^3)					205.52		
Total reservoir capacity (m^3)					2260.75		
Existing Reservoir Capacity					1500		

Based on the above table 4.10 and mass curve in the figure 4.1 below the estimated reservoir capacity of the town was 2260.75m^3 including 10% for the reserve of the firefighting demand and other emergencies demand, while the existing reservoir capacity was 1500m^3 indicating the requirement for additional service reservoir to balance the water supply and demand from the water network system.

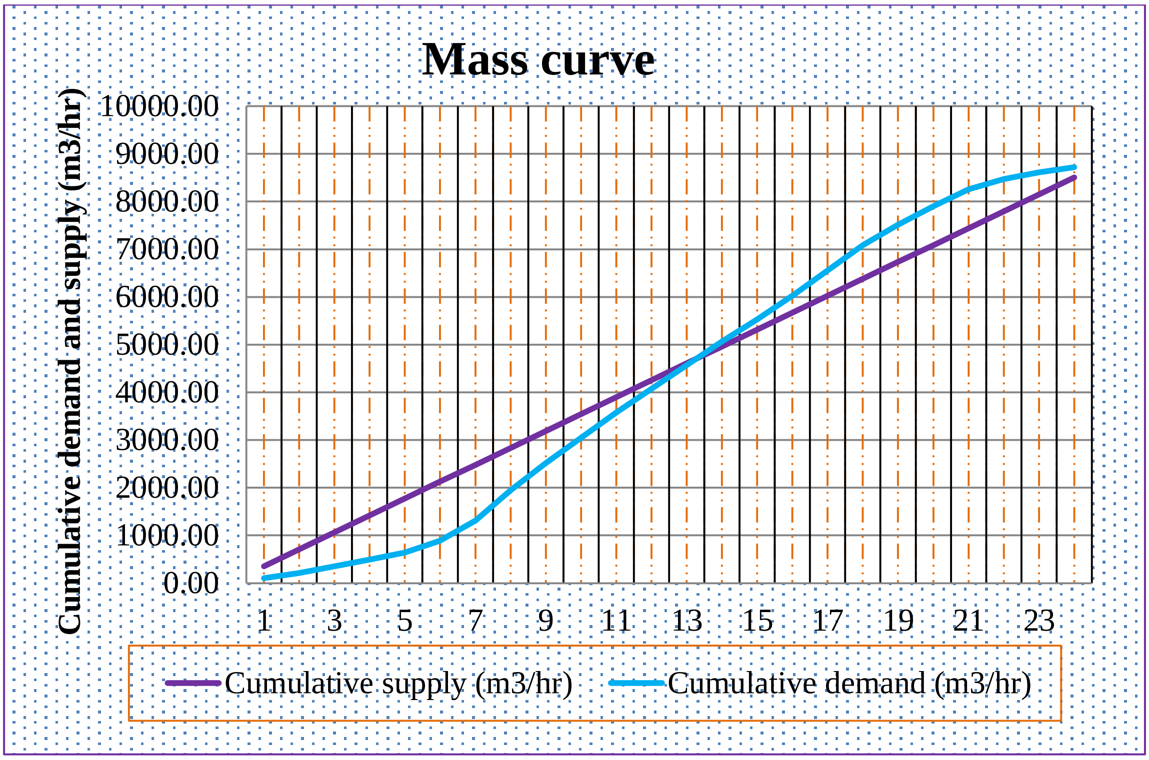

Figure 4.1 Mass curve analyses for reservoir capacity determination

4.1.7.2. Distribution network simulation

The simulation of the pipe network was carried out using computer model Water Gems connected edition software. The model representation of the water distribution system start from the treatment plant where water produced of the source is ready to be supply into the distribution system. The model representation of town water distribution system was indicated as in the figure 4.2 below.

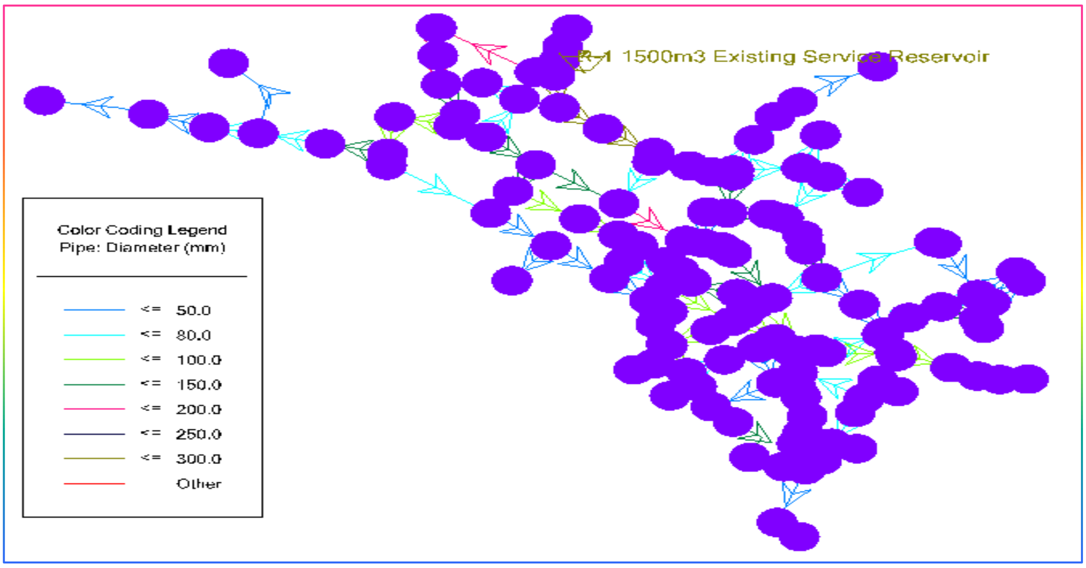

Figure 4.2 Adola Wayou Town water distribution networks

4.1.7.3. Demand pattern

The computer model representation of town was performed by using water distribution system computer modeling program Water GEMs connected edition. The capacity of the water supply system to deliver sufficient amount of water into the system to meet the demand for phase one has been evaluated under maximum and minimum day demand scenarios in order to optimize the system for extended period of 24 hourly time step simulation by considering the water consumption pattern. Consumption pattern are multipliers that vary with time and are applied to a given based demand, the most typically the average daily demand.

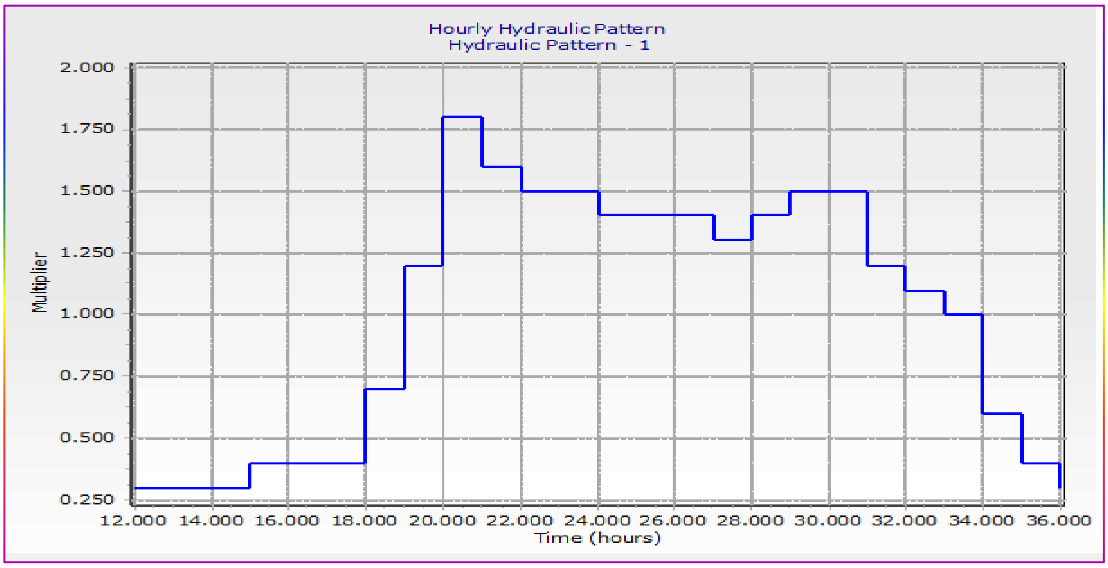

Figure 4.3 Water demand usage pattern

The criteria scenario has been identified as during maximum and minimum consumption time. During low consumption time velocity in the network of pipes will be lower and the junction pressure of water system is become higher whereas during peak hour consumption time the velocity water distribution system is relatively high and the nodal pressure in the water distribution system were become lower. Therefore a great care has been taken into consideration in order to bring the model output result within acceptable range as per water supply infrastructure design criteria adopted by Ministry Water Resource of Ethiopia.

4.2. Hydraulic performance analysis

4.2.1. Nodal pressure analysis in the distribution system

The existing water distribution system has been evaluated based on the existing maximum and minimum operating pressure and velocity criteria proposed by Ministry Water Resource in the pipe network of urban water supply system as described in the below.

The minimum pressure at peak hour consumption hour: it appropriate to assist the maximum water supply idea of the system classify main, the nodal pressure not less than 15m would be prescribed based on MoWR, 2006 to efficiently make water available to each demand categories including during high withdrawal period.

The maximum pressure at low consumption hour: The maximum pressure in the main is considered not to exceed 70m to limit the leakage volume and the stress on the pipe in water system during minimum consumption in day (MoWR, 2006).

For Adola Wayou Town water distribution system, the operating pressure which ranges from 15-70 was used as guideline. With regard to the current simulation, result of pressure in the existing water distribution system at peak flow and low flow is summarized as shown in figure 4.4 and figure 4.5 below.

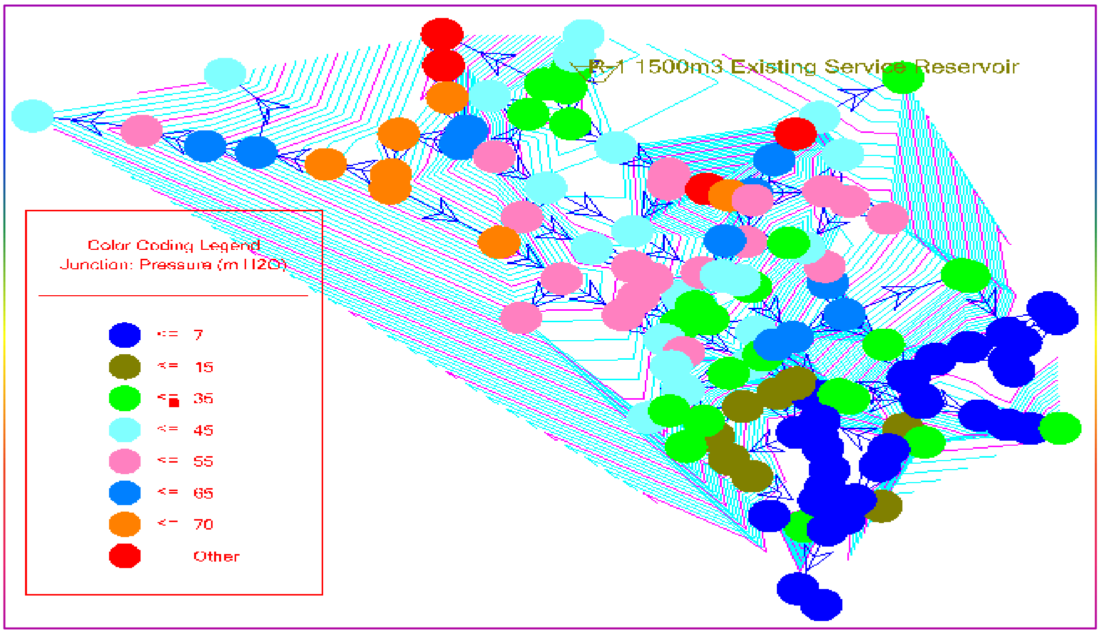

Figure 3.4 Pressure contour maps at peak hour consumption time

During modeling of water pressure of Adola Wayou Town water distribution network, the 129 nodes and 144 pipes network were identified for the analysis of the water system performance evaluation. The simulation results of the nodes pressure during peak hour consumption times in the water distribution network system was summarized in the table 4.11 below and to see in detail the simulation result of the system in the appendix I

Table 4.11 Pressure distribution during peak hour consumption time

Pressure m (H2o)	number of node	Percentage
≤ 15	35	27.13%
≤25	13	10.08%
≤35	17	13.18%
≤45	24	18.60%
≤55	16	12.40%
≤ 65	13	10.08%
≤70	6	4.65%
Above 70	5	3.88%
Total	129	100%

Using Water GEMs connected edition software the hydraulic analysis result based on table 4.3, about 27.13% of the nodes were under the minimum allowable pressure and 3.88% of the nodes were exceeding the maximum allowable pressure during steady state simulation. The negative pressure was observed in the 11.62% of the nodes which show no water flow reaches the segment of water distribution system, meaning no provision of water to consumer during peak consumption times in the area covered by these nodes.

The main reasons for the negative pressure occurrence in water distribution network system might be the existence of the high ground or elevated area in the water distribution system (Chamber et al., 2004). Demand greater than the design demand, the distance of the ends of the long length of the pipe in the water distribution system especially in the downstream side of the system can also bring negative nodes. Additionally, pipe inadequate capacity or too small pipe diameter and the equipment failure can also bring negative pressure at nodes in the distribution system.

According to Swamee, et al., 2008 the minimum design of 15m nodal pressure are prescribed to discharge design flow to water supply system to satisfy the consumer water demand. To provide water supply with the minimum optimum ranges of pressure, the possible solution to avoid inadequate water pressure in water distribution network was by providing District Metered Area Approach which helps to eliminate especially negative pressure within the water network and for not allowing contaminant sucked into water distribution system through any small leaks in the pipe example at joint.

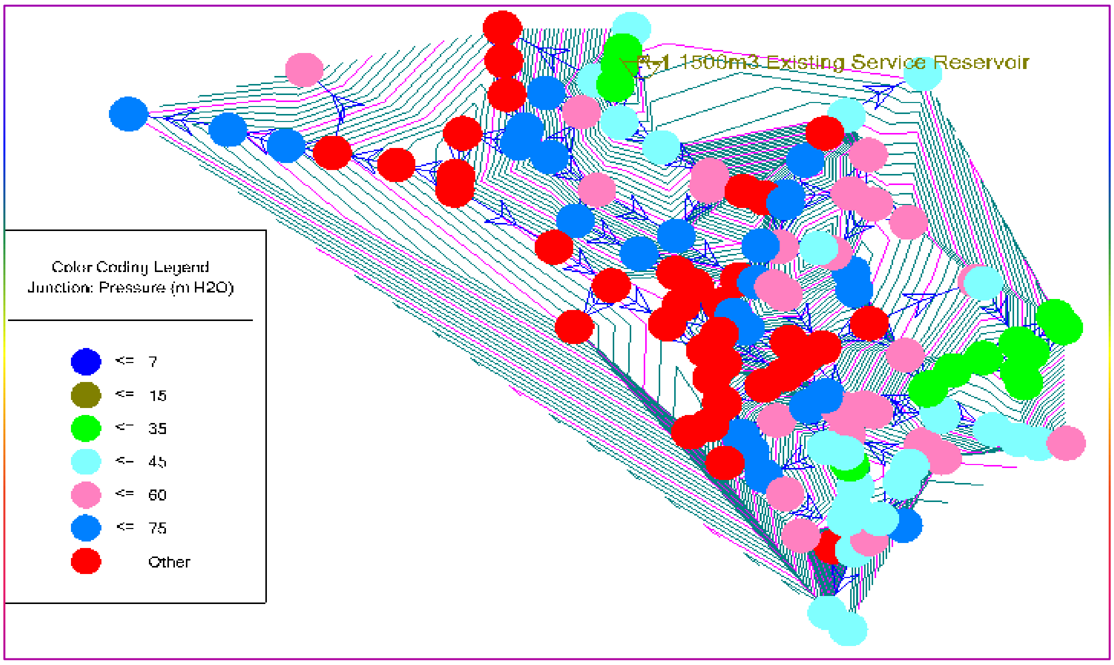

Figure 4.5 Pressure contour maps during minimum consumption time

Table 4.12 Pressure distribution during minimum consumption time

Pressure m (H2o)	number of node	Percentage (%)
≤ 15	1	0.78%
≤25	2	1.55%
≤35	6	4.65%
≤45	23	17.83%
≤55	18	13.95%
≤ 65	20	15.50%
≤70	13	10.08%
Above 70	46	35.66%
Total	129	100%

Based on the above table 4.12, about 35.66% of the node is exceeding maximum allowable pressure during minimum demand hour and only 0.78% of the node was under desirable minimum pressure during steady- state simulation. Thus, in the town water system about 63.57% of the nodes are in the permissible ranges of minimum 15m and maximum of 70m pressure. Though, almost one third of node were getting water above allowable pressure (>70) occurring due to low consumption at mid night when most consumer are sleeping indicating low consumption for domestic purpose and in some case lower elevation area.

According to Jeffery and Gilbert, 2012 the excessive pressure in water distribution system (>70) can be regulated through pressure zoning in the location where large grade changes will be created too much water pressure at lower ends of the system. Besides to this there are some methods used to regulate the problem of excessive water pressure in the water distribution network which may include using pressure reducing valve, break pressure tank, and improving pipe diameter. Break pressure tank was provided to limit the system water pressure in the ranges of allowable water pressure by ensuring zero back flow into water supply system. Generally, the management of the excessive pressure in the distribution system by the above method was used to reduce the magnitude leakage loss caused from pipe burst that may occur during low consumption time.

4.2.2. Velocity analysis

The velocity of water flow in the pipe is also one of the significant parameter required to analysis the hydraulic performance of water distribution system. According to (MoWR, 2006) the velocity of water in the pipe below 0.6m/s cause water stagnation and bacterial growth, on the other hand the velocity of water above 2m/s cause water hammer problem. This shows that a pipe designed to flow at velocity between 0.6m/s and 2m/s, depending on diameter, is usually at optimum condition. But for loop system the minimum limit, of minimum velocity which was in the range of 0.05m/s -0.3m/s can be taken. Therefore, controlling water flow velocity in the pipe should be maintained in the optimum ranges in order to avoid pipe break, water hammer and water stagnation which are the main cause for sedimentation deposition in the pipe and head loss. In water distribution network system of Adola Wayou Town the velocity during peak hour consumption time is indicated as in the figure 4.6 below.

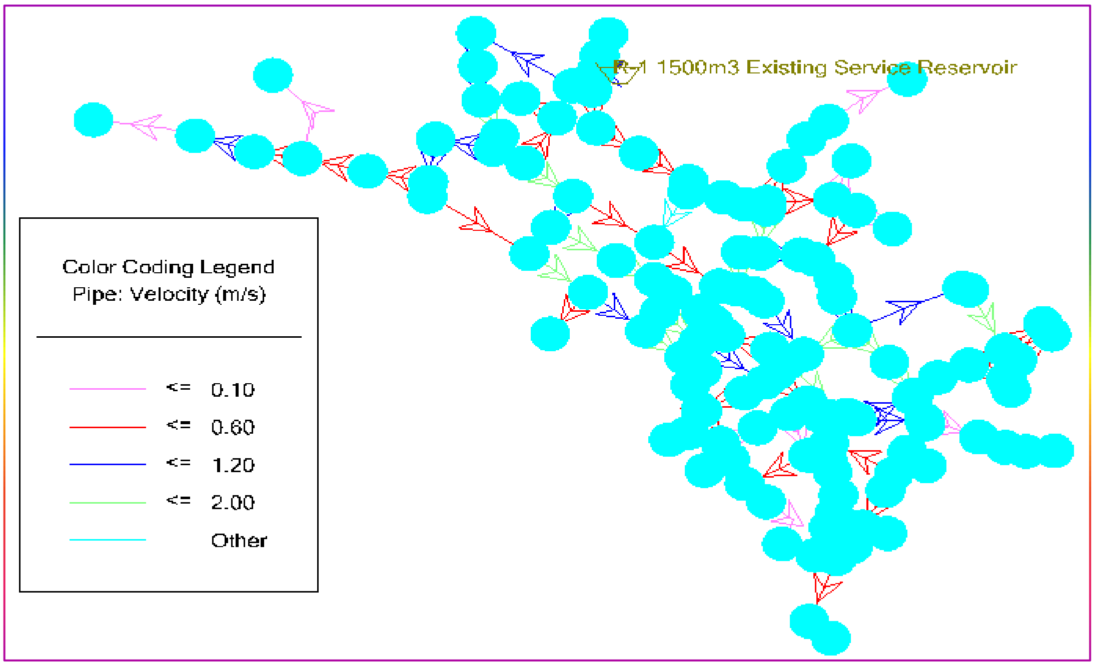

Figure 4.6 Velocity distributions during peak hour consumption time

Table 4.13 Velocity distribution during peak hour consumption time

Velocity	Number of pipe	Percentage
< 0.1m/s	15	10.42%
< 0.6m/s	48	33.33%
< 1.2m/s	54	37.50%
< 2m/s	22	15.28%
> 2m/s	5	3.47%
Total	144	100%

As indicated in the table above 4.13 in the water distribution network of the town, about 63 number of pipe in the system is less than the minimum velocity ranges of 0.6m/s. About 76 number of pipe in the system is in the optimum ranges of 0.6m/s to 2m/s based on the Ethiopia urban water supply design manual used as guide lines and about 3.47% number of pipe are above the optimum range of velocity.

Undersized pipes can be usually be found by looking for pipes with high velocities. Increasing the diameter of the pipe in the water distribution system should result in the corresponding decrease in velocity.

Table 4.14 Velocity distribution during low consumption time

Velocity	Number of pipe	Percentage
< 0.1m/s	38	26.39%
< 0.6m/s	92	63.89%
< 1.2m/s	13	9.03%
< 2m/s	1	0.69%
> 2m/s	0	0%
Total	144	100%

As it is understand from the table above of the velocity distribution during low consumption time, only about 14 number of pipe is in the recommended ranges of velocity, 92 number of the pipe between 0.1m/s to 0.6m/s and the rest of the pipe of the below 0.1m/s velocity ranges. And also there is no pipe in the system above allowable velocity during minimum consumption times in the water distribution system. The most of pipe in the water distribution network have low water velocity during low consumption times, since all tap are closed at mid night except in the area of the water system supplying intermittent water supply to consumer. For the existence of lower velocity in the town water system, there might be water stagnation, sediment accumulation and bacterial growth. But there is no the probability of occurrence of water hammer and head loss during minimum consumption times in the town water distribution network.

The velocity in water distribution system is varying with demand pattern changes. The values of velocity during low consumption times are different from the velocity during high consumption times due to the variation of water consumption in day. In the water distribution network system the velocity during low consumption time' is summarized as in the figure 4.7 below.

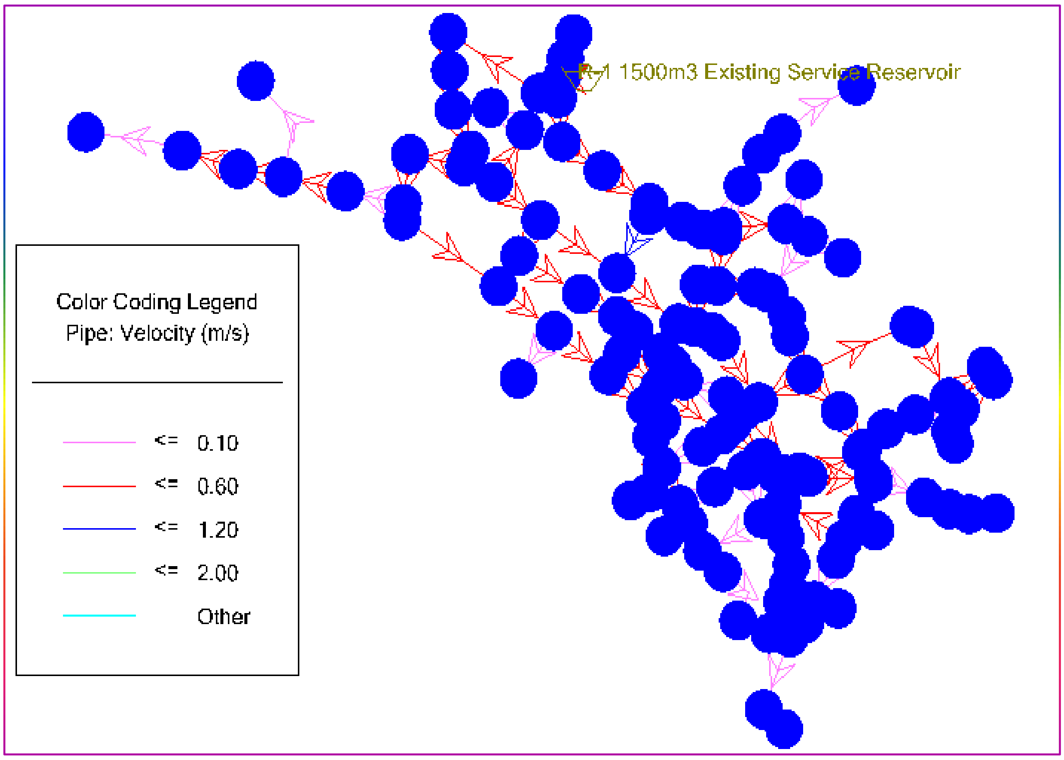

Figure 4.7 Velocity distributions during low consumption time

In general solving the problem of water system is also requires considering and checking the velocity in water system helped in order to avoid pipe break, water hammer and water stagnation which cause sediment deposition in the pipe and head loss.

4.2.3. Analysis of water demand variation in the distribution network

The consumption of water by the population of the town or city, based on the different factors, determines the demand of urban area which is depending on distribution network performance of the system. As far as the distribution network is concerned, the hydraulic parameter in distribution network allowable limit were estimated and based on this issues the peak hour demand (131.23ℓ/s) of design period (2031) simulation of Water Gems connected edition. For this study the peak hour factor is greater for a small population and hence, this peak hour demand result did not match with that of the growing population of the town and this demand can vary from each distribution network as shown in the figure 4.8 below.

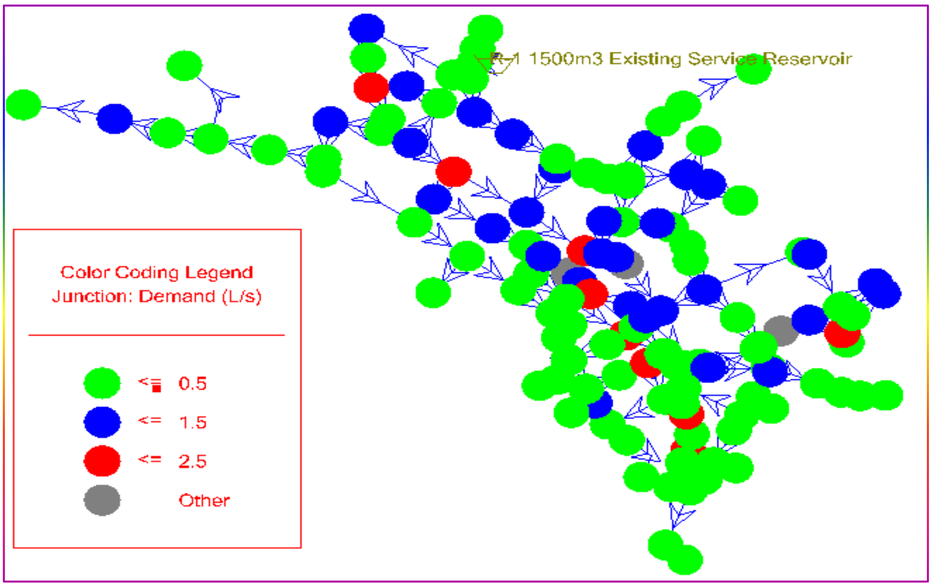

Figure 4.8 Water demand distribution in the pipe network

Hydraulic grade line is a hypothetical line used to indicate the relative elevation of the total energy head of the water at any point in the pipeline. In the no flow condition, the elevation of the hydraulic line is level because there is no flow in the pipe and therefore no frictional losses. The hydraulic grade line and base elevation in the distribution system was the plot as shown in the figure below.

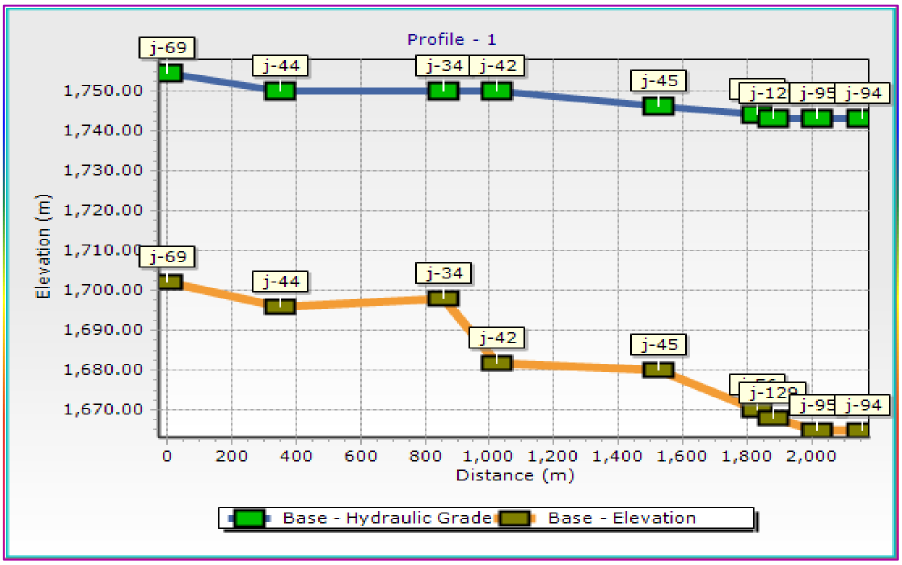

Figure 4.9 Hydraulic grade line verses base elevation in water network

4.2.4. Model Calibration and Validation

Model calibration is the process of comparing the analysis result to field observation and if necessary, adjusting the data describing the system until the system predicted performance reasonable agrees with measured system performance. In order to calibrated and validated the model result and for comparison purpose, some quantitative information required is measured at high, low and medium pressure area in the distribution network to asses based on observed and simulated pressure data by the model. The agreement of overall the times series of pressure value of statistical performance indices such as Root Mean Square Error (RMSE) and the goodness of fit (R square) are the techniques used for calibration check (Legates, 1999) in this research study with both during peak hour and low consumption time). The table 4.15 below shows the variation of observed and simulated pressure at sample node during calibration.

Table 4.15 Pressure calibration based on observed and simulated pressure during low consumption time

Time (hr)	Label	Location			Observed pressure (mH20)	Simulated pressure (mH20)	Error
		X	Y	Z			
7:00 PM To	j-126	495,459.10	650,977.07	1,691	58.25	55	3.25
	j-7	496,406.01	651,246.24	1,698	46	48.84	-2.84
	j-26	498,087.60	651,156.14	1,725	32.29	29	3.29
	j-92	497,757.00	650,167.78	1,669	80.76	77	3.76
	j-68	498,870.24	650,177.73	1,691	55.53	60	-4.47
6:00 AM	j-31	500,522.79	648,977.00	1,698	34	39	5
	J-70	498,778.91	650,509.48	1,675	71.5	71	0.5
	j-5	499,748.16	651,222.39	1,722	25.75	30	-4.25
	J-38	499,116.50	649,511.94	1,674	74	70	4
	RMSE = 0.59m						

As shown in the table 4.15 above and table 4.16 below the computed pressure values both during low consumption times and peak hour consumption times was with Root Mean Square Error (RMSE) was 0.59m and 1.66m pressure respectively is the difference between observed and simulated pressure values at sample in water distribution system. According Japan Water Work Association, 1990 the model is acceptable calibrated which is satisfied the setting pressure calibration and validation criteria under average level (average level ± 0.5m to maximum±5m). Therefore the value 0.59m and 1.66m pressure indicate that the model is acceptable calibrated through satisfying the setting criteria of pressure calibration and validation.

Table 4.16 Pressure calibration based on observed and simulated pressure during peak consumption time

Time (Hr)	Label	Location			Observed pressure (mH20)	Simulated pressure (mH20)	Error
		X	Y	Z			
7:00 AM	j-126	495,459.10	650,977.07	1,691	37.41	34.16	3.25
	j-7	496,406.01	651,246.24	1,698	25.59	28	-2.41
	j-26	498,087.60	651,156.14	1,725	15.29	12	3.29
To	j-92	497,757.00	650,167.78	1,669	57.76	55	3.76
	j-68	498,870.24	650,177.73	1,691	44.18	46.65	-2.47
6:00 PM	j-31	500,522.79	648,977.00	1,698	6.07	3	3.07
	j-70	498,778.91	650,509.48	1,675	71.5	75	4.5
	j-5	499,748.16	651,222.39	1,722	15.75	17	-2.25
	J-38	499,116.50	649,511.94	1,674	47.7	45	2.7
	RMSE= 1.66						

The graphical representation of the pressure value of water distribution system both during peak hour and low consumption times indicated as in the figure 4.8 and 4.9 below.

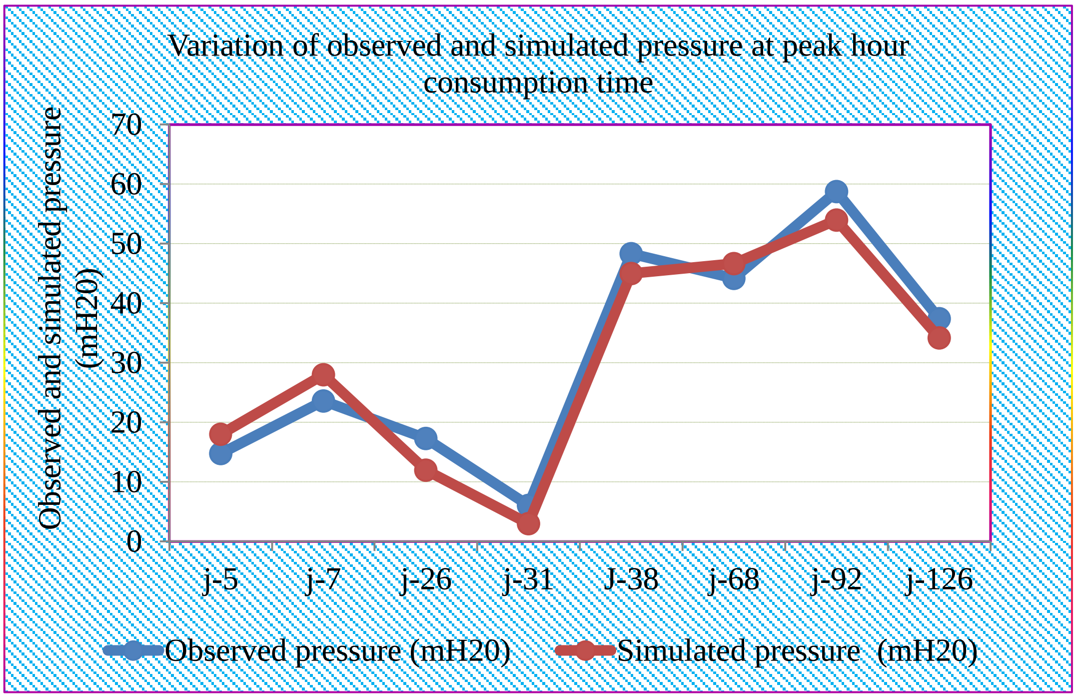

Figure 4.10 Variation of observed and simulated pressure at peak hour consumption time

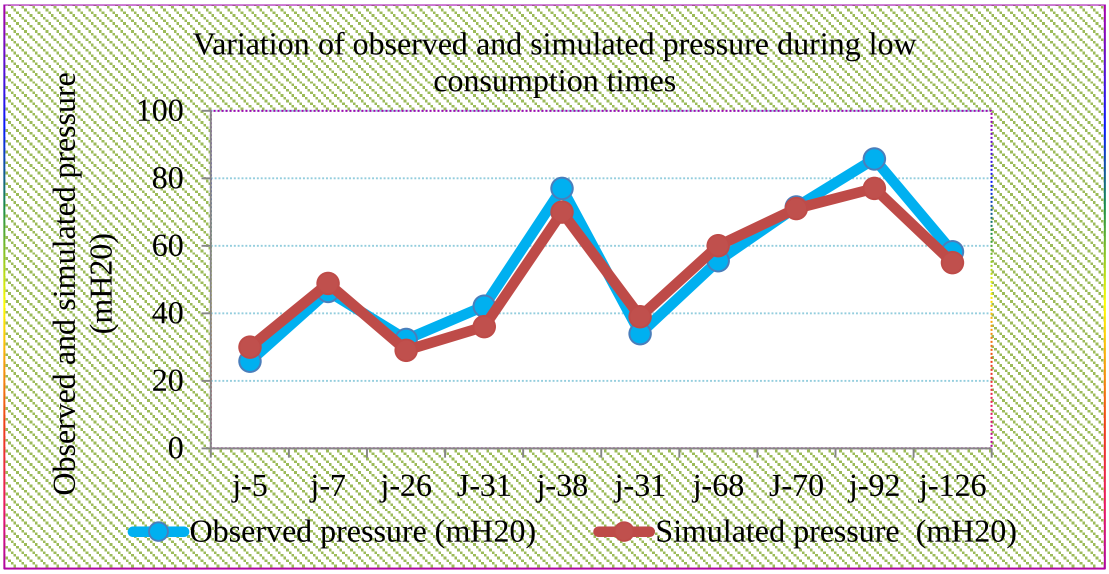

Figure 4.11 Variation of observed and simulated pressure at low consumption time

There is money way to evaluate the model performance for calibration. The evaluation was made by calculating the square relative difference between observed and simulated pressure for each test. Coefficient of determination (R square) describes the degree of linearity between simulated and observed pressure data of the water network system. Observed and simulated pressure giving a correlation coefficient of determination which is in the ranges between 0 and 1, describes the proportion of variance in the measured data which is explained by the model with higher values indicating less error variance of measured data. Typically coefficient of determination (R square) is greater than 0.5 considered as acceptable (Singh, 2004).

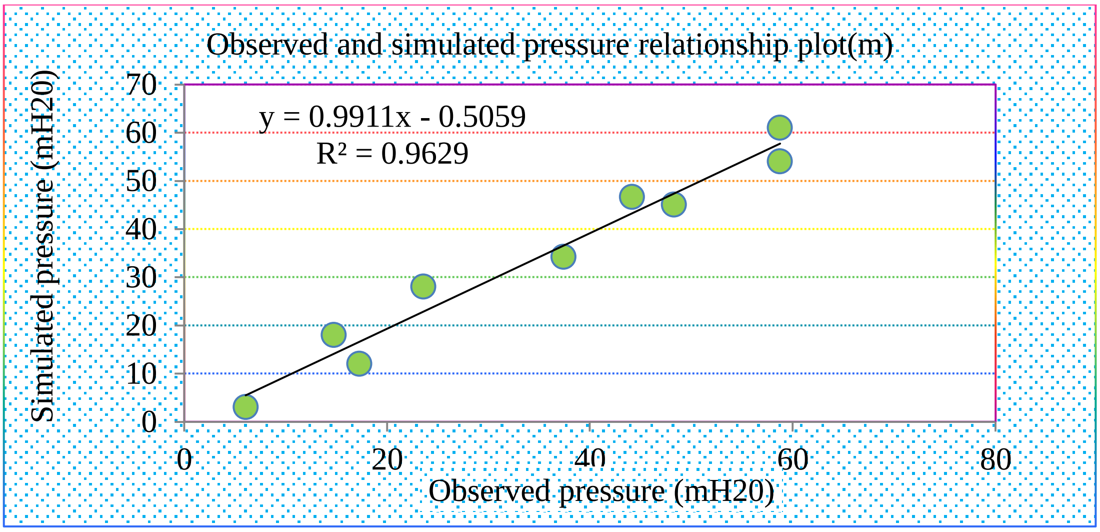

Figure 4.12 Correlation between observed and simulated pressure values at peak hour consumption time

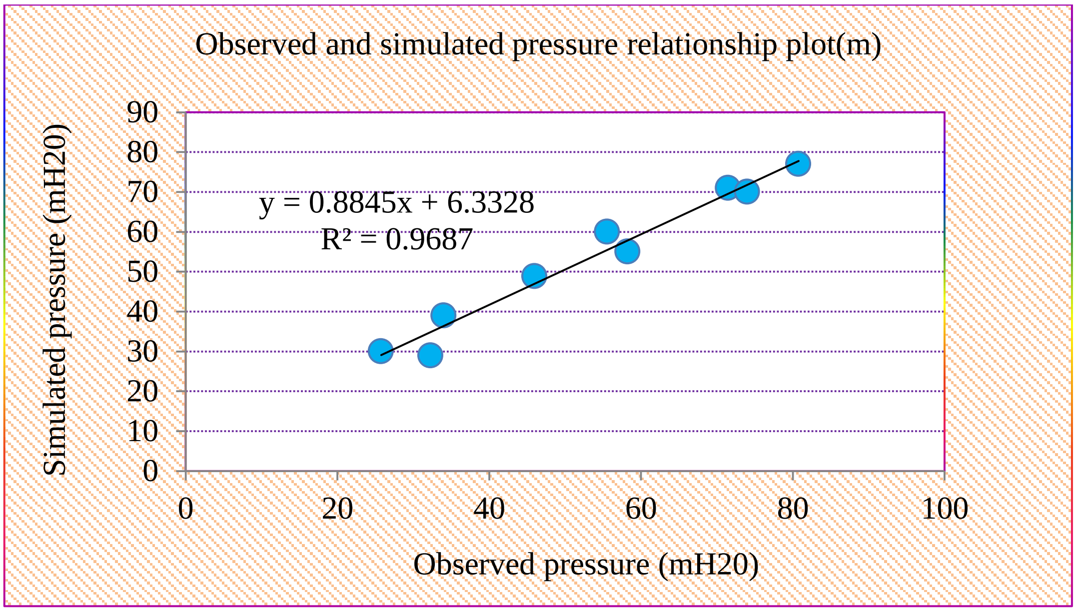

Figure 4.13 Correlation between simulated and measured pressure values at low consumption time

As we understand from the figure 4.12 and 4.13 above the correlation coefficient (R square) during peak hour and low consumption times was 96.29% and 96.87% respectively. Therefore the calibrated pressure was validated since the value 96.29% and 96.87%, are in the ranges of 0.5 to 1 indicating strong correlation.

4.3. Water loss analysis

One of the major challenges of the town water distribution system created from different factor was the availability of high level of non-revenue water in the water system. If large quantity of supplied water is lost from the system; it is difficult to meet the required quantity of water demand for the population of the resident. Additionally it brings the problem of keeping water supply system tariff at reasonable level. The total annual water produced and the water billed that was aggregated from all types of customer meter reading was used to quantify the total water loss for Adola Wayou Town water supply system as shown in the table 4.17 below.

Table 4.17Annual water loss from the year (2016-2021)

No	Year	Water production (m^3/year)	Water consumption (m^3/year)	NRW	
				m^3/year	Percentage (%)
1	2016	1159786	650152	509634	43.94%
2	2017	1160156	681211	478945	41.28%
3	2018	1161379	731231	430148	37.04%
4	2019	1165070	750530	414540	35.58%
5	2020	1169795	779510	390285	33.36%
6	2021	1172903	798420	374483	31.93%

Source Adola Wayou Town Water Utility Office, 2021

As we understand from the annual water loss table 4.17 the annual water produced and distributed to the water distribution network at end of the year 2021 was 1172903m^3/year and the total billed water in water system was 798420m^3/year. Therefore, the volume of non-revenue water was estimated using the mathematical method of non-revenue water determination by percentage which was 374483m^3/year and account 31.93% of the total water production in this year.

Water loss from water distribution system is usually expressed in different ways. Some of the water loss expression of water supply system was in terms of percentage of the input volume, per kilometer of the main pipe and water loss per service connection and it has been analyzed based on the measurement approach.

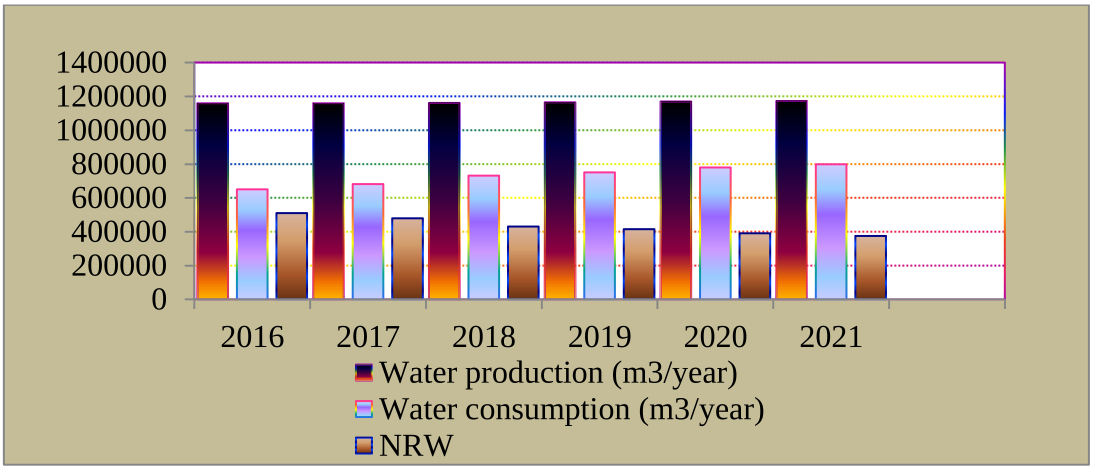

Figure 4.14 Annual water losses

4.3.1. Non-revenue water

Non-revenue water is the water loss expressed in terms of percentage input volume which includes leakage water loss, pipe burst, and illegal connection, improper reading and recording of the bill. The total water loss can be calculated by subtracting the unbilled authorized consumption from non-revenue water. Based on the town water utility report the unbilled authorized consumption is 1525 m^3/year. Therefore the total water loss was calculated by subtracting from 374483^3/year equal to 372958m^3year. According to McKenzie and Seago (2005) the productivity of water supply system is good when above 75% of the distributed water in the distribution system is consumed by consumer. Based on this suggestion the water supply system of the town was not effectively delivering the water to the consumer because from the water distributed in the distribution system the consumed percentage of water is 68.07% which is far below the recommended ranges of the consumed water from the system.

4.3.2. Water loss expressed as the length of main line

Determining water loss per length of main line is used as an indicator for existence of water loss in the distribution system to identify the severity of the problem in water supply system. As per information obtained from Adola Wayou Town during filled survey of water utility office, the total length of water distribution network greater than or equal 50mm pipe diameter was 30.394km. Therefore, the water loss per length of main pipe line is estimated using the length of main pipe and it was determined as 372958m^3/year/ (365day*30.394km) = 33.62 m^3/km/day. According to Farley et al, 2008 the performance indicator of physical loss target matrix is poor condition if water loss per length of water distribution pipe line is greater than 18m^3/km/day. Based on the calculated result, water loss per length of main pipe of town was 33.62m^3/km/day indicating the poor condition of system.

4.3.3. Water loss expressed as number of service connection

As per recommendation of some literature the water loss expressed as number service connection is the good indicator for the comparison of water loss between different water supply systems. Using the existing total number of service connection available in the town water distribution network as 3061, the water loss per number of service connection for similar duration was estimated as water loss= (372958*1000m^3)/year /(365*3061)=333.81ℓ/connection/day.

As per recommendation of Farley et al 2008, the performance indicator of physical loss target matrix was expressed as number of service connection is in good condition if it is between 150 - 450 liter/connection/day. Regarding to this the total water loss expressed as number of service connection in the water distribution network of Adola Wayou Town is 333.81liter/connection/day/ which was categorized under normal condition.

4.3.4 Customer meter in accuracies

Water meter in accuracies are consider to be significant component of apparent loss in the water distribution system. Using the town water service report the total amount of customer meter in the water distribution system was 4103. Based on the regional water resource development and energy bureau, the organization was taken the meter testing flow rate of 200l/c/day for the all customer meter as testing bench. Whereas, as per town water utility annual report, the average meter reading per connection of Adola Wayou Town was 165l/c/day.

Table4.18 Water loss due to meter inaccuracies

Description	Number of meters	Total authorized water in 2021	Average meter reading per connection	Meter test flow rates	Difference	Total water loss
All customer meters in the town	A	B	C	D	E= D-C	F=A*E
	4103	798420m^3/year	165 ℓ/c/d	200 ℓ/c/d	34 ℓ/c/d	143605 ℓ/c/d
Total						52415.83 m^3/year

As shown in the table 4.18 above the total water loss due customer meter in accuracies in the town was 52415.83m^3/year. Therefore, this figure shows that under registration is the main technical problem of customer water meter in Adola Wayou Town.

Apparent loss consists of unauthorized consumption, customer metering inaccuracies and data handling error. Based on the water utility office report (2021) unauthorized consumption was 7037m^3/year and the systematic data handling error was taken as taken as 959.96m^3/year. The volume of apparent loss was calculated by the aggregating of unauthorized consumption, data handling error and customer meter inaccuracies which is equal to 52415.83m^3/year +7037m^3/year+959.96m^3/year = 60412.79m^3/year.

4.3.5. Estimating water loss of the system using water balance method

The amount of water loss across water distribution network can be estimated using water balanced method by considering the each component of water balance method to determine where water loss occurring. By quantifying NRW from the water balance concept, volumes of lost water in system can be calculated and they will priorities and implement the required policy changes and operational practices which lead to the proper understood and take the required actions. The water loss from water distribution system using water balance component estimated above were summarized as in the table 4.19 below.

Table 4.19 Summary of water loss using water balance method

<table>
<tr><td rowspan="7">System input volume =1172903 m^{3}year or100%</td><td rowspan="4">Authorized consumption =799945 m^3/year or 68.20%</td><td rowspan="2">Billed authorized consumption = 798420 m^3/year or 68.07%</td><td colspan="2">Billed metered consumption =798302.71m^3/year 68.06%</td><td rowspan="2">Revenue water = 798420 m^3/year or 68.07%</td></tr>
<tr><td colspan="2">Billed unmetered consumption = 0</td></tr>
<tr><td rowspan="2">Unbilled authorized consumption =1525m^3/year or 0.13%</td><td colspan="2">Unbilled metered consumption =1056m^3/year or 0.09%</td><td rowspan="5">Non-revenue water = 374483 m^3/year or 31.93%</td></tr>
<tr><td colspan="2">Unbilled unmetered water consumption = 469m^3/year or 0.04%</td></tr>
<tr><td rowspan="3">Total water loss =372958 m^3/year or 31.80%</td><td colspan="3">Real/actual loss = 312545.21m^3/year or 26.65%</td></tr>
<tr><td colspan="2" rowspan="2">Apparent loss =60412.79m^3/year or 5.15%</td><td>Unauthorized consumption =7037m3/year 0.06%</td></tr>
<tr><td>Customer meter in accuracy and data handling error = 53375.79m^3/year or 4.55%</td></tr>
</table>

Based on the above table 4.19 the volume of non-revenue water estimated using water balance method was 374483m^3/year of the system input volume and the total water losses was 372958m^3/year of the system input volume indicating the need to implement water loss management strategies for water supply system of Adola Wayou Town.

4.3.6. Factors for water loss in Adola Wayou Town

One of the basic principles of proper management of water supply system was collecting detailed information about water supply system regarding to the factor causing water loss, to meet the increasing requirement of water demand from the water supply system. To accurately determine and reduce water loss it requires the main factor that causes water loss in the water distribution system. As per information obtained from water utilities office there are several factor for the cause for high level of water loss in the distribution system. The major factors experienced in the distribution system were as follows.

4.3.6.1. Age of the pipe network

The water distribution network of under developing countries is characterized by long time served pipe material which is the main cause for the failure of water distribution system because as pipe age increase, the water entering water supply system was wasted due to the leakage from the system. The water utility data of Adola Wayou Town indicate that 15% of the town water distribution network was above 20 year and majority of aged water network existed in densely populated area of the town. This part of the network was the early constructed water supply system for the town population to deliver water from borehole source to the population of the resident. So it is necessary to replace the aged main from this area to reduce the volume of water loss from the distribution network.

4.3.6.2. Evaluating data handling error

Data handling error contribute for water loss in distribution system. These types of water loss factor which may occur due to the mistake happened during reading and billing process by workmanship in water distribution network that contribute for apparent loss. As per information obtained from water utility office during filled survey of water supply system in year 2021, data handling error account 0.12% of billed authorized volume. Based on this the calculated volume of data handling error was 0.12%*798420 m^3/year which is equal to 959.96m^3/year.

4.3.6.3. Water scheduling

Water scheduling happened due to existence of intermittent water supply of water supply system. The supply turned on or off of water system in some area of Adola Wayou Town especially in the area of Adola Wayou District Hospital may bring cyclic pressure situation creation which increases the level of leakage due to the stress being inflected on the pipe causing them to rupture. There is clear inconsistence in this situation as the problem of water scheduling is caused by water shortage. Due to high level of water loss and other factor continues supplies are not available resulting in water schedules.

4.3.6.4. Illegal connection

Adola Wayou Town is as it is one of the towns existed in developing countries which may contain a significance number of illegal connection user of water in the water distribution system. The town water utility office has no exact data about the number of illegal connection that do not pay water tariffs but as information at the corner of the town there is the illegal user of water from water distribution system. But do to the limit of data water loss from illegal connection which contributes for apparent losses were evaluated using unauthorized consumption from table water loss analysis by water balance method. In line of this the town water utility has 7037m^3/year or 0.06% of water due to illegal connection. Therefore, illegal connection users have also contributed 7037m^3/year which looks large volume of water.

4.3.7. Unavoidable annual real loss indicator (UARL)

The Unavoidable Annual Real Loss (UARL) is the volume of losses that are considered unavoidable, since the detection of them is difficult and the removal cost is economically unprofitable. The amount of unavoidable leakage depends primarily on the length of water distribution network, nodal pressure and failure of pipe network and number of recipients. The minimum level of leakage or UARL in the water distribution system was determined using the total length of main pipes 30.394km, number of service connection of the system 3061, the average pressure of system 35m from the result of water GEMs was used in calculation of unavoidable annual real loss. Using the following data unavoidable annual real loss index is determined from the relation:

$$\begin{aligned} UARL &= (18*L_m + 0.8*N_C + 25*L_P)*P \\ &= (18*30.394km + 0.8*3061 + 25*0)\ 35m \end{aligned}$$

$= 104.86m^3/day$

$= 38272.52m^3/year$

Where:

UARL = Unavoidable Annual Real Loss (ℓ/day)

L_m = Length of mains (km)

N_C = Number of service connection (main to meter)

L_P = Length of unmetered underground pipe form street edge to customer meter (km)

p = average operating pressure (m)

4.3.7.1. Infrastructure leakage index

The infrastructure leakage index shows the multiplicity of actual/real water loss relative to minimum (unavoidable) water loss that can be achieved in a properly operated water distribution system. It is the measure of how a well water system of urban infrastructure is managed, repaired and rehabilitated for control of actual water loss at the current operating pressure. The infrastructure leakage index of the water distribution system was equal to 312545.2m3/year/38272.52m3/year = 8.17

Based on the calculated result the infrastructure leakage index of town was 8.17 indicating that the current actual water loss was 8.17 times as high as unavoidable annual real loss of the system. This result indicates that very inefficient use of water resource and the leakage reduction programs imperatively high priority since the ILI above 8 was not tolerable even if the water is plentiful and cheap (Farley et al, 2008).

4.4. Evaluating the current water distribution of the town

4.4.1. Domestic water supply coverage

Water supply coverage is usually evaluated based on the quantity, quality, distance of the source and etc., the intention of this research was not to evaluate all these but related to the quantity of supply, the level of connection per family that are related to the imbalance between supply and consumption of water to the town. Of course distance is not the big problem in the urban area rather in rural area. In this part of the analysis, the number of domestic connection per family and the average daily per capita consumption is used to analysis the domestic water supply coverage for the entire study area. The town water supply coverage of the town is as follows.

1. **The present nominal water supply coverage**

The present nominal water supply coverage of the town is as follows if the existing water sources are fully exploited.

From the table 4.1 of population projection of the town in the year 2021 = 60308, the domestic per capita water demand = 25l/c/day, the total domestic water demand was 25l/c/day *60308 = 1507.7m^3/day, non- domestic water demand was 50% of domestic water demand = 753.85m3/day, total daily demand = 2261.55m^3/day, non-revenue water (30%) = 678.47m^3/day and the total water demand including non-revenue water demand was = 2940m^3/day. The annual water demand was 2940m^3/day*365day/year = 1,073,105m^3/year. The consumed water was = 798420m^3/year. Taking the water production of the year 2021 = 1,073,105m^3, the nominal water supply coverage of the town was as follows.

$$\text{The nominal water supply coverage} = \frac{(798420\text{m}^3/\text{year})*100}{1073105\text{m}^3/\text{year}} = 74\%$$

2. **Actual present water supply coverage**

Water supply coverage can be defined in the form of either service coverage or connection coverage depending on the availability of data required for computation. The recommended step in defining water supply coverage in the form of service coverage was:

1) Determined total population of Adola Wayou Town in (2021) is 60308
2) Estimated theoretical minimum water demand (TMWD). In this process we assumed a certain service level for different connection project to satisfy the nutritional and hygienic water requirement at a given study area.
3) Determined actual consumed water amount (ACWA) for town =7999445m^3/year.

Per capita domestic water demand of Adola Wayou Town can be taken as 40l/c/day.

Domestic water demand = 40l/c/day*365 day/year*60308

= 880496.8m^3/year and

Based on the above table, commercial, institutional & industrial water demand, firefighting demand, animal demand and NRW = (45%) domestic demand

= 880496.8m3/year*45%

$= 396223.6m^3/year$

Therefore the total TMWD = $880496.8m^3/year + 396223.6m^3/year$

$= 1,276720m^3/year.$

$$\text{The town service coverage} = \frac{(799945m^3/year)*100}{1276720m^3/year} = 62.65\%$$

4.4.1. Average daily per capita water consumption of the town

The volume of water consumed for domestic purpose has been aggregated from all customers of the system so as to analyze the distribution of the water coverage in the study area. According to (Desalegn, 2005) evaluating water supply coverage using the volume of consumption may not allow realizing the distribution comparison among the study area. The average per capita water consumption was determined using water consumption recorded data available on the monthly base, collected from customer meter reading using the estimated population in the year 2021.

$$\text{Per capita water consumption (L/p/day)} = \frac{798420m^3*1000l/m^3}{60310*365} = 36.27L/p/day$$

Using the calculated result the average per capita water consumption of Adola Wayou Town is 36.27L/p/day which is higher than 25liter/capita/day the former per capita water consumption of the design document of the town. It is lower than 50 liter/ capita/day which is the revised water supply feasibility study per capita water consumption collected from OWWDSE, 2018 with radius 0.5km. Based on this the estimated per capita water consumption of town was very low relatively as compared with the revised average per capita water consumption.

4.4.2. Level of connection per family

Level of water connection is an important element on the one hand for evaluating the level of water supply coverage that will be the focus of this section.

According to the town water utility office the total numbers of connection within the town is about 4103 house hold that obtaining drinking water from tap inside compound for domestic use. In order to compare the distribution of the water connection among the different sites of city or town, the total number of connection per town are converted to connection per family using population data of the town. The average population size of the town is 5.7 and it used for estimating the average number of connection per family.

$$\text{Level of connection per family} = \frac{4103 * 5.7}{60310} = 0.39$$

This number implies that fifteen person are sharing one connection or water tap. In other words the average connection per family in house or yard connection of the town is about 39%.

4.4.3. The major problems identified in the distribution system of the town

This research study was carried out to analysis the hydraulic performance of the existing water distribution system, and the main target to be achieved was to identify the main problems affecting the delivering efficiency of existing water distribution system and, also to suggest the possible solution to the underlined problem of the water supply system. Additionally it is undertaken to improve existing system, expand service of the system to meet the need of water for rapidly growing urban population of the town. In this research study according to the analysis result, the main problems that lower the service of water supply system in the existing water distribution network of town were separated and described as follows.

i. Water GEMs connected edition is modeling tool used for modeling of water distribution system for hydraulic analysis. The investigation of the result reflect that the hydraulic performance of the existing water distribution network was insufficient resulting from the under or oversized pipe diameter, over and under the optimum ranges of the nodal pressure of the water network and high and low water flow velocity in distribution system.
ii. Water distribution system of the town is characterized by high level of both apparent and real/actual water loss.
iii. The existence of the gap between water demand and water supply and low water consumption of the water system.
iv. Pressure is one of the hydraulic parameter required to be in the optimum ranges for providing water supply efficiently available to all types of water demands including domestic and non-domestic water demand, animal watering, firefighting demand and

the like. The pressure based performance evaluation of water distribution system indicate that the negative pressure values in the system showing of disconnection of water service during peak demand hour and the water does not reach the consumer area of living which served from the negative nodal pressure.

v. In water supply system sufficient storage facility was required to meet the present and the future water demand of the given study area. Based on the estimated result the storage capacity of existing service reservoir was lower than the estimated storage capacity indicating that the existing service reservoir is not safe regarding to storage capacity and it was one of the main cause for intermittent water supply distribution in the town.

vi. The velocity based hydraulic performance evaluation of water distribution network indicate that there are some pipes in the network being suffered by low velocity of below 0.60m/s due to over size of the pipe network. This is to the extent of no flow occurring condition in the pipe available in this area.

4.4.4. The method used to improves the distribution system of town

Based on the analysis result, the performance of the Adola Wayou Town water distribution network in term of pressure and velocity require some modification to provide in the optimum ranges of nodal pressure and velocity at the pipe to improve the service coverage for the population of resident. To improve this situation the possible improvement method selected for this system were by using pressure reducing valves, pipe diameter improvement where necessary and using higher PN class of the pipe. The modification toward the problem is done using design criteria through creating of the new alternative and the trial and error producer until it match with the water supply design guide line.

4.4.4.1. Using higher PN class of the pipe in the water network

The main reason for water loss occurrence during low consumption times in water supply system was due to excessive pressure or the pressure greater than 70m and it can be improved by using higher PN class of the pipe which has the capacity to resist maximum pressure. The existing water distribution network of the Adola Wayou Town was constructed from the PVC PN6 and PVC PN10 pipe material. The leakage occur most commonly in the UPV PN6 which may be the main cause of pipe burst by having relatively low pressure resistance capacity.

The frequent pipe burst in the distribution system can be happened for the use of relatively low capacity of the pressure resistance pipe material. Therefore water loss in the Adola Wayou Town distribution system can be improved by using the same pipe material uPVC pipe, but by using pipe material having maximum pressure resistance capacity or uPVC PN10 and PVC PN16 can be used to solve the problem of water loss in the distribution system.

4.4.4.2. Excessive pressure

One of the best methods used to optimize the operation of water distribution system was through controlling the excessive pressure in the water supply system. The excessive pressure during minimum consumption times in the system can be managed by installing of the pressure valves (PRV). By maintaining of the pressure in system in the ranges of the existing design guide line, it is possible to reduce the volume of water loss in water supply system. The excessive pressure which is greater than the recommended range was indicated in the table 4.20 below during low consumption times.

Table 4.20 Excessive pressure location at low consumption time

No	Label	X(m)	Y(m)	Elevation (m)	Hydraulic grade line (m/km)	Maximum pressure (mH20)
1	j-6	497,865.64	649,683.93	1,673.00	1,758.19	85
2	j-16	498,889.00	649,327.96	1,671.00	1,756.98	86
3	j-17	498,660.18	649,226.89	1,665.00	1,756.96	92
4	j-18	498,678.96	648,857.78	1,672.00	1,756.89	85
5	j-19	498,492.40	649,044.51	1,661.00	1,756.96	96
6	j-20	498,667.00	649,218.78	1,666.00	1,756.96	91
7	j-21	498,596.74	649,088.36	1,667.00	1,756.96	90
8	j-22	498,572.61	649,542.58	1,667.00	1,757.03	90
9	j-23	498,667.24	649,461.67	1,654.00	1,757.00	103
10	j-24	498,605.04	649,374.00	1,664.00	1,756.98	93
11	j-33	499,218.24	650,862.35	1,679.00	1,763.20	84
12	j-37	497,484.39	651,301.03	1,678.49	1,763.10	84
13	j-38	499,116.50	649,511.94	1,674.00	1,761.16	87
15	j-40	497,262.95	650,861.12	1,671.00	1,761.99	91
16	j-54	499,204.33	649,560.03	1,677.00	1,761.18	84
17	j-56	498,413.53	650,011.57	1,670.00	1,759.03	89
18	j-57	499,025.84	649,592.42	1,676.00	1,758.99	83
19	j-62	499,459.59	649,705.48	1,680.00	1,762.37	82
20	j-70	498,778.91	650,509.48	1,675.00	1,763.52	88
21	j-90	496,903.95	650,667.67	1,673.00	1,761.88	89

22	j-91	497,219.86	650,513.47	1,671.00	1,761.80	91
23	j-92	497,757.00	650,167.78	1,669.00	1,761.45	92
24	j-93	498,065.85	649,935.33	1,667.00	1,759.50	92
25	j-94	498,366.95	649,702.40	1,665.00	1,758.42	93
26	j-95	498,443.12	649,817.50	1,665.00	1,758.42	93
27	j-96	498,649.76	649,641.13	1,675.00	1,757.48	82
28	j-97	499,000.00	649,391.95	1,660.00	1,756.98	97
29	j-98	499,060.65	649,445.40	1,672.00	1,756.98	85
30	j-101	499,263.77	648,347.56	1,671.00	1,756.86	86
31	j-128	497,224.69	650,600.44	1,671.00	1,761.88	91
32	j-129	498,512.55	649,935.25	1,668.00	1,758.63	90

For the above excess pressure of the distribution network can be modified with pressure reducing valves added to water network system. The pressure was high in the system in low area; the installation of pressure reducing valves (PRV) was the possible solution at link in low elevation area of high pressure zone to reduce excessive pressure during low consumption times to the desired allowable ranges. The main advantages of pressure reducing valves to use in the distribution system were:

1. Relatively simple to install since it need only the use of pressure reducing valves.
2. Relatively require low cost at as it involves no electric equipment.
3. Pressure reducing valves maintenance and operating is relatively simple.

4.4.4.3. Improving pipe size

The model result of water distribution system indicate as the diameter of the pipe network increase the corresponding model result decrease in velocity and increase in nodal pressure. During maximum consumption times the velocity outside the optimum design ranges are modified by resizing pipe diameter. The pipe which does not meet the required minimum and maximum velocity for loop system was selected for modification to improve the distribution system as shown in the table below.

Table 4.21 Modified pipe size during peak hour consumption time

S.no	Label	Existing pipe diam	Improved pipe size	Velocity of the existing pipe size	Velocity of modified pipe size
1	p-7	100	50	0.12	0.61
2	p-31	150	50	0.06	0.67
3	p-32	150	50	0.02	0.12
4	p-35	150	50	0.01	0.14
5	p-30	50	25	0.06	0.6
6	p-41	150	100	4.29	1.05
7	p-43	150	80	0.05	0.25
8	p-48	80	150	2.31	0.67
9	p-59	50	100	2.71	0.95
10	p-72	80	25	0.02	0.25
11	p-80	80	25	0.02	0.31
12	p-83	80	40	0.07	0.28
13	p-86	80	150	2.06	1.58
14	p-98	50	80	2.29	0.98
15	p-109	100	50	0.07	0.18
16	p-112	80	25	0.08	0.12
17	p-121	80	25	0.04	0.25
18	p.33	150	50	0.04	0.65
19	p-38	150	80	0.09	0.65
20	p-51	50	100	2.03	0.84
21	p-58	150	80	0.01	0.31

From the above table the velocity of flow in the water distribution network was improved to above 0.1m/s for the velocity below 0.1m/s which are greater than the minimum limits, of minimum velocity in the water distribution system of loop system. The velocity of the flow above the recommended ranges was improved into the recommended ranges. In general the performance of the system is modified to satisfactory condition except p-7, p- 31, p-33, p-38, p-30, p-41, p-48, p-59, p-86, p-98, and p-51 which is improved to optimum velocity ranges of water supply system.

Table4.22 Improved velocities at pipes during peak hour consumption time

Velocity	Number of pipe	Percentage
< 0.1m/s	0	0.00%
< 0.6m/s	57	39.58%
< 1.2m/s	64	44.44%
< 2m/s	23	15.97%
> 2m/s	0	0.00%
Total	144	100%

After modifying the pipe sizes in the existing water system as indicated in the table above 64.16% of the pipes are in the recommended ranges of 0.6m/s and 2m/s and there is no pipe below 0.1m/s and above 2m/s

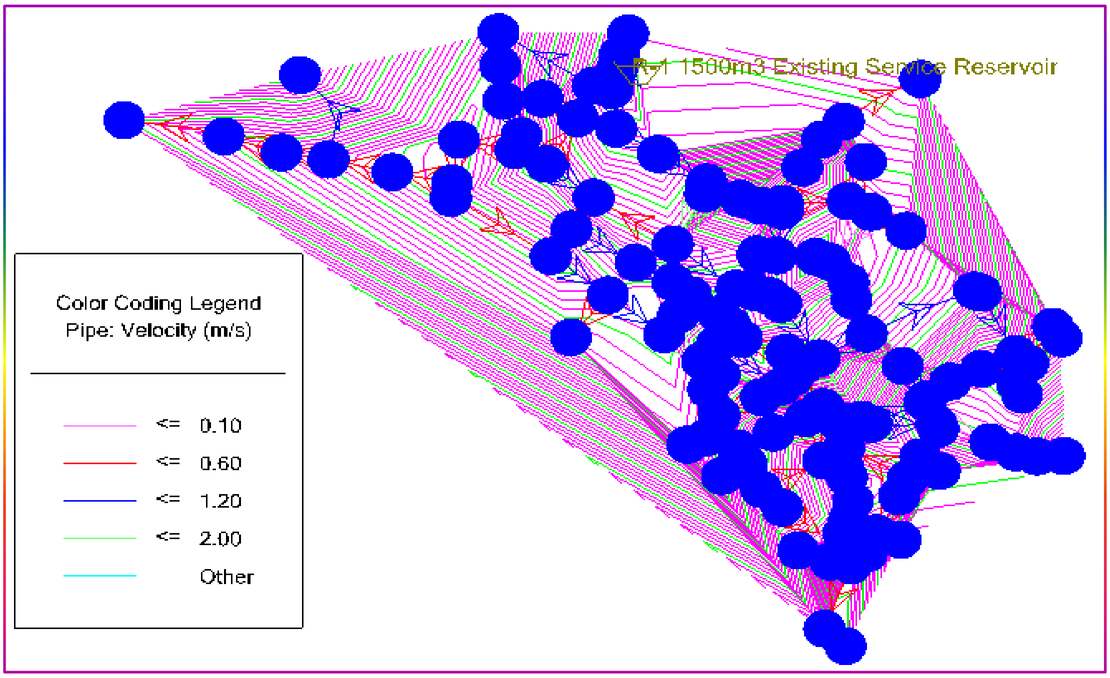

Figure 4.15 Improved velocities at the pipe during peak hour consumption time

5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1. Summary and conclusion

The provision of adequate and reliable water supply in developing countries is becoming a challenge for most water utilities especially public service providers. Water demand has been increasing significantly in most cities due to population growth and other factors. As result, in many countries public service utilities have failed to provide consumers with adequate water service.

The research study focused on water demand for the population of the resident, water loss analysis and hydraulic performance analysis. Based on the analysis the following conclusion was provided for Adola Wayou Town water distribution network in general.

- After computing the existing water distribution network, at maximum consumption time under steady-state simulation, about 27.13% of the nodes are failed to meet the desirable minimum pressure and about 3.88% of the nodes are failed to meet the desirable maximum pressure during maximum consumption time under steady- state simulation. About 11.62% of the nodes have the negative pressure as result of the ground elevation and the rest of the node almost about 68.99% have the pressure between the optimum recommended ranges of 15m to 7mm. During minimum consumption times under steady-state simulation about 35.66% of the nodes have the pressure above the maximum allowable ranges and about 63.56% of the nodes are in the permissible ranges between minimum pressure of 15m and maximum 70m pressure.
- Based on the analysis result in water distribution system the velocity of the water flow during peak hour consumption times violated the permitted level of water velocity under the recommended ranges of MoWR for urban water supply system design. In line to this about 63 numbers of pipes in the water system has the velocity less than the minimum velocity 0.6 l/s and about 76 pipes are in the optimum ranges. On one hand during low consumption times most of the pipe has the velocity below minimum optimum ranges of velocity and there is no water velocity above the maximum allowable ranges during minimum consumption times.

- ☞ One of the main problems of the town water distribution network which could limit the quantity of water supply was the size of existing service reservoir, its location and town population expansion.
- ☞ Non-revenue water in the distribution system in year 2021 was 374483m^3/year and it account about 31.93% of the total water produced of the treatment source. Among the two types of water loss component actual/real loss types is a dominant in Adola Wayou Town water distribution system by accounting 312545.2m^3/year or by percent 26.65% of water loss in the system annually.
- ☞ The analysis result indicates that the actual domestic water supply coverage of the town was 62.65%. The level of connection per family of the town was 0.39 or 39%. The average per capita water consumption indicates in some extent the level of water supply distribution among the consumer of resident. The average per capita water consumption of Adola Wayou Town was found 36.27L/p/day. Based on water demand analysis result, the current maximum day demand was 4105.35m^3/day and the average water production of water source was 3077.93m3/day by showing gap between demand and supply 752m^3/day and 274626m^3/year.
- ☞ In water distribution network, 32 excess pressure locations require pressure reducing valves (PRV), to overcome the problem of high pressure effect in the system including the leakage due to pipe burst which happen during low consumption time. The use of the higher PN class of pipe in the water system and redefining the size of pipe diameter in the problematic area was feasible suggested to optimize the velocity in the design ranges in the distribution network.

In general the analysis indicate that the overall performance of the water distribution network was inefficient indicating that the town water supply system does not deliver its responsibility in providing sufficient water supply to the population of resident properly. And it was expressed through high level of non-revenue water, pressure and velocity variation, low level of water supply service coverage and lower water production on the supply side.

5.2. Recommendation

The current situation of Adola Wayou Town water distribution system needs the major correction to improve the performance of the system component which was necessary to improve water supply service level of the town. Based on the analysis finding the following recommendation was drawn to the town water distribution system.

- The necessary measurement should be taken to satisfy the gap between water supply and the existing water supply demand including the planning of new water distribution system, the expansion of the existing water supply system and increasing the pump hour of pump.
- During the time of water loss analysis it was identified that large amount of water loss was expected due to mainly leakage water loss, illegal connection, improper meter reading and water scheduling. Therefore it was necessary to implement water loss reducing strategies to manage water demand by minimizing the waste or loss occurred from leakage, illegal connection and improper meter reading. In addition, the requirement of the replacement of the aged pipe in the water distribution system to avoid the occurrences of water loss as real loss was suggested.
- To improve the hydraulic character of water distribution system the pressure zones are to be established to ensure minimum pressure and can be provided to the critical area, especially to the part of higher elevation area in water distribution system. The use of pressure sustaining valves is also suggested as to control the occurrences of minimum pressure.
- Based on the analysis result of system component using mass curve method of reservoir sizing, the town water distribution system require additional service reservoir located at appropriate location to deliver adequate water into water distribution network.

One of the basic problems in the town water distribution system was the effective data organizing and gathering practice was very low. Due to this they do not manage properly water utility and keeping wellness of water distribution system. So the water utility office of the town should be collecting, organizing and handle data with modern computer support form.

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APPENDIX

Appendix I: Nodal output during peak hour consumption time

Label	X(m)	Y(m)	Elevation (m)	Hydraulic Grade(m)	Pattern	Pressure (mH20)	Demand (l/s)
j-1	498,111.37	651,273.54	1,730.00	1,764.62	Fixed	35	0
j-2	498,174.29	651,493.11	1,724.00	1,764.44	Fixed	40	0.4
j-3	499,089.36	648,414.82	1,706.00	1,701.92	Fixed	4	0.02
j-4	499,328.31	648,918.63	1,715.00	1,702.23	Fixed	-13	0.01
j-5	499,748.16	651,222.39	1,722.00	1,751.03	Fixed	29	0.07
j-6	497,865.64	649,683.93	1,673.00	1,712.25	Fixed	39	0.37
j-7	496,406.01	651,246.24	1,698.00	1,739.82	Fixed	42	0.3
j-8	500,508.74	649,678.83	1,732.00	1,720.30	Fixed	-12	0.83
j-9	499,782.84	649,314.88	1,721.00	1,722.84	Fixed	2	0.16
j-10	499,852.50	648,887.41	1,696.00	1,719.42	Fixed	23	0.15
j-10	499,513.42	648,517.35	1,706.95	1,703.69	Fixed	3	0.09
j-11	499,004.34	648,668.92	1,692.00	1,701.93	Fixed	10	0.1
j-12	499,332.64	648,515.03	1,710.00	1,701.24	Fixed	-9	0.16
j-13	499,225.44	648,950.19	1,711.00	1,702.23	Fixed	-9	0.16
j-14	499,677.80	648,839.00	1,712.00	1,704.13	Fixed	-8	0.12
j-15	499,336.57	649,025.72	1,704.00	1,702.26	Fixed	2	0.19
j-16	498,889.00	649,327.96	1,671.00	1,702.83	Fixed	32	0.24
j-17	498,660.18	649,226.89	1,665.00	1,702.71	Fixed	38	0.2
j-18	498,678.96	648,857.78	1,672.00	1,702.12	Fixed	30	0.18
j-19	498,492.40	649,044.51	1,661.00	1,702.69	Fixed	42	0.12
j-20	498,667.00	649,218.78	1,666.00	1,702.69	Fixed	37	0.13
j-21	498,596.74	649,088.36	1,667.00	1,702.69	Fixed	36	0
j-22	498,572.61	649,542.58	1,667.00	1,703.21	Fixed	36	0
j-23	498,667.24	649,461.67	1,654.00	1,702.99	Fixed	49	0.29
j-24	498,605.04	649,374.00	1,664.00	1,702.86	Fixed	39	0.26
j-25	498,126.74	651,363.82	1,728.00	1,764.61	Fixed	37	0
j-26	498,087.60	651,156.14	1,725.00	1,755.00	Fixed	30	0
j-27	499,344.79	647,845.80	1,712.00	1,701.45	Fixed	16	0.3
j-28	499,231.01	647,947.91	1,712.00	1,701.68	Fixed	10	0.17
j-29	500,263.00	648,998.71	1,717.00	1,721.83	Fixed	5	0.08
j-30	500,375.56	648,974.15	1,715.00	1,721.76	Fixed	7	0.12
j-31	500,522.79	648,977.00	1,698.00	1,721.73	Fixed	24	0.14
j-32	499,006.23	650,437.89	1,698.00	1,751.54	Fixed	53	0.23
j-33	499,218.24	650,862.35	1,679.00	1,751.03	Fixed	72	0.21

j-34	497,988.07	650,516.05	1,698.00	1,737.96	Fixed	40	1.84
j-35	498,108.72	650,926.57	1,720.00	1,754.86	Fixed	35	1.22
j-36	497,983.91	651,181.99	1,722.00	1,754.43	Fixed	32	0.18
j-37	497,484.39	651,301.03	1,678.49	1,750.24	Fixed	72	0.12
j-38	499,116.50	649,511.94	1,674.00	1,735.24	Fixed	61	1.15
j-39	500,329.26	649,527.80	1,727.00	1,721.00	Fixed	-6	0.27
j-40	497,262.95	650,861.12	1,671.00	1,741.70	Fixed	71	0.7
j-41	497,566.82	650,798.87	1,684.00	1,743.45	Fixed	59	0.15
j-42	497,870.42	650,328.19	1,682.00	1,737.30	Fixed	55	1.07
j-43	497,732.98	650,716.31	1,694.00	1,741.18	Fixed	47	1.14
j-44	498,415.27	650,237.84	1,696.00	1,737.33	Fixed	41	1.32
j-45	498,214.42	650,127.89	1,680.00	1,725.16	Fixed	45	1
j-46	498,660.97	649,820.45	1,678.00	1,715.35	Fixed	37	2.5
j-47	498,756.37	649,973.69	1,681.00	1,736.75	Fixed	56	2.24
j-49	498,849.85	649,954.21	1,692.00	1,736.65	Fixed	45	1.28
j-50	498,725.79	649,755.62	1,683.00	1,715.40	Fixed	32	1.27
j-51	498,788.87	649,675.47	1,685.00	1,718.28	Fixed	33	1.73
j-52	498,997.29	649,882.66	1,701.00	1,736.45	Fixed	35	3.49
j-53	498,942.48	649,927.25	1,699.00	1,736.53	Fixed	37	1.17
j-54	499,204.33	649,560.03	1,677.00	1,735.40	Fixed	58	1.33
j-55	499,298.86	649,183.00	1,695.00	1,702.29	Fixed	7	0
j-56	498,413.53	650,011.57	1,670.00	1,718.70	Fixed	49	0.15
j-57	499,025.84	649,592.42	1,676.00	1,718.38	Fixed	42	1.39
j-58	499,353.83	648,848.76	1,718.00	1,701.87	Fixed	-16	1.52
j-59	499,770.88	649,299.56	1,720.00	1,722.94	Fixed	3	0.22
j-60	499,909.49	649,420.17	1,726.00	1,722.22	Fixed	-4	2.53
j-61	500,462.57	649,747.22	1,735.00	1,720.33	Fixed	-15	0.54
j-61	500,075.23	649,948.65	1,713.00	1,736.24	Fixed	23	1.26
j-62	499,459.59	649,705.48	1,680.00	1,744.65	Fixed	65	1.17
j-63	499,377.64	649,906.00	1,687.00	1,745.80	Fixed	59	0.17
j-64	499,361.74	650,012.18	1,696.00	1,746.42	Fixed	50	0.22
j-65	499,263.00	650,133.16	1,708.00	1,747.28	Fixed	39	0.24
j-66	499,184.55	650,162.75	1,714.00	1,747.71	Fixed	34	1.4
j-67	498,973.48	650,170.82	1,703.00	1,749.03	Fixed	46	0.29
j-68	498,870.24	650,177.73	1,691.00	1,748.98	Fixed	58	1.37
j-69	498,588.36	650,540.42	1,702.00	1,754.20	Fixed	52	1
j-70	498,778.91	650,509.48	1,675.00	1,753.54	Fixed	78	0.1
j-71	498,596.69	650,605.68	1,702.00	1,754.26	Fixed	52	0
j-72	498,333.65	650,776.05	1,716.00	1,754.54	Fixed	38	1.14
j-73	497,476.73	651,500.00	1,680.00	1,751.25	Fixed	71	1.05

j-74	497,502.41	651,094.00	1,681.00	1,749.20	Fixed	68	1.91
j-75	497,598.84	650,881.91	1,686.00	1,745.03	Fixed	59	0.16
j-77	498,891.52	650,467.03	1,682.00	1,751.93	Fixed	70	0.31
j-78	500,124.05	649,059.65	1,717.00	1,721.98	Fixed	5	0.4
j-79	500,294.75	649,342.74	1,726.00	1,720.90	Fixed	-5	0.43
j-80	500,268.89	649,407.70	1,729.00	1,721.01	Fixed	-8	1.67
j-81	500,074.49	649,495.92	1,725.00	1,721.06	Fixed	4	1.37
j-82	500,261.35	649,584.88	1,723.00	1,721.33	Fixed	-2	0.38
j-83	499,653.10	649,513.00	1,706.00	1,732.17	Fixed	26	0.23
j-84	499,432.23	649,193.15	1,701.00	1,726.00	Fixed	25	0.25
j-85	499,482.62	649,167.52	1,703.00	1,724.77	Fixed	22	1.29
j-86	497,902.91	650,988.50	1,706.00	1,740.63	Fixed	35	0.24
j-87	497,711.97	651,105.97	1,696.00	1,740.35	Fixed	44	1.39
j-88	496,559.18	650,742.89	1,677.00	1,739.87	Fixed	63	0.08
j-89	496,308.19	650,784.29	1,682.00	1,739.39	Fixed	57	0.35
j-90	496,903.95	650,667.67	1,673.00	1,740.81	Fixed	68	0.13
j-91	497,219.86	650,513.47	1,671.00	1,740.19	Fixed	69	0
j-92	497,757.00	650,167.78	1,669.00	1,737.51	Fixed	68	0.09
j-93	498,065.85	649,935.33	1,667.00	1,722.34	Fixed	55	0.23
j-94	498,366.95	649,702.40	1,665.00	1,713.99	Fixed	49	0.17
j-95	498,443.12	649,817.50	1,665.00	1,714.02	Fixed	49	0.16
j-96	498,649.76	649,641.13	1,675.00	1,706.70	Fixed	32	0.1
j-97	499,000.00	649,391.95	1,660.00	1,702.84	Fixed	43	2.32
j-98	499,060.65	649,445.40	1,672.00	1,702.81	Fixed	31	0.14
j-99	499,212.58	649,261.96	1,688.00	1,702.33	Fixed	17	0
j-100	498,890.19	648,778.99	1,690.00	1,701.98	Fixed	16	0.26
j-101	499,263.77	648,347.56	1,671.00	1,701.92	Fixed	31	0.19
j-102	499,459.83	648,396.22	1,703.00	1,702.75	Fixed	0	0.19
j-103	498,815.73	648,923.95	1,688.00	1,702.12	Fixed	16	1.28
j-104	499,633.32	648,737.20	1,713.00	1,703.98	Fixed	9	0.16
j-105	498,764.73	649,022.97	1,682.00	1,702.27	Fixed	20	0.23
j-106	499,642.62	648,478.08	1,689.00	1,703.64	Fixed	16	0.2
j-107	498,959.22	649,115.66	1,693.00	1,702.25	Fixed	9	0.31
j-108	499,749.00	648,970.21	1,707.00	1,719.45	Fixed	12	0.21
j-109	499,128.74	649,201.17	1,688.00	1,702.25	Fixed	16	1.84
j-110	499,385.36	648,709.47	1,715.00	1,701.68	Fixed	-13	0.48
j-111	499,333.68	649,183.71	1,696.00	1,702.28	Fixed	6	0.5
j-112	499,836.34	649,165.46	1,717.00	1,722.02	Fixed	5	0.07
j-113	499,224.95	649,268.00	1,687.00	1,702.32	Fixed	16	0.27
j-114	499,844.84	649,139.46	1,716.00	1,721.85	Fixed	6	1.18

j-115	499,363.68	648,595.32	1,711.00	1,700.98	Fixed	-10	1.59
j-116	499,671.49	650,318.98	1,701.00	1,747.49	Fixed	46	0.15
j-117	499,376.00	648,326.51	1,712.00	1,702.12	Fixed	-10	0.16
j-118	499,482.55	650,429.87	1,700.00	1,747.50	Fixed	47	0.58
j-119	499,410.53	648,431.94	1,707.00	1,702.45	Fixed	5	0.2
j-120	499,112.47	650,695.31	1,686.00	1,751.05	Fixed	65	1.12
j-121	499,334.94	650,968.55	1,714.00	1,751.03	Fixed	37	0.07
j-122	499,453.65	650,728.93	1,711.00	1,749.88	Fixed	39	0.09
j-123	499,355.50	650,495.21	1,704.00	1,749.88	Fixed	46	1
j-124	499,007.02	650,478.76	1,695.00	1,751.40	Fixed	56	0.2
j-125	500,038.88	649,962.30	1,711.00	1,739.19	Fixed	28	0.19
j-126	495,459.10	650,977.07	1,691.00	1,735.49	Fixed	44	0.1
j-127	495,995.59	650,880.53	1,684.00	1,735.55	Fixed	51	1.26
j-128	497,224.69	650,600.44	1,671.00	1,740.85	Fixed	70	0.14
j-129	498,512.55	649,935.25	1,668.00	1,715.63	Fixed	48	1.5

Appendix II: Nodal output during minimum consumption time

Label	X(m)	Y(m)	Elevation (m)	Hydraulic Grade(m)	Fixed	Pressure (mH20)	Demand (l/s)
j-1	498,111.37	651,273.54	1,730.00	1,764.95	Fixed	35	0.00
j-2	498,174.29	651,493.11	1,724.00	1,764.93	Fixed	41	0.13
j-3	499,089.36	648,414.82	1,706.00	1,756.86	Fixed	51	0.01
j-4	499,328.31	648,918.63	1,715.00	1,756.90	Fixed	42	0.00
j-5	499,748.16	651,222.39	1,722.00	1,763.20	Fixed	41	0.02
j-6	497,865.64	649,683.93	1,673.00	1,758.19	Fixed	85	0.12
j-7	496,406.01	651,246.24	1,698.00	1,761.75	Fixed	64	0.10
j-8	500,508.74	649,678.83	1,732.00	1,759.23	Fixed	**27**	0.27
j-9	499,782.84	649,314.88	1,721.00	1,759.56	Fixed	38	0.05
j-10	499,852.50	648,887.41	1,696.00	1,759.12	Fixed	63	0.05
j-10	499,513.42	648,517.35	1,706.95	1,757.09	Fixed	50	0.03
j-11	499,004.34	648,668.92	1,692.00	1,756.86	Fixed	65	0.03
j-12	499,332.64	648,515.03	1,710.00	1,756.77	Fixed	47	0.05
j-13	499,225.44	648,950.19	1,711.00	1,756.90	Fixed	46	0.05
j-14	499,677.80	648,839.00	1,712.00	1,757.15	Fixed	45	0.04
j-15	499,336.57	649,025.72	1,704.00	1,756.91	Fixed	53	0.06
j-16	498,889.00	649,327.96	1,671.00	1,756.98	Fixed	86	0.08
j-17	498,660.18	649,226.89	1,665.00	1,756.96	Fixed	92	0.06
j-18	498,678.96	648,857.78	1,672.00	1,756.89	Fixed	85	0.06
j-19	498,492.40	649,044.51	1,661.00	1,756.96	Fixed	96	0.04

j-20	498,667.00	649,218.78	1,666.00	1,756.96	Fixed	91	0.04
j-21	498,596.74	649,088.36	1,667.00	1,756.96	Fixed	90	0.00
j-22	498,572.61	649,542.58	1,667.00	1,757.03	Fixed	90	0.00
j-23	498,667.24	649,461.67	1,654.00	1,757.00	Fixed	103	0.10
j-24	498,605.04	649,374.00	1,664.00	1,756.98	Fixed	93	0.08
j-25	498,126.74	651,363.82	1,728.00	1,764.95	Fixed	37	0.00
j-26	498,087.60	651,156.14	1,725.00	1,763.71	Fixed	39	0.00
j-27	499,344.79	647,845.80	1,712.00	1,756.80	Fixed	45	0.10
j-28	499,231.01	647,947.91	1,712.00	1,756.83	Fixed	45	0.06
j-29	500,263.00	648,998.71	1,717.00	1,759.43	Fixed	42	0.03
j-30	500,375.56	648,974.15	1,715.00	1,759.42	Fixed	44	0.04
j-31	500,522.79	648,977.00	1,698.00	1,759.42	Fixed	61	0.04
j-32	499,006.23	650,437.89	1,698.00	1,763.26	Fixed	65	0.07
j-33	499,218.24	650,862.35	1,679.00	1,763.20	Fixed	84	0.07
j-34	497,988.07	650,516.05	1,698.00	1,761.51	Fixed	63	0.59
j-35	498,108.72	650,926.57	1,720.00	1,763.69	Fixed	44	0.39
j-36	497,983.91	651,181.99	1,722.00	1,763.64	Fixed	42	0.06
j-37	497,484.39	651,301.03	1,678.49	1,763.10	Fixed	84	0.04
j-38	499,116.50	649,511.94	1,674.00	1,761.16	Fixed	87	0.37
j-39	500,329.26	649,527.80	1,727.00	1,759.32	Fixed	15	0.09
j-40	497,262.95	650,861.12	1,671.00	1,761.99	Fixed	91	0.23
j-41	497,566.82	650,798.87	1,684.00	1,762.22	Fixed	78	0.05
j-42	497,870.42	650,328.19	1,682.00	1,761.43	Fixed	79	0.35
j-43	497,732.98	650,716.31	1,694.00	1,761.93	Fixed	68	0.37
j-44	498,415.27	650,237.84	1,696.00	1,761.43	Fixed	65	0.43
j-45	498,214.42	650,127.89	1,680.00	1,759.86	Fixed	80	0.32
j-46	498,660.97	649,820.45	1,678.00	1,758.59	Fixed	80	0.81
j-47	498,756.37	649,973.69	1,681.00	1,761.36	Fixed	80	0.72
j-49	498,849.85	649,954.21	1,692.00	1,761.34	Fixed	69	0.41
j-50	498,725.79	649,755.62	1,683.00	1,758.60	Fixed	75	0.41
j-51	498,788.87	649,675.47	1,685.00	1,758.97	Fixed	74	0.56
j-52	498,997.29	649,882.66	1,701.00	1,761.32	Fixed	60	1.13
j-53	498,942.48	649,927.25	1,699.00	1,761.33	Fixed	62	0.38
j-54	499,204.33	649,560.03	1,677.00	1,761.18	Fixed	84	0.43
j-55	499,298.86	649,183.00	1,695.00	1,756.91	Fixed	62	0.00
j-56	498,413.53	650,011.57	1,670.00	1,759.03	Fixed	89	0.05
j-57	499,025.84	649,592.42	1,676.00	1,758.99	Fixed	83	0.45
j-58	499,353.83	648,848.76	1,718.00	1,756.86	Fixed	39	0.49
j-59	499,770.88	649,299.56	1,720.00	1,759.57	Fixed	39	0.07
j-60	499,909.49	649,420.17	1,726.00	1,759.48	Fixed	23	0.81

j-61	500,462.57	649,747.22	1,735.00	1,759.24	Fixed	24	0.17
j-61	500,075.23	649,948.65	1,713.00	1,761.29	Fixed	48	0.41
j-62	499,459.59	649,705.48	1,680.00	1,762.37	Fixed	82	0.38
j-63	499,377.64	649,906.00	1,687.00	1,762.52	Fixed	75	0.05
j-64	499,361.74	650,012.18	1,696.00	1,762.60	Fixed	66	0.07
j-65	499,263.00	650,133.16	1,708.00	1,762.71	Fixed	55	0.08
j-66	499,184.55	650,162.75	1,714.00	1,762.77	Fixed	49	0.45
j-67	498,973.48	650,170.82	1,703.00	1,762.94	Fixed	60	0.09
j-68	498,870.24	650,177.73	1,691.00	1,762.93	Fixed	72	0.44
j-69	498,588.36	650,540.42	1,702.00	1,763.61	Fixed	61	0.32
j-70	498,778.91	650,509.48	1,675.00	1,763.52	Fixed	88	0.03
j-71	498,596.69	650,605.68	1,702.00	1,763.61	Fixed	61	0.00
j-72	498,333.65	650,776.05	1,716.00	1,763.65	Fixed	48	0.37
j-73	497,476.73	651,500.00	1,680.00	1,763.23	Fixed	83	0.34
j-74	497,502.41	651,094.00	1,681.00	1,762.96	Fixed	82	0.62
j-75	497,598.84	650,881.91	1,686.00	1,762.42	Fixed	76	0.05
j-77	498,891.52	650,467.03	1,682.00	1,763.31	Fixed	81	0.10
j-78	500,124.05	649,059.65	1,717.00	1,759.45	Fixed	42	0.13
j-79	500,294.75	649,342.74	1,726.00	1,759.31	Fixed	33	0.14
j-80	500,268.89	649,407.70	1,729.00	1,759.32	Fixed	30	0.54
j-81	500,074.49	649,495.92	1,725.00	1,759.33	Fixed	34	0.44
j-82	500,261.35	649,584.88	1,723.00	1,759.37	Fixed	36	0.12
j-83	499,653.10	649,513.00	1,706.00	1,760.76	Fixed	55	0.07
j-84	499,432.23	649,193.15	1,701.00	1,759.97	Fixed	59	0.08
j-85	499,482.62	649,167.52	1,703.00	1,759.81	Fixed	57	0.42
j-86	497,902.91	650,988.50	1,706.00	1,761.86	Fixed	56	0.08
j-87	497,711.97	651,105.97	1,696.00	1,761.82	Fixed	66	0.45
j-88	496,559.18	650,742.89	1,677.00	1,761.76	Fixed	85	0.02
j-89	496,308.19	650,784.29	1,682.00	1,761.70	Fixed	80	0.11
j-90	496,903.95	650,667.67	1,673.00	1,761.88	Fixed	89	0.04
j-91	497,219.86	650,513.47	1,671.00	1,761.80	Fixed	91	0.00
j-92	497,757.00	650,167.78	1,669.00	1,761.45	Fixed	92	0.03
j-93	498,065.85	649,935.33	1,667.00	1,759.50	Fixed	92	0.07
j-94	498,366.95	649,702.40	1,665.00	1,758.42	Fixed	93	0.05
j-95	498,443.12	649,817.50	1,665.00	1,758.42	Fixed	93	0.05
j-96	498,649.76	649,641.13	1,675.00	1,757.48	Fixed	82	0.03
j-97	499,000.00	649,391.95	1,660.00	1,756.98	Fixed	97	0.75
j-98	499,060.65	649,445.40	1,672.00	1,756.98	Fixed	85	0.05
j-99	499,212.58	649,261.96	1,688.00	1,756.91	Fixed	69	0.00
j-100	498,890.19	648,778.99	1,690.00	1,756.87	Fixed	67	0.08

j-101	499,263.77	648,347.56	1,671.00	1,756.86	Fixed	86	0.06
j-102	499,459.83	648,396.22	1,703.00	1,756.97	Fixed	54	0.06
j-103	498,815.73	648,923.95	1,688.00	1,756.89	Fixed	69	0.41
j-104	499,633.32	648,737.20	1,713.00	1,757.13	Fixed	44	0.05
j-105	498,764.73	649,022.97	1,682.00	1,756.91	Fixed	75	0.07
j-106	499,642.62	648,478.08	1,689.00	1,757.08	Fixed	68	0.06
j-107	498,959.22	649,115.66	1,693.00	1,756.90	Fixed	64	0.10
j-108	499,749.00	648,970.21	1,707.00	1,759.12	Fixed	52	0.07
j-109	499,128.74	649,201.17	1,688.00	1,756.90	Fixed	69	0.59
j-110	499,385.36	648,709.47	1,715.00	1,756.83	Fixed	42	0.15
j-111	499,333.68	649,183.71	1,696.00	1,756.91	Fixed	61	0.16
j-112	499,836.34	649,165.46	1,717.00	1,759.46	Fixed	42	0.02
j-113	499,224.95	649,268.00	1,687.00	1,756.91	Fixed	70	0.09
j-114	499,844.84	649,139.46	1,716.00	1,759.43	Fixed	43	0.38
j-115	499,363.68	648,595.32	1,711.00	1,756.74	Fixed	46	0.51
j-116	499,671.49	650,318.98	1,701.00	1,762.74	Fixed	62	0.05
j-117	499,376.00	648,326.51	1,712.00	1,756.89	Fixed	45	0.05
j-118	499,482.55	650,429.87	1,700.00	1,762.74	Fixed	63	0.19
j-119	499,410.53	648,431.94	1,707.00	1,756.93	Fixed	50	0.06
j-120	499,112.47	650,695.31	1,686.00	1,763.20	Fixed	77	0.36
j-121	499,334.94	650,968.55	1,714.00	1,763.20	Fixed	49	0.02
j-122	499,453.65	650,728.93	1,711.00	1,763.05	Fixed	52	0.03
j-123	499,355.50	650,495.21	1,704.00	1,763.05	Fixed	59	0.32
j-124	499,007.02	650,478.76	1,695.00	1,763.25	Fixed	68	0.06
j-125	500,038.88	649,962.30	1,711.00	1,761.67	Fixed	51	0.06
j-126	495,459.10	650,977.07	1,691.00	1,761.19	Fixed	70	0.03
j-127	495,995.59	650,880.53	1,684.00	1,761.20	Fixed	77	0.41
j-128	497,224.69	650,600.44	1,671.00	1,761.88	Fixed	91	0.05
j-129	498,512.55	649,935.25	1,668.00	1,758.63	Fixed	90	0.48

Appendix III: Input base water demand to Bentlay water GEMs

Label	Number of house hold	Base Population at node	X(m)	Y(m)	Elevation (m)	Base Demand (ℓ/s)
j-1	0	0	498,111.37	651,273.54	1,730.00	0
j-2	56.00	320.00	498,174.29	651,493.11	1,724.00	0.21
j-3	3.00	15.00	499,089.36	648,414.82	1,706.00	0.01
j-4	3.00	15.00	499,328.31	648,918.63	1,715.00	0.01
j-5	11.00	61.00	499,748.16	651,222.39	1,722.00	0.04
j-6	51.00	289.00	497,865.64	649,683.93	1,673.00	0.19

j-7	43.00	244.00	496,406.01	651,246.24	1,698.00	0.16
j-8	115.00	655.00	500,508.74	649,678.83	1,732.00	0.43
j-9	21.00	122.00	499,782.84	649,314.88	1,721.00	0.08
j-10	22.00	122.00	499,852.50	648,887.41	1,696.00	0.08
j-10	13.00	76.00	499,513.42	648,517.35	1,706.95	0.05
j-11	13.00	76.00	499,004.34	648,668.92	1,692.00	0.05
j-12	21.00	122.00	499,332.64	648,515.03	1,710.00	0.08
j-13	22.00	122.00	499,225.44	648,950.19	1,711.00	0.08
j-14	16.00	91.00	499,677.80	648,839.00	1,712.00	0.06
j-15	27.00	152.00	499,336.57	649,025.72	1,704.00	0.1
j-16	35.00	198.00	498,889.00	649,327.96	1,671.00	0.13
j-17	27.00	152.00	498,660.18	649,226.89	1,665.00	0.1
j-18	27.00	152.00	498,678.96	648,857.78	1,672.00	0.1
j-19	16.00	91.00	498,492.40	649,044.51	1,661.00	0.06
j-20	19.00	107.00	498,667.00	649,218.78	1,666.00	0.07
j-21	0.00	0.00	498,596.74	649,088.36	1,667.00	0
j-22	0.00	0.00	498,572.61	649,542.58	1,667.00	0
j-23	40.00	228.00	498,667.24	649,461.67	1,654.00	0.15
j-24	35.00	198.00	498,605.04	649,374.00	1,664.00	0.13
j-25	0.00	0.00	498,126.74	651,363.82	1,728.00	0
j-26	0.00	0.00	498,087.60	651,156.14	1,725.00	0
j-27	43.00	244.00	499,344.79	647,845.80	1,712.00	0.16
j-28	24.00	137.00	499,231.01	647,947.91	1,712.00	0.09
j-29	11.00	61.00	500,263.00	648,998.71	1,717.00	0.04
j-30	16.00	91.00	500,375.56	648,974.15	1,715.00	0.06
j-31	19.00	107.00	500,522.79	648,977.00	1,698.00	0.07
j-32	32.00	182.00	499,006.23	650,437.89	1,698.00	0.12
j-33	29.00	167.00	499,218.24	650,862.35	1,679.00	0.11
j-34	256.00	1462.00	497,988.07	650,516.05	1,698.00	0.96
j-35	168.00	959.00	498,108.72	650,926.57	1,720.00	0.63
j-36	27.00	152.00	497,983.91	651,181.99	1,722.00	0.1
j-37	16.00	91.00	497,484.39	651,301.03	1,678.49	0.06
j-38	160.00	913.00	499,116.50	649,511.94	1,674.00	0.6
j-39	37.00	213.00	500,329.26	649,527.80	1,727.00	0.14
j-40	96.00	548.00	497,262.95	650,861.12	1,671.00	0.36
j-41			497,566.82	650,798.87	1,684.00	0.07
j-42	150.00	853.00	497,870.42	650,328.19	1,682.00	0.56
j-43	157.00	899.00	497,732.98	650,716.31	1,694.00	0.59
j-44	184.00	1051.00	498,415.27	650,237.84	1,696.00	0.69
j-45	139.00	792.00	498,214.42	650,127.89	1,680.00	0.52

j-46			498,660.97	649,820.45	1,678.00	1.3
j-47	313.00	1782.00	498,756.37	649,973.69	1,681.00	1.17
j-49	179.00	1020.00	498,849.85	649,954.21	1,692.00	0.67
j-50	176.00	1005.00	498,725.79	649,755.62	1,683.00	0.66
j-51	241.00	1371.00	498,788.87	649,675.47	1,685.00	0.9
j-52			498,997.29	649,882.66	1,701.00	1.82
j-53	163.00	929.00	498,942.48	649,927.25	1,699.00	0.61
j-54	184.00	1051.00	499,204.33	649,560.03	1,677.00	0.69
j-55	0.00	0.00	499,298.86	649,183.00	1,695.00	0
j-56	21.00	122.00	498,413.53	650,011.57	1,670.00	0.08
j-57	192.00	1097.00	499,025.84	649,592.42	1,676.00	0.72
j-58	211.00	1203.00	499,353.83	648,848.76	1,718.00	0.79
j-59	29.00	168.00	499,770.88	649,299.56	1,720.00	0.11
j-60	350.00	1995.00	499,909.49	649,420.17	1,726.00	1.31
j-61	174.00	990.00	500,462.57	649,747.22	1,735.00	0.65
j-61	75.00	426.00	500,075.23	649,948.65	1,713.00	0.28
j-62	163.00	929.00	499,459.59	649,705.48	1,680.00	0.61
j-63	24.00	137.00	499,377.64	649,906.00	1,687.00	0.09
j-64	30.00	168.00	499,361.74	650,012.18	1,696.00	0.11
j-65	32.00	183.00	499,263.00	650,133.16	1,708.00	0.12
j-66	195.00	1112.00	499,184.55	650,162.75	1,714.00	0.73
j-67	40.00	229.00	498,973.48	650,170.82	1,703.00	0.15
j-68	190.00	1081.00	498,870.24	650,177.73	1,691.00	0.71
j-69	139.00	792.00	498,588.36	650,540.42	1,702.00	0.52
j-70	13.00	76.00	498,778.91	650,509.48	1,675.00	0.05
j-71	0.00	0.00	498,596.69	650,605.68	1,702.00	0
j-72	157.00	899.00	498,333.65	650,776.05	1,716.00	0.59
j-73	147.00	838.00	497,476.73	651,500.00	1,680.00	0.55
j-74	265.00	1508.00	497,502.41	651,094.00	1,681.00	0.99
j-75	21.00	122.00	497,598.84	650,881.91	1,686.00	0.08
j-77	43.00	244.00	498,891.52	650,467.03	1,682.00	0.16
j-78	56.00	320.00	500,124.05	649,059.65	1,717.00	0.21
j-79	61.00	350.00	500,294.75	649,342.74	1,726.00	0.23
j-80	232.00	1325.00	500,268.89	649,407.70	1,729.00	0.87
j-81	190.00	1081.00	500,074.49	649,495.92	1,725.00	0.71
j-82	54.00	305.00	500,261.35	649,584.88	1,723.00	0.2
j-83	32.00	183.00	499,653.10	649,513.00	1,706.00	0.12
j-84	35.00	198.00	499,432.23	649,193.15	1,701.00	0.13
j-85	179.00	1021.00	499,482.62	649,167.52	1,703.00	0.67
j-86	32.00	183.00	497,902.91	650,988.50	1,706.00	0.12

j-87	193.00	1097.00	497,711.97	651,105.97	1,696.00	0.72
j-88	11.00	61.00	496,559.18	650,742.89	1,677.00	0.04
j-89	48.00	275.00	496,308.19	650,784.29	1,682.00	0.18
j-90	19.00	107.00	496,903.95	650,667.67	1,673.00	0.07
j-91	0.00	0.00	497,219.86	650,513.47	1,671.00	0
j-92	13.00	76.00	497,757.00	650,167.78	1,669.00	0.05
j-93	32.00	183.00	498,065.85	649,935.33	1,667.00	0.12
j-94	24.00	137.00	498,366.95	649,702.40	1,665.00	0.09
j-95	21.00	122.00	498,443.12	649,817.50	1,665.00	0.08
j-96	13.00	76.00	498,649.76	649,641.13	1,675.00	0.05
j-97	323.00	1843.00	499,000.00	649,391.95	1,660.00	1.21
j-98	21.00	122.00	499,060.65	649,445.40	1,672.00	0.08
j-99	0.00	0.00	499,212.58	649,261.96	1,688.00	0
j-100	35.00	198.00	498,890.19	648,778.99	1,690.00	0.13
j-101	27.00	152.00	499,263.77	648,347.56	1,671.00	0.1
j-102	27.00	152.00	499,459.83	648,396.22	1,703.00	0.1
j-103	179.00	1020.00	498,815.73	648,923.95	1,688.00	0.67
j-104	21.00	122.00	499,633.32	648,737.20	1,713.00	0.08
j-105	32.00	183.00	498,764.73	649,022.97	1,682.00	0.12
j-106	27.00	152.00	499,642.62	648,478.08	1,689.00	0.1
j-107	43.00	244.00	498,959.22	649,115.66	1,693.00	0.16
j-108	30.00	168.00	499,749.00	648,970.21	1,707.00	0.11
j-109	256.00	1461.00	499,128.74	649,201.17	1,688.00	0.96
j-110	67.00	381.00	499,385.36	648,709.47	1,715.00	0.25
j-111	69.00	396.00	499,333.68	649,183.71	1,696.00	0.26
j-112	11.00	61.00	499,836.34	649,165.46	1,717.00	0.04
j-113	37.00	213.00	499,224.95	649,268.00	1,687.00	0.14
j-114	163.00	929.00	499,844.84	649,139.46	1,716.00	0.61
j-115	222.00	1264.00	499,363.68	648,595.32	1,711.00	0.83
j-116	21.00	122.00	499,671.49	650,318.98	1,701.00	0.08
j-117	21.00	122.00	499,376.00	648,326.51	1,712.00	0.08
j-118	80.00	457.00	499,482.55	650,429.87	1,700.00	0.3
j-119	27.00	152.00	499,410.53	648,431.94	1,707.00	0.1
j-120	155.00	881.00	499,112.47	650,695.31	1,686.00	0.58
j-121	11.00	61.00	499,334.94	650,968.55	1,714.00	0.04
j-122	13.00	76.00	499,453.65	650,728.93	1,711.00	0.05
j-123	139.00	792.00	499,355.50	650,495.21	1,704.00	0.52
j-124	27.00	152.00	499,007.02	650,478.76	1,695.00	0.1
j-125	28.00	152.00	500,038.88	649,962.30	1,711.00	0.1
j-126	13.00	76.00	495,459.10	650,977.07	1,691.00	0.05

j-127	160.00	914.00	495,995.59	650,880.53	1,684.00	0.6
j-128	21.00	122.00	497,224.69	650,600.44	1,671.00	0.09
j-129	208.00	1188.00	498,512.55	649,935.25	1,668.00	0.78

Appendix IV: Pipe result during peak hour consumption times

Label	scaled length (m)	stop node	stop node	diam	material	Hazen William C	flow (l/s)	velocity (l/s)	Head Loss Gradient (m/km)
p-1	201	j-73	j-37	200	PVC	150	33.75	0.04	5.019
p-2	208	j-37	j-74	200	PVC	130	33.63	1.07	4.986
p-3	164	j-103	j-100	80	PVC	150	1.11	0.62	0.853
p-4	160	j-100	j-11	100	PVC	150	1.13	0.14	0.3
p-5	239	j-98	j-99	100	PVC	150	3.26	0.41	2.043
p-6	137	j-129	j-95	100	PVC	150	8.56	1.09	11.751
p-7	138	j-95	j-94	100	PVC	150	0.92	0.12	0.208
p-8	222	j-34	j-42	150	PVC	150	13.85	0.78	3.996
p-9	74	j-4	j-58	80	PVC	150	2.93	0.68	4.941
p-10	143	j-58	j-110	80	PVC	150	1.41	0.28	1.314
p-11	118	j-110	j-115	50	PVC	150	0.93	0.47	5.944
p-12	307	j-112	j-78	100	PVC	150	0.74	0.09	0.139
p-13	116	j-29	j-30	50	PVC	150	0.26	0.13	0.585
p-14	391	j-15	j-14	80	PVC	150	-2.9	0.68	4.842
p-15	377	j-13	j-100	50	PVC	150	0.28	0.14	0.66
p-16	322	j-43	j-86	80	PVC	150	1.63	0.32	1.701
p-17	153	j-28	j-27	50	PVC	150	0.3	0.65	0.785
p-18	355	j-85	j-112	100	PVC	150	6.84	0.87	7.834
p-19	449	j-38	j-84	100	PVC	150	11.61	1.48	20.389
p-20	432	j-44	j-47	200	PVC	150	16.24	0.62	1.336
p-21	242	j-124	j-120	80	PVC	150	1.47	0.29	1.419
p-22	547	j-127	j-126	50	PVC	150	0.1	0.05	0.103
p-23	639	j-91	j-92	80	PVC	150	2.66	0.63	4.15
p-24	346	j-9	j-81	80	PVC	150	2.96	0.61	5.035
p-25	122	j-1	R-1	300	PVC	150	-76.2	1.08	3.12
p-26	253	j-51	j-57	150	PVC	150	-3.93	0.22	0.409
p-27	339	j-11	j-3	150	PVC	150	1.03	0.06	0.036
p-28	187	j-3	j-101	150	PVC	150	1.01	1.06	0.035
p-29	108	j-13	j-4	150	PVC	150	-0.36	0.02	0.006
p-30	107	j-15	j-4	150	PVC	150	3.3	0.19	0.298

p-31	269	j-32	j-67	150	PVC	150	22.13	1.25	9.327
p-32	369	j-118	j-65	80	PVC	150	0.91	0.68	0.598
p-33	487	j-121	j-5	150	PVC	150	0.07	0.03	0
p-34	321	j-6	j-93	50	PVC	150	-0.37	0.19	1.119
p-35	328	j-128	j-90	150	PVC	150	2.21	0.13	0.144
p-36	327	j-127	j-89	50	PVC	150	-1.36	0.69	11.749
p-37	596	j-7	j-88	80	PVC	150	-0.3	0.06	0.08
p-38	120	j-1	j-26	150	PVC	150	75.84	4.29	86.698
p-39	214	j-81	j-80	150	PVC	150	3.02	0.67	0.253
p-40	135	j-80	j-39	150	PVC	150	0.91	0.05	0.029
p-41	138	j-25	j-2	50	PVC	150	0.4	0.2	1.288
p-42	634	j-62	j-125	80	PVC	150	3.98	0.79	8.611
p-43	398	j-42	j-45	100	PVC	150	12.78	1.63	24.291
p-44	231	j-45	j-56	100	PVC	150	11.78	1.5	20.961
p-45	125	j-56	j-129	80	PVC	150	11.63	2.31	59.889
p-46	188	j-129	j-46	80	PVC	150	1.57	0.61	1.601
p-46	92	j-46	j-50	80	PVC	150	-0.93	0.19	0.62
p-47	102	j-50	j-51	50	PVC	150	-2.2	1.12	28.194
p-48	95	j-47	j-49	200	PVC	150	14	0.45	1.021
p-49	96	j-49	j-53	200	PVC	150	15.91	0.61	1.287
p-50	71	j-53	j-52	200	PVC	150	14.74	0.47	1.119
p-51	383	j-52	j-54	150	PVC	150	11.25	0.64	2.74
p-52	310	j-40	j-41	100	PVC	150	-5.72	0.73	5.662
p-53	186	j-41	j-43	150	PVC	150	25.69	1.45	12.219
p-54	510	j-34	j-44	150	PVC	150	7.23	0.41	1.232
p-55	121	j-57	j-38	50	PVC	150	-5.32	2.71	139.335
p-56	57	j-84	j-85	100	PVC	150	11.35	1.45	19.596
p-57	294	j-54	j-62	80	PVC	150	-8.15	1.62	31.463
p-58	273	j-83	j-62	50	PVC	150	-2.87	1.46	45.727
p-59	217	j-62	j-63	150	PVC	150	-16.2	0.92	5.291
p-60	107	j-63	j-64	150	PVC	150	-16.4	0.93	5.39
p-61	156	j-64	j-65	150	PVC	150	-16.6	0.94	5.524
p-62	84	j-65	j-66	150	PVC	150	-15.9	0.9	5.12
p-63	211	j-66	j-67	150	PVC	150	-17.3	0.98	5.967
p-64	103	j-67	j-68	150	PVC	150	4.55	0.26	0.533
P-65	70	j-79	j-80	50	PVC	150	-0.43	0.22	1.49
p-66	233	j-74	j-75	150	PVC	150	31.72	1.8	17.897
p-67	143	j-118	j-123	50	PVC	150	-1.65	0.84	16.655
p-68	253	j-123	j-122	80	PVC	150	0.09	0.02	0.01

p-69	118	j-32	j-77	200	PVC	150	-26.8	0.85	3.297
p-70	120	j-77	j-70	150	PVC	150	-27.1	1.53	13.434
p-71	89	j-75	j-41	150	PVC	150	31.56	1.79	17.736
p-72	599	j-73	j-36	200	PVC	150	-34.8	1.11	5.305
p-73	224	j-86	j-87	80	PVC	150	1.39	0.28	1.28
p-74	66	j-71	j-69	300	PVC	150	38.5	0.54	0.904
p-75	193	j-70	j-69	200	PVC	150	-27.2	0.86	3.389
p-76	219	j-116	j-118	80	PVC	150	-0.15	0.63	0.024
p-77	349	j-123	j-124	80	PVC	150	-2.73	0.64	4.348
p-78	158	j-121	j-33	80	PVC	150	-0.14	1.03	0.02
p-79	198	j-33	j-120	80	PVC	150	-0.35	0.07	0.106
p-80	41	j-124	j-32	100	PVC	150	-4.4	0.62	3.525
p-80	313	j-72	j-71	300	PVC	150	38.5	0.54	0.906
p-81	349	j-44	j-69	80	PVC	150	-10.3	2.06	48.324
p-82	224	j-68	j-49	50	PVC	150	3.18	1.62	55.033
p-83	271	j-72	j-35	300	PVC	150	-39.6	1.56	0.955
p-84	324	j-43	j-34	150	PVC	150	22.93	1.3	9.943
p-85	235	j-39	j-8	50	PVC	150	0.64	0.33	3.003
p-86	83	j-8	j-61	50	PVC	150	-0.2	0.1	0.351
p-87	259	j-61	j-82	50	PVC	150	-0.74	0.37	3.877
p-89	409	j-61	j-82	50	PVC	150	2.54	1.29	36.461
p-90	39	j-125	j-61	50	PVC	150	3.79	1.93	75.582
p-91	207	j-82	j-81	80	PVC	150	1.42	0.28	1.332
p-92	165	j-60	j-9	80	PVC	150	-2.53	0.5	3.776
p-93	19	j-9	j-59	80	PVC	150	-3	0.6	5.161
p-94	100	j-38	j-54	200	PVC	150	-18.1	0.58	1.621
p-95	237	j-83	j-9	50	PVC	150	2.65	1.35	39.367
p-95	317	j-85	j-59	80	PVC	150	3.22	0.64	5.866
p-96	27	j-112	j-114	100	PVC	150	6.04	0.77	6.245
p-97	195	j-114	j-108	80	PVC	150	4.85	0.97	12.312
p-98	149	j-108	j-14	50	PVC	150	4.5	2.29	102.796
p-99	111	j-14	j-104	80	PVC	150	1.48	0.29	1.427
p-100	250	j-104	j-10	80	PVC	150	1.32	0.26	1.16
p-101	132	j-10	j-102	50	PVC	150	1.03	0.52	7.1
p-102	133	j-108	j-10	50	PVC	150	0.15	0.12	0.224
p-103	135	j-106	j-10	50	PVC	150	-0.2	0.61	0.36
p-104	61	j-102	j-119	50	PVC	150	0.84	1.43	4.902
p-105	111	j-119	j-117	50	PVC	150	0.64	0.33	3.009
p-106	181	j-101	j-12	50	PVC	150	0.82	1.42	4.712

p-107	86	j-12	j-115	50	PVC	150	0.66	0.34	3.183
p-109	158	j-15	j-111	100	PVC	150	-0.59	0.07	0.092
p-110	35	j-111	j-55	100	PVC	150	-1.09	0.64	0.281
p-111	113	j-55	j-113	100	PVC	150	-1.09	0.14	0.282
p-112	190	j-109	j-107	80	PVC	150	-0.03	0.02	0.002
p-113	215	j-107	j-105	80	PVC	150	-0.34	1.07	0.098
p-114	111	j-105	j-103	100	PVC	150	2.58	0.33	1.338
p-115	269	j-109	j-13	50	PVC	150	0.08	0.04	0.069
p-116	14	j-113	j-99	100	PVC	150	-1.36	0.17	0.422
p-117	104	j-109	j-99	100	PVC	150	-1.89	0.24	0.767
p-118	81	j-98	j-97	150	PVC	150	-3.4	1.19	0.316
p-119	128	j-97	j-16	150	PVC	150	1.66	0.63	0.086
p-120	250	j-16	j-17	100	PVC	150	1.41	0.18	0.452
p-121	152	j-103	j-18	80	PVC	150	0.18	0.04	0.032
p-122	113	j-19	j-21	80	PVC	150	-0.12	1.02	0.017
p-123	148	j-21	j-20	80	PVC	150	-0.12	0.02	0.015
p-124	11	j-17	j-20	100	PVC	150	3.39	0.43	2.208
p-125	219	j-20	j-105	100	PVC	150	3.14	0.4	1.916
p-126	157	j-17	j-24	100	PVC	150	-2.18	0.28	0.985
p-127	107	j-24	j-23	100	PVC	150	-2.43	0.31	1.206
p-129	125	j-23	j-22	100	PVC	150	-2.73	0.35	1.483
p-130	430	j-96	j-97	100	PVC	150	7.38	0.94	8.98
p-131	272	j-96	j-95	80	PVC	150	-7.48	1.49	26.908
p-132	260	j-22	j-94	50	PVC	150	-2.73	1.39	41.603
p-133	381	j-94	j-93	50	PVC	150	-1.97	1	23.127
p-134	387	j-93	j-92	50	PVC	150	-2.57	1.31	37.358
p-135	107	j-26	j-36	200	PVC	150	34.99	1.11	5.355
p-136	231	j-35	j-26	300	PVC	150	-40.9	0.62	1.009
p-137	92	j-25	j-1	80	PVC	150	-0.4	0.11	0.136
p-138	405	j-117	j-28	50	PVC	150	0.48	0.24	1.787
p-139	152	j-78	j-29	50	PVC	150	0.34	0.17	0.972
p-140	147	j-30	j-31	50	PVC	150	0.14	1.11	0.185
p-141	254	j-88	j-89	80	PVC	150	1.71	0.34	1.856
p-142	353	j-90	j-88	80	PVC	150	2.08	0.41	2.662
p-143	263	j-40	j-128	100	PVC	150	5.02	0.64	4.47
p-144	87	j-128	j-91	80	PVC	150	2.66	0.63	4.15

Appendix V: Pipe result during low consumption (night flow) time

Label	scaled length (m)	stop node	stop node	diam	material	Hazen William C	flow (l/s)	velocity (l/s)	Head Loss Gradient (m/km)
p-1	152	j-103	j-18	80	PVC	150	0.06	0.01	0.004
p-2	201	j-73	j-37	200	PVC	150	10.89	0.35	0.647
p-3	208	j-37	j-74	200	PVC	130	10.85	0.35	0.643
p-4	164	j-103	j-100	80	PVC	150	0.36	0.17	0.11
p-5	160	j-100	j-11	100	PVC	150	0.36	0.15	0.039
p-6	239	j-98	j-99	100	PVC	150	1.05	0.13	0.264
p-7	137	j-129	j-95	100	PVC	150	2.76	0.35	1.516
p-8	138	j-95	j-94	100	PVC	150	0.3	0.04	0.027
p-9	222	j-34	j-42	150	PVC	150	4.47	0.25	0.515
p-10	74	j-4	j-58	80	PVC	150	0.95	0.19	0.638
p-11	143	j-58	j-110	80	PVC	150	0.46	0.12	0.17
p-12	118	j-110	j-115	50	PVC	150	0.3	0.15	0.767
p-13	307	j-112	j-78	100	PVC	150	0.24	0.03	0.018
p-14	116	j-29	j-30	50	PVC	150	0.08	0.04	0.076
p-15	391	j-15	j-14	80	PVC	150	-0.94	0.19	0.625
p-16	377	j-13	j-100	50	PVC	150	0.09	0.05	0.085
p-17	322	j-43	j-86	80	PVC	150	0.52	0.1	0.219
p-18	153	j-28	j-27	50	PVC	150	0.1	0.05	0.101
p-19	355	j-85	j-112	100	PVC	150	2.21	0.28	1.011
p-20	449	j-38	j-84	100	PVC	150	3.74	0.48	2.63
p-21	432	j-44	j-47	200	PVC	150	5.24	0.17	0.172
p-22	242	j-124	j-120	80	PVC	150	0.47	0.19	0.183
p-23	547	j-127	j-126	50	PVC	150	0.03	0.02	0.013
p-24	639	j-91	j-92	80	PVC	150	0.86	0.17	0.535
p-25	346	j-9	j-81	80	PVC	150	0.96	0.19	0.65
p-26	122	j-1	R-1	300	PVC	150	-24.6	0.35	0.403
p-27	253	j-51	j-57	150	PVC	150	-1.27	0.11	0.049
p-28	339	j-11	j-3	150	PVC	150	0.33	0.02	0.004
p-29	187	j-3	j-101	150	PVC	150	0.33	0.02	0.004
p-30	108	j-13	j-4	150	PVC	150	-0.12	0.01	0.001
p-31	107	j-15	j-4	150	PVC	150	1.07	0.06	0.035
p-32	269	j-32	j-67	150	PVC	150	7.14	0.4	1.203
p-33	369	j-118	j-65	80	PVC	150	0.29	0.06	0.077
p-34	487	j-121	j-5	150	PVC	150	0.02	0.01	0

p-35	321	j-6	j-93	50	PVC	150	-0.12	0.24	4.049
p-36	328	j-128	j-90	150	PVC	150	0.71	0.04	0.017
p-37	327	j-127	j-89	50	PVC	150	-0.44	0.22	1.516
p-38	596	j-7	j-88	80	PVC	150	-0.1	0.02	0.01
p-39	120	j-1	j-26	150	PVC	150	24.47	1.34	10.362
p-40	214	j-81	j-80	150	PVC	150	0.97	0.05	0.03
p-41	135	j-80	j-39	150	PVC	150	0.29	0.02	0.004
p-42	138	j-25	j-2	50	PVC	150	0.13	0.13	0.166
p-43	634	j-62	j-125	80	PVC	150	1.29	0.26	1.111
p-44	398	j-42	j-45	100	PVC	150	4.12	0.63	3.134
p-45	231	j-45	j-56	100	PVC	150	3.8	0.63	2.704
p-46	125	j-56	j-129	80	PVC	150	3.75	0.75	7.726
p-46	188	j-129	j-46	80	PVC	150	0.51	0.11	0.206
p-47	92	j-46	j-50	80	PVC	150	-0.3	0.06	0.079
p-48	102	j-50	j-51	50	PVC	150	-0.71	0.36	3.64
p-49	95	j-47	j-49	200	PVC	150	4.52	0.14	0.132
p-50	96	j-49	j-53	200	PVC	150	5.13	0.16	0.166
p-51	71	j-53	j-52	200	PVC	150	4.75	0.15	0.145
p-52	383	j-52	j-54	150	PVC	150	3.63	0.21	0.354
p-53	310	j-40	j-41	100	PVC	150	-1.84	0.23	0.731
p-54	186	j-41	j-43	150	PVC	150	8.29	0.64	1.577
p-55	510	j-34	j-44	150	PVC	150	2.33	0.13	0.159
p-56	121	j-57	j-38	50	PVC	150	-1.72	0.87	17.98
p-57	57	j-84	j-85	100	PVC	150	3.66	0.47	2.528
p-58	294	j-54	j-62	80	PVC	150	-2.63	0.62	4.059
p-59	273	j-83	j-62	50	PVC	150	-0.93	0.47	5.899
p-60	217	j-62	j-63	150	PVC	150	-5.22	0.3	0.683
p-61	107	j-63	j-64	150	PVC	150	-5.27	0.3	0.695
p-62	156	j-64	j-65	150	PVC	150	-5.34	0.3	0.712
p-63	84	j-65	j-66	150	PVC	150	-5.13	0.29	0.661
p-64	211	j-66	j-67	150	PVC	150	-5.58	0.32	0.77
P-65	103	j-67	j-68	150	PVC	150	1.47	0.08	0.069
p-66	70	j-79	j-80	50	PVC	150	-0.14	0.07	0.193
p-67	233	j-74	j-75	150	PVC	150	10.23	0.68	2.309
p-68	143	j-118	j-123	50	PVC	150	-0.53	0.27	2.148
p-69	253	j-123	j-122	80	PVC	150	0.03	0.01	0.001
p-70	118	j-32	j-77	200	PVC	150	-8.63	0.27	0.426
p-71	120	j-77	j-70	150	PVC	150	-8.73	0.49	1.733
p-72	89	j-75	j-41	150	PVC	150	10.18	0.68	2.288

p-73	599	j-73	j-36	200	PVC	150	-11.23	0.36	0.685
p-74	224	j-86	j-87	80	PVC	150	0.45	0.11	0.165
p-75	66	j-71	j-69	300	PVC	150	12.42	0.18	0.117
p-76	193	j-70	j-69	200	PVC	150	-8.76	0.28	0.437
p-77	219	j-116	j-118	80	PVC	150	-0.05	0.01	0.003
p-78	349	j-123	j-124	80	PVC	150	-0.88	0.18	0.561
p-79	158	j-121	j-33	80	PVC	150	-0.04	0.01	0.003
p-80	198	j-33	j-120	80	PVC	150	-0.11	0.02	0.014
p-80	41	j-124	j-32	100	PVC	150	-1.42	0.18	0.454
p-81	313	j-72	j-71	300	PVC	150	12.42	0.18	0.117
p-82	349	j-44	j-69	80	PVC	150	-3.33	0.66	6.235
p-83	224	j-68	j-49	50	PVC	150	1.03	0.62	7.1
p-84	271	j-72	j-35	300	PVC	150	-12.79	0.18	0.123
p-85	324	j-43	j-34	150	PVC	150	7.4	0.42	1.282
p-86	235	j-39	j-8	50	PVC	150	0.21	0.11	0.388
p-87	83	j-8	j-61	50	PVC	150	-0.06	0.03	0.045
p-89	259	j-61	j-82	50	PVC	150	-0.24	0.12	0.499
p-90	19	j-9	j-59	80	PVC	150	-0.97	0.19	0.666
p-91	409	j-61	j-82	50	PVC	150	0.82	0.42	4.704
p-92	100	j-38	j-54	200	PVC	150	-5.83	0.19	0.21
p-93	39	j-125	j-61	50	PVC	150	1.22	0.62	9.75
p-94	237	j-83	j-9	50	PVC	150	0.85	0.43	5.079
p-95	207	j-82	j-81	80	PVC	150	0.46	0.11	0.172
p-95	317	j-85	j-59	80	PVC	150	1.04	0.21	0.757
p-96	27	j-112	j-114	100	PVC	150	1.95	0.25	0.805
p-97	195	j-114	j-108	80	PVC	150	1.57	0.31	1.588
p-98	149	j-108	j-14	50	PVC	150	1.45	0.74	13.262
p-99	111	j-14	j-104	80	PVC	150	0.48	0.11	0.185
p-100	250	j-104	j-10	80	PVC	150	0.42	0.18	0.149
p-101	132	j-10	j-102	50	PVC	150	0.33	0.17	0.916
p-102	133	j-108	j-10	50	PVC	150	0.05	0.12	0.029
p-103	135	j-106	j-10	50	PVC	150	-0.06	0.13	0.046
p-104	61	j-102	j-119	50	PVC	150	0.27	0.14	0.634
p-105	111	j-119	j-117	50	PVC	150	0.21	0.11	0.387
p-106	181	j-101	j-12	50	PVC	150	0.26	0.13	0.608
p-107	86	j-12	j-115	50	PVC	150	0.21	0.11	0.411
p-109	35	j-111	j-55	100	PVC	150	-0.35	0.04	0.038
p-110	113	j-55	j-113	100	PVC	150	-0.35	0.04	0.036

p-111	190	j-109	j-107	80	PVC	150	-0.01	0	0
p-112	215	j-107	j-105	80	PVC	150	-0.11	0.02	0.13
p-113	111	j-105	j-103	100	PVC	150	0.83	0.11	0.173
p-114	269	j-109	j-13	50	PVC	150	0.02	0.01	0.008
p-115	14	j-113	j-99	100	PVC	150	-0.44	0.06	0.054
p-116	104	j-109	j-99	100	PVC	150	-0.61	0.18	0.098
p-117	81	j-98	j-97	150	PVC	150	-1.1	0.16	0.04
p-118	128	j-97	j-16	150	PVC	150	0.53	0.13	0.01
p-119	113	j-19	j-21	80	PVC	150	-0.04	0.11	0
p-120	148	j-21	j-20	80	PVC	150	-0.04	0.21	0.002
p-121	11	j-17	j-20	100	PVC	150	1.09	0.14	0.285
p-122	219	j-20	j-105	100	PVC	150	1.01	0.13	0.247
p-123	157	j-17	j-24	100	PVC	150	-0.7	0.11	0.127
p-124	107	j-24	j-23	100	PVC	150	-0.78	0.1	0.156
p-125	125	j-23	j-22	100	PVC	150	-0.88	0.11	0.191
p-126	430	j-96	j-97	100	PVC	150	2.38	0.3	1.159
p-127	272	j-96	j-95	80	PVC	150	-2.41	0.68	3.472
p-129	260	j-22	j-94	50	PVC	150	-0.88	0.45	5.368
p-130	381	j-94	j-93	50	PVC	150	-0.64	0.32	2.983
p-131	387	j-93	j-92	50	PVC	150	-0.83	0.42	4.82
p-132	107	j-26	j-36	200	PVC	150	11.29	0.36	0.691
p-133	231	j-35	j-26	300	PVC	150	13.18	0.19	0.131
p-134	92	j-25	j-1	80	PVC	150	-0.13	0.03	0.15
p-135	405	j-117	j-28	50	PVC	150	0.15	0.12	0.231
p-136	152	j-78	j-29	50	PVC	150	0.11	0.06	0.125
p-137	147	j-30	j-31	50	PVC	150	0.04	0.02	0.024
p-138	254	j-88	j-89	80	PVC	150	0.55	0.11	0.239
p-139	353	j-90	j-88	80	PVC	150	0.67	0.13	0.344
p-140	263	j-40	j-128	100	PVC	150	1.62	0.21	0.577
p-141	87	j-128	j-91	80	PVC	150	0.86	0.17	0.536
p-142	165	j-60	j-9	80	PVC	150	-0.81	0.16	0.487
p-143	158	j-15	j-111	100	PVC	150	-0.19	0.02	0.012
p-144	250	j-16	j-17	100	PVC	150	0.46	0.06	0.058