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JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

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HYDRAULIC ENGINEERING MASTER OF SCINCE PROGRAM

SUSTAINABILITY ASSESSMENT OF URBAN WATER SUPPLY DISTRIBUTION SYSTEM: A CASE STUDY OF BICHENA TOWN, AMHARA REGION, ETHIOPIA

ATHESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF JIMMA UNIVERSITY INSTITUTE OF TECHNOLOGY IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN HYDRAULIC ENGINEERING STREAM.

BY

DAMTE TEGEGNE

OCTOBER, 2016

JIMMA, ETHIOPIA

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OCTOBER, 2016

JIMMA, ETHIOPIA

DECLARATION

I, the undersigned, declare that this thesis:

Sustainability assessment of urban water supply distribution system is my original work, and it has not been presented for a degree in Jimma University or any other University and that all sources of materials used for the thesis have been fully acknowledged.

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ABSTRACT

Water is a vital resource no matter where in the world we live. But two out of five people without access to an improved drinking water source live in Africa. The lowest levels of drinking water coverage are in Sub-Saharan Africa (50–75%). In sub-Saharan Africa the proportion of people with access to potable water supply and adequate sanitation is actually low. Based on 2009/10 data the regional water supply coverage is not exceeding 60%. This indicates that 40% of the people have no access to clean water. Nowadays sustainability assessment is crucial issue and Ethiopian government give consideration on urban water supply sustainability by the second growth transformation plan. Sustainability of urban water supply is major challenge facing many towns generally in Ethiopia. So, the study focuses on sustainability assessment of urban water supply distribution system of Bichena Town by investigating technical performance indicators which were velocity and pressure in the water supply distribution system. Watergemsv8i was used for simulation the distribution water supply network. Arc GIS 9.3 was used for mapping. A methodology was presented for determining sustainability indices for pressure and velocity in water distribution systems. These sustainability indices were based upon performance criteria including reliability, resiliency, and vulnerability indicators. The result of the study area was analyzed by excel. From the result of the analysis the per capita consumption of Bichena town was 13.3 liter per capita per day which was lower than World Health Organization 2008 standard and Ethiopian government second growth transformation plan. The value of pressure and velocity were used to determine reliability, resiliency and vulnerability performance criteria. The overall sustainability index of Bichena town water supply was 0.46 which shows the unacceptable level. The study findings of indicators show that Bichena town water supply distribution system was not sustainable. Therefore the water supply should be redesigned and additional borehole should be drilled in order to meet customers demand. Since velocity of water supply of the study area was low and affect water quality of the distribution system, pipe size should be modified. Additional boreholes should be drilled.

Key words: *Nodal pressure; Sustainability assessment; Sustainability indicators; Velocity; Water demand; Water distribution systems.*

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ACRONYMES

ACC	African Centre for Cities
ADSWE	Amhara Design Supervision Works Enterprise
masl	Meter Above Sea Level
ANRS	Amhara National Regional State
AWWA	American Water Works Association
AWWCE	Amhara Water Works Construction Enterprise
ARHBR	Amhara Region Health Bureau Report
CSA	Central Statistics Agency
EPS	Extended Period Simulation
GIS	Geographical Information System
GPS	Global Positioning System
HDPE	High Density Polyethylene Pipes
IWA	International Water Association
LPCD	Liter Per Capita Demand
Masl	Meter above Sea Level
M^3/D	Meter Cube Per Day
MDG	Minimum Development Goals
MOWIE	Minstry Of Water Irigation And Electric
No	Number
PHF	Peak Hour Factor
PT	Public Tape
PIS	Performance Indicators System
SSA	Sub-Saharan Africa

TDS	Total Dissolved Solid
UAP	Universal Assess Plan
UFW	Unacounted For Water
UN	United Nation
UK	United Kingdom
USA	United States of America
WCED	World Commission On Environment And Development
WDN	Water Distribution Networks
WHO	World Health Organization
WSSE	Water Supply and Sewerage Enterprise
WUP	Water Utility Partnership
WWC	World Water Council

1 INTRODUCTION

1.1 Background

Water is among the most important resources for developing of all kind of economic and noneconomic activities. The sustainable provisions of adequate and safe drinking water are the most important of all public services. Anything that disturbs the sustainable provision and supply of water therefore, tends to disturb the very survival of humanity. Former UN Secretary General Kofi Annan once said, “All resources that nourish life owe their existence to water…”From the tiniest algae to the giant mammals along with everything they live on, feed on, and make possible their breeding are the creations of water (Informer, 2010).

Water required for drinking purpose is further stressed by continuously increasing population and in order to fulfill this ever increasing demand at urban as well as rural level. Therefor need to replace the traditional and obsolete methods of designing water distribution networks with accurate, speedy and computer based software’s and methods. Designing of water distribution networks is a critical part of the water supply system which contributes for the major share of overall expenditures incurred in it so as to systematic and proper design as well as modeling becomes the critical one (Sonaje, 2015).

Even though Safe drinking water is one of the basic necessities for human beings billions of people in the world have no access safe drinking water. Significant number of the population is from the developing countries. The most vulnerable parts of the society are particularly women and children. Each day in the World and in Ethiopia significant number of children are dying due to lack of safe drinking water, appropriate sanitation and hygiene (MOWIE, 2015).

With increasing global change pressures coupled with existing un-sustainability factors and risks inherent to conventional urban water management, cities of the future will experience difficulties in efficiently managing scarcer and less reliable water resources. In order to meet the future challenges, there needs to be a shift in the way we manage urban water systems (Khatri, 2007).

Particularly, of any region in the world, the problem of water supply is deep rooted and multi-dimensional in Africa. In the year 2000, according to World Health Organization

WHO (2000) report Africa contains 28% of the world's population without access to improved water supplies. Even though Africa is stated that it is currently urbanizing rapidly and by 2020 it is expected that over 50% of the population in Africa will reside in urban areas, more than 30% of the residents in urban areas currently lack access to adequate water services and facilities (WUP, 2003).

In urban areas of Ethiopia, most households have access only through common taps, consumption levels are low and unscheduled disruptions in services are common. In 2008, for the first time more than half of the world's population lives in cities. Sub Saharan Africa is the least urbanized region, but is expected to have the highest rates of growth for decades to come, including massive growth in urban slums African Centre for Cities (ACC, 2008).

Similar to the urban water sector in many developing countries, there are serious constraints in meeting the challenge to provide adequate water sustainably for all urban residents in Ethiopia. Water supply shortages and quality deteriorations are among the problems which require greater attention and action. Various strategies are always being developed to make water accessible to all inhabitants. However due to insufficient structures coupled with rapid population growth and urbanization, the gap between demand and supply of water continues to widen (Degnet, 2011).

The adequate provision of urban services, and in particular, the three water related services water supply, sanitation provision and drainage are vital in the quest to eradicate poverty and ultimately provide the environment for sustainable development (De Carvalho, 2007).

Sustainability literally refers to the maintenance or sustenance of something over the long term. The concept of sustainability is a challenge to conventional thinking and practice, and represents a need for positive alternatives to the present unsustainable path we are on.

How well a water supply and distribution system can satisfy its diverse objectives can be determined by evaluation of its functional performance. However this evaluation is extremely complex because it depends on a variety of parameters, some of which vary continually. Changing parameters include the quality and quantity of water available at the source, the variation in daily, weekly and seasonal demands as well as demand growth over the service life. But there are some other factors that depend on the characteristics of water distribution system(WDS) itself, such as failure rates of supply pumps, power outages, and flow capacity of transmission mains, roughness characteristics, pipe breaks and valve failures (Mahdi, 2008).

In Amhara region Systems are frequently broken and not functioning with poor arrangements for maintenance and repair. Access to sanitation facilities is reported to be 56 %. Water and sanitation-related diarrheal disease is among the top three causes of all deaths in Ethiopia, and Amhara region is one of the regions that have faced this life threatening challenge for many years (Seifu et al, 2012). Evaluation of alternative concepts and showing the different options to achieve sustainability are significant steps in the decision-making procedure. In this process, it is important to illustrate the options to decision makers and make them fully understand the reasoning as well as cause and effects of each policy that has been proposed to improve the sustainability of the current and future water resources. From the technical sustainability perspective, providing water to remote communities (i.e. moving water long distances) requires high-pressure operations, which results in loss of fresh water resources due to possible bursts in pipes (Aydin,2014).

1.2 Statement of the Problem

Water is a vital resource no matter where in the world we live. Fresh water is not only indispensable for human alimentation but also an important primary product for industrial and agricultural production. Therefore, the availability of fresh water is directly linked to the welfare and prosperity of our society. However, fresh water is a limited, sometimes even scarce resource and rapid global changes, such as population growth, economic development, migration and urbanization are placing new strains on water resources and on the infrastructure that supplies drinking water to citizens, businesses, industries and institutions (WWC, 2009).

The world is under transition in water resource development and management (Gleick, 2003). All contemporary societies are under a problem of water system due to an over exploitation of water resources (Kostas and Chrysostomos, 2006). Problems can be particularly acute in urban areas that face ever increasing difficulties in efficiently managing scarcer and less reliable water resources. Worldwide a major challenge is the development of practical tools to measure and enhance urban sustainability especially through the design and management of infrastructure (Sahely *et al.*, 2006).

The issue of sustainability is critical when resource scarcity and equity matters are raised. The sustainability of water supply projects and the benefits they deliver are some of the overriding concerns of the water sector (Wonduante, 2013). Water has a vital role to play in responding to the socio-economic crisis facing Africa. Two out of five people without access to an improved drinking water source live in Africa. Although several economic instruments are being deployed to address this crisis, the success of these efforts will depend heavily on the availability of sustainable water resources. Inadequacies of water supply along with the deterioration of water quality in a distribution system are the major problems facing city water works all over the world. The problem is especially severe in most developing-country like Ethiopian cities where increased urbanization, population growth, poor city planning, and shortage of sufficient resources creating combined effect (Chali, 2013). The lowest levels of drinking water coverage are in Sub-Saharan Africa (50–75%). In sub-Saharan Africa the proportion of people with access to potable water supply and adequate sanitation is very low (Yitayh, 2011).

Ethiopia is often referred to as the “water tower” of Africa, only a quarter of the country’s population has access to improved water sources. In Ethiopia, the water supply service level, in terms of coverage quantity and quality, is very low due to factors like topography, sources of water reserve, distribution systems, treatment plants, and community health centers. Due to its unreliability and non-sustainable nature, the existing service level in different parts of Ethiopia is lesser than the required levels (Solomon, 2011).

In the Amhara region, although the region is well endowed with a substantial amount of water resources potential, the performance of potable water supply and distribution is found to be low. Based on 2009/10 data the regional water supply coverage is not exceeding 60%. This indicates that 40% of the people have no access to clean water (ARHBR, 2011).

This coverage also less than the standard set by World Health Organization which is a daily requirement of 45 liters per person and Ethiopian water access of 15 l/c/d in the 1.5 km source distance. Thus, people who are not accessed are forced to use unsafe drinking water from unprotected wells, rivers and ponds.

Most studies conducted on water supply at large city levels focused mainly on large urban settlements. But in small and medium towns like Bichena there is no adequate researches have been yet carried out. Also the studies conducted on water loss and water quality but no more research studies on sustainability. The problem of water supply in the Bichena town is not only the problem of distribution and reliability but also it has the problem of adequacy and accessibility.

1.3 Objectives

1.3.1 General objective

The main aim of this research was to assess the sustainability of urban water supply distribution system in Bichena Town with modeling package of Bentley WateGemsv8i.

1.3.2 Specific objectives

The specific objective of the study or activity of the study were the following:

1. To assess water supply and demand in the water supply system.
2. To determine nodal pressure in the distribution system.
3. To evaluate velocity of distribution system

1.4 Research questions

In order to achieve the mentioned research objectives and to seek answers for the stated problems, the following major research questions were formulated.

- How much water serves to the town?
- How much water consumed by the town customers?
- Are the velocity and pressure in normal level?

1.5 Significance of the Study

For developing countries like Ethiopia where there is a problem of safe and adequate water to fulfill the need of the population, research on sustainability assessment is vital. There have been few studies on sustainability assessment in Ethiopia but none has been done in Bichena Town.

Now a day's Ethiopia is straggling to reduce urban water scarcity. Due to this reason the government and non-governmental organizations are interested to invest in water sectors. Therefor assessing sustainability of urban water supply has vital role to different sectors especially who are interested to do related to water resource.

The research findings can strongly assist decision / policy makers in planning urban water supply and other development activities in a way to achieve sustainability of urban water supply and the distribution system. In addition, this study can provide scientific information on the future water resource development and fill the gaps of other research works by incorporating the recommendations in other research works.

1.6 Limitations of the study

The full data for analyses were not found. In addition instruments used for water quality as well as pressure gage and flow were critical limitation. Further, on account lack of related written materials or literatures concerning provision of water supply sustainability at local level, the investigator was forced to depend on the corresponding external country of urban water supply sustainability sources.

1.7 Scope of the Study

This study specifically focused on assessing sustainability of Bichena Town urban water supply distribution system by performing hydraulic performance of water supply schemes. The study area is limited to Bichena Town water supply scheme. Because of sustainability assessment is wide the study was restricted to water demand determination and hydraulic parameter nodal pressure and velocity analyses. The result and findings of the modeling are the reflections of the study area. But, it might reflect problems in other areas of water Supply scheme with similar characteristics. Livestock demand source was given revers and ponds.

2 LITERATURE REVIEW

2.1 Background

Water supply and distribution system is complex systems which fulfill various objectives. These are meet public health and environmental constraints, considering the ever-increasing needs for fresh water and other essential non-potable applications. Water supply and distribution system consists of several components such as pipes, pumps, reservoir tanks and hydraulic control elements that collectively supply (at least to some extent) the required quantities of water with adequate pressure from sources to all customers. It is generally desired that the water should be supplied in a continuous manner. However this is an ideal condition, and occasional disruptions by random failures of their components and unexpected variation of demands may occur over the service life. As a result, measuring and evaluating a systems' performance is itself a complex problem (Mahdi, 2008).

Bichena town water supply source was from two boreholes which were drilled in 1999. The first borehole; which was known as Bichena borehole -1 was located on the North side of the town. It was reported as having 2.50 1/s safe yield at the drilling and testing time. The second borehole is known as Bichena borehole -2. It was reported as having 4.50 1/s safe yield at the drilling and testing time. All bore wells were drilled at Balla-Wadeba Well field, located about 6 km north of the town, which are fitted with submersible pumps others still sealed. Currently these require rehabilitation to be operational.

Current, only One well which is known as Suha borehole which has a depth of 138 meters and yields of 13.8 1/s .But it was reported as having 18 1/s safe yield before five years i.e. at the drilling and testing time is the productive source for the town. Water from source is pumped directly to the existing service reservoir and connects to the distribution system (ADSWE, 2015). The daily water production of the study area was presented in Table 2.1.

Table 2.1 Current water supply production **(**ADSWE, 2015)

	Average Current yield(l/s)	Current Working Hour/day	Daily Production(m3)	Monthly Production (m3)	Annual Production (m3)
Current borehole	13.8	12	596.16	17884.8	217598.4

2.2 The Meaning of sustainability

The word sustainability is derived from the Latin word of sustainer, which means to hold-up (ten ere, to hold and sues, up) (Oxford Advanced Learner's Dictionary - 8th Edition).The concepts of sustainability first came from the environmental influence and attempts to protect natural resources and ecological systems from over-extraction, shocks or stresses. However, it has also been extended to integrate other dimensions like economic, social and institutional. In every recent development endeavor, the issue of sustainability is given serious consideration. As a result, sustainable development has been given several definitions by different institutions and researchers. World Commission and Environment Development have the most commonly mentioned definition of sustainable development that defines as: “Sustainable development is development that meets the needs of the present generations without compromising the ability of future generations to meet their own needs” (WCED, 1987).

Sustainability by definition enforces decision makers to consider not only current populations but future generations as well. The current problem with sustainable water resources is that limited fresh water resources are distributed unevenly around the world and in some developing countries; part of the population still does not have access to safe drinking water. Consequently, water demand and supply management are very important in order to prevent renewable fresh water resources degradation. International Institute for Sustainable Development, United States of America (USA); describes as “To be sustainable, development must improve economic efficiency, protect and restore ecological systems and enhance the well-being of all peoples (Wonduante, 2013).

2.3 Sustainability of water services in Ethiopia

In the last several years, developing as well as in developed countries throughout the world water resource also been dealing with water stress due to internal and external factors such as increasing population, climate change, increasing industrial and residential water usage and declining water availability.

Ethiopia has made significant progress in extending access to improved water sources under its Universal Access Plan (UAP). Although data are contested, all sources confirm the strong upward trajectory. However, the ability of the country to sustain progress is difficult to predict. One key challenge is ensuring that investment translates into sustainable services that continue to meet users' needs in terms of water quantity, quality, ease of access, and reliability. Although data are limited, available evidence suggests that many schemes provide unreliable services or fail completely. Service sustainability is not a new issue in Ethiopia, or elsewhere in SSA (Roger Calow *et al.*, 2013).

Sustainable access to water supply is central to social and economic development, improving health and educational achievement, reducing child mortality, and improving livelihoods (Hutton, 2004). But these benefits are not sustained if access to water supply itself is not sustainable. A water service is said to be sustainable if it continues to work over time, with service itself defined in terms of the quantity and quality of water accessible to users over time. According to Roger Calow *et al* (2013) specific indicators include Quantity, measured in liters per capita per day (lpcd), quality in terms of one or more separate indicators of chemical and biological quality, distance from a household or center of a community to a water point, number of people sharing a source, often termed 'crowding' and reliability in terms of the proportion of the time the service functions to its prescribed level. Monitoring the services accessed by individuals over time and space is clearly difficult. This is one reason why planners have focused on systems and the extension of new supplies, with assumptions then made about service levels using government standards to determine water coverage.

Ensure good governance improving sustainability, effectiveness and efficiency of water supply services. Establish urban wastewater management system is the core stratagem of Ethiopian government to day and for the next years Roger Calow *et al.*, 2013.

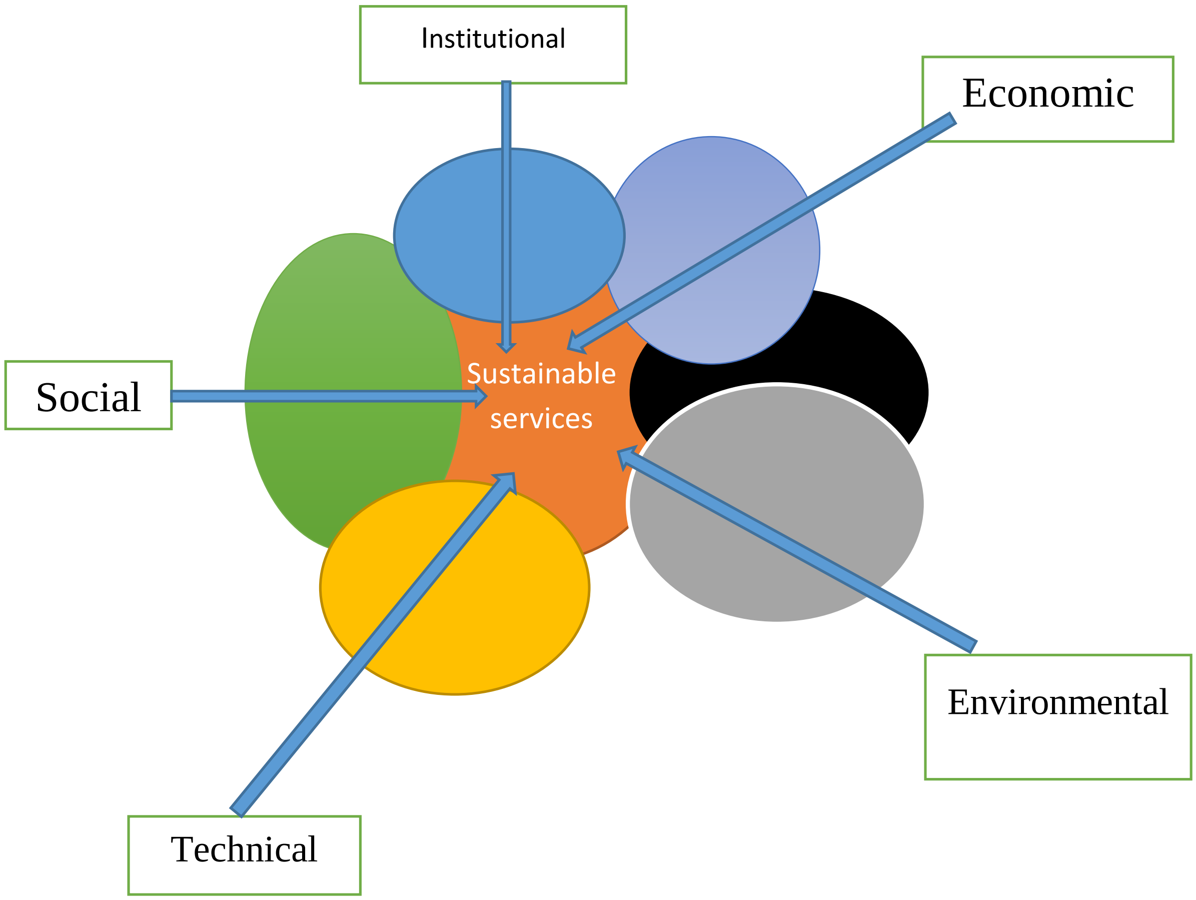

Figure 2.1 Conceptual framework for sustainability of water services (Roger Calow *et al.*, 2013)

2.4 Water supply Source

Ground and surface water are the most common water sources developed for water supply requirement of towns.

a. Ground water is tapped from aquifers through wells, springs and infiltration galleries. The yield depends on the depth, type of aquifer and ground water table gradient. Good yielding aquifers can be considered as reliable sources of water supply for community purposes.

Spring is points at which groundwater comes to surface naturally. It is not always reliable sources of water supply because the shallow water tables that supply the spring are usually subject to rise and fall in elevation during rainy and dry season.

b. Surface water is perennial streams, lakes, rivers and canals. It also includes stored floods by constructing impoundments. Ground water is generally preferred, because usually it is lower in bacterial count, is cleaner, cooler and more uniform. The lower bacterial count and the greater clarity are due to the filtering action of the soil and sand through which the groundwater flows. Also, the required treatment is minimal.

2.5 Hydraulic models

A computer model is composed of two parts a database and a computer program. The database contains information that describes the infrastructure, demands, and operational characteristics of the system. The computer program solves a set of energy, continuity, transport, or optimization equations to solve for pressure flows, tank levels, valve position, pump status, water age or water chemical concentrations. The computer program also aids in creating and maintaining the database and presents model results in graphical and tabular forms (AWWA, 2012).

In networks of interconnected hydraulic elements, every element is influenced by each of its Neighbors; the entire system is interrelated in such a way that the condition of one element must be consistent with the condition of all other element (Walski *et al.*, 2003). According to Swamee And Sharma (2008) interconnections of hydraulic elements are defined in concepts of conservation of mass and energy.

2.5.1. Conservation of mass

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

$\sum_{pi} Qi - U$..………………………………………………………………………..……2. 1

Where, Qi = inflow to node in i^{th} pipe (L3/T); U = water used at node (L3/T)

2.5.2 Conservation of energy

The Energy equation is known as Bernoulli's equation. Energy equation consist the pressure head, elevation head, and velocity head. There may be also energy added to the system (such as by a pump), and energy removed from the system (due to friction). The changes in energy are referred to as head gains and head losses. The principle of conservation of energy dictates that the difference in energy between two points must be the same regardless of the path that is taken. The equation for conservation of energy is written in terms of head as follows:

$$Z_1+\frac{P1}{\gamma}+\frac{v_1{}^2}{2g}+\sum hp=z_2+\frac{P2}{\gamma}+\frac{v_2{}^2}{2g}+\sum hL+\sum hm \quad \text{2. 2}$$

Where; Z = elevation (L); P = Pressure (M/L/T2); γ = fluid specific weight (M/L2/T2); V = velocity (L/T); g = gravitational acceleration constant (L/T2); Hp = head added at pump (L); hL = head loss in pipes (L); hm = head loss due to minor losses (L)

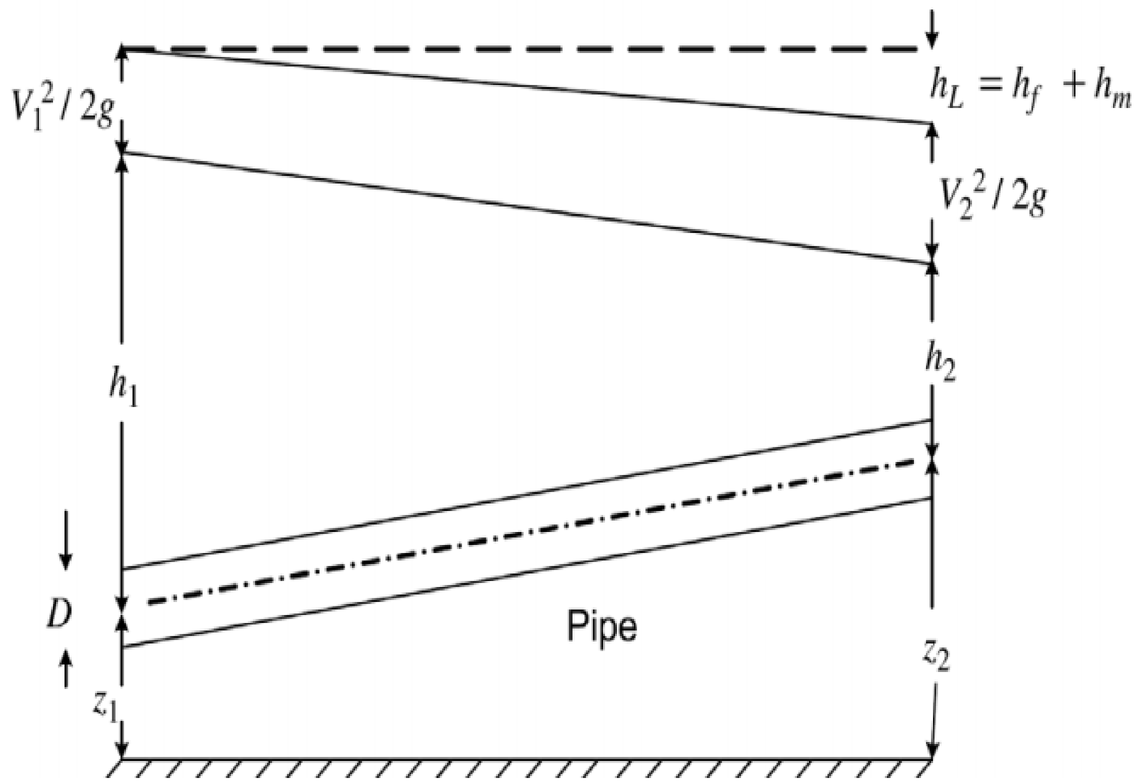

Figure 2.2 Forms of energy in water pipes (BentleyWaterCAD/GEMs, 2008)

Therefore, in connected network the difference in energy at any two point is equal to the energy increases from pumps and energy losses in pipes (frictional head loss) as well as energy losses in bending and fittings (minor head loss) that occur in the path between them.

2.6 Water Distribution Systems

Although the size and complexity of water distribution systems vary dramatically, they all have the same basic purpose to deliver water from the source (or treatment facility) to the customer.

For efficient distribution it is required that the water should reach to every consumer with required rate of flow. Water supply systems are generally constructed to provide sufficient water to the users with a specified pressure, quantity and quality. These systems consist of various major components like, pipes, valves, junctions, pumps, elevated storage tanks, water treatment plants, etc. The three competing goals for the water supply systems are: reliable delivery of water even in case of emergencies like pipe failures, power outages, efficient and economic operation of the system, and, meeting water quality standards.

Therefore, some pressure in pipeline is necessary, which should force the water to reach at every place. Water distribution systems are comprised of three primary components; water source, treatment, and distribution network. Water sources can be reservoirs, rivers, and groundwater wells. Water treatment facilities disinfect the water to drinking water quality standards prior to delivering it to its consumers. The distribution network is responsible for delivering water from the source or treatment facilities to its consumers at serviceable pressures and mainly consists of pipes, pumps, junctions (nodes), valves, fittings and storage tank (Hopkins, 2012).

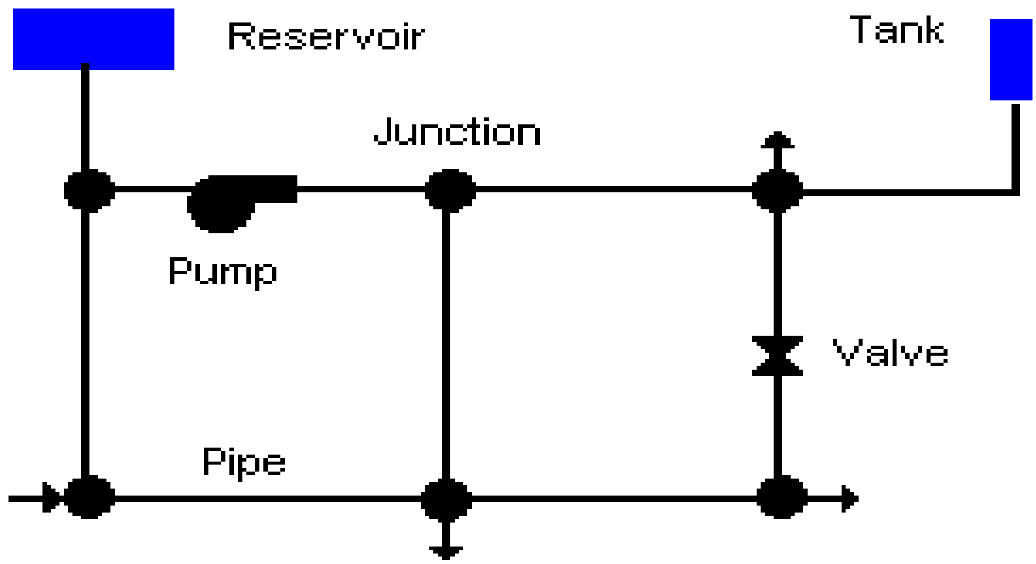

Figure 2.3 Physical Components in a water distribution system (EPANET users Gide, 2000)

Depending upon the methods of distribution, the distribution system Venkateswara classify as the follows (Venkateswara, 2005).

1. Gravity system
2. Pumping system
3. Dual system or combined gravity and pumping system

2.6.1 Gravity system

When some ground sufficiently high above the city area is available, this can be best utilized for distribution system in maintaining pressure in water mains. This method is also much suitable when the source of supply such as lake, river or impounding reservoir is at sufficiently higher than city. The water flows in the mains due to gravitational forces.

2.6.2 Pumping system

Constant pressure can be maintained in the system by direct pumping into mains. Rate of flow cannot be varied easily according to demand unless numbers of pumps are operated in addition to stand by ones. Supply can be affected during power failure and breakdown of pumps. Hence diesel pumps also in addition to electrical pumps as stand by to be maintained. During fires, the water can be pumped in required quantity by the stand by units.

2.6.3 Combined pumping and gravity system

This is also known as dual system. The pump is connected to the mains as well as elevated reservoir. In the beginning when demand is small the water is stored in the elevated reservoir, but when demand increases the rate of pumping, the flow in the distribution system comes from the both the pumping station as well as elevated reservoir. As in this system water comes from two sources one from reservoir and second from pumping station, it is called dual system. This system is more reliable and economical, because it requires uniform rate of pumping but meets low as well as maximum demand. The water stored in the elevated reservoir meets the requirements of demand during breakdown of pumps and for firefighting.

2.7 Urban water demand

The lowest levels of drinking water coverage are in sub-Saharan Africa which was between 50% and 75%.Two out of five people without access to an improved drinking water source live in Africa (WHO, 2014). Figure 2.4 show number without assess water in the world.

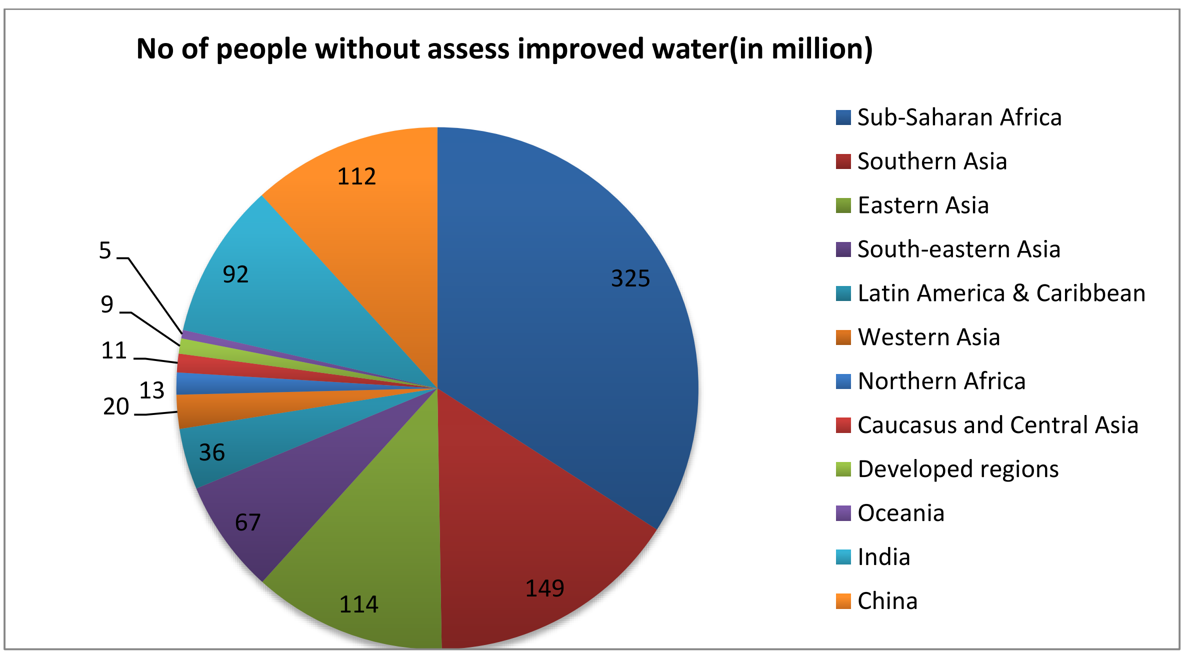

Figure 2.4 Number of people (in millions) without access to an improved drinking water source in 2012, by MDG region (WHO, 2014)

The accurate assessment of current and future water demand is the starting point for the design work. The main purpose of demand projection is thus to ensure that not only the current demand, but also the future demand up to the design horizon can be covered by all infrastructure elements of the water supply system to be designed.

Water demand is thus to be understood as the amount of water that will be used by all groups of consumers, assuming that no limiting factor such as lack of resource, lack of pressure, negatively perceived water quality, inaccurate distribution etc. will interfere. In well-functioning systems, water demand and water consumption match each other.

Water consumption or water demand is the driving force behind the operation of a water distribution system. Any location at which water leaves the system can be characterized as a demand on the system. The water demands are aggregated and assigned to nodes, which represent an obvious simplification of real-world situations in which individual house taps are distributed along a pipe rather than at junction nodes. It is important to be able to determine the amount of water being used, where it is being used, and how this usage varies with time (Walski *et al.*, 2003).

Demand may be estimated by a count of structures of different types using a representative consumption per structure, by meter readings and the assignment of each meter to a node, and by general land use. A universal adjustment factor should be used to account for losses and other unaccounted-for water usage so that total usage in the model corresponds to total production.

A typical hierarchy for assigning demands includes the following:

• **Baseline demands**: Baseline demands usually correspond to consumer demands and unaccounted-for water associated with average day conditions. This information is often acquired from a water utility's existing records, such as customer meter and billing records. Although the spatial assignment of these demands is extremely important and should include the assignment of customer classes such as industrial, residential, and commercial use, actual metering data should be used when available.

• **Seasonal variation**: Water use typically varies over the course of the year with higher demands occurring in warmer months.

When developing a steady-state model, the baseline (average day) demand can be modified by multipliers in order to reflect other conditions such as maximum day demand, peak-hour demand and minimum day demand.

• **Fire demands***:* Water provided for fire services can be the most important consideration in developing design standards for water systems. Typically, a system is modeled corresponding to maximum-use conditions, with needed fire flow added to a single node at a time. It is not uncommon for a requirement that multiple hydrants be flowing simultaneously.

• **Diurnal variation*:*** All water systems are unsteady because of continuously varying demands. It is important to account for these variations in order to achieve an adequate hydraulic model. Diurnal varying demand curves should be developed for each major consumer class or geographic zones within a service area. For example, diurnal demand curves might be developed for industrial establishments, commercial establishments, and residences. Large users such as manufacturing facilities may have unique usage patterns.

2.7.1 Urban water demand classification

The water demand for various purposes is divided under the following categories:

1) Domestic water demand
2) Non domestic water demand
3) Fire fighting water demand
4) Loss and waste domestic water demand

2.7.1.1Domestic water demand

Household (domestic) water demand usually accounts for the majority of the demand. Therefore, it is the most importance to assess it as realistically as possible, even if the future is hard to predict.

Domestic demand includes water furnished to residential houses for sanitary, drinking, washing, bathing and other purposes. It varies according to living conditions of consumers such as habit, social status, climatic conditions and customs of the people. The use of water for domestic purposes may be divided into various categories as drinking, cooking, ablutions, washing dishes, laundry, house cleaning, bath and shower, and toilets. In the design of any water supply project it is necessary to estimate the amount of water that is required to satisfactory serve up to the end of the design period.

This involves determining the number of people who will be served and their per capita water consumption, together with an analysis of the factors that may operate to affect consumption.

The major factors that affect rate of water usage are location and climatic condition, Standard of living, pressure in the distribution system, cost and quality of water, installation of water meter and efficiency of the water service administration.

2.7.1.2 Public and commercial Water Demand

This demand category includes the water requirements of all schools, hospitals, public facilities government offices and etc. According to Ministry of Water and Energy guideline (2006) the demand of each institute is assessed as follows

Restaurants	10 l/seat
Boarding school	60 l/pupil
Day schools	5 l/pupil
Public offices	5 l/employee
Workshop/shops	5 l/employee
Mosques & Church	5 1/worshipper
Hospitals	50 - 75 l/bed
Hotels	25 -50 l/bed
Public Bath	30 l/visitor
Railway & Bus station	5 l/user

Generally, for insufficient data none domestic water demand can be computed by 20 to 40% of domestic water demand.

2.7.1.3 Industrial Water Demand

It is also assumed that industrial developments will secure their own sources of water. Water so classified is that furnished to industrial and commercial plants. Its importance will depend up on local conditions, such as the existence of large industries and whether or not the industries patronize (utilize) the public water or not. In most case big industries are assumed to have their own water supply system. Generally large industries develop their own water supply systems. Only small industries purchase water and, therefore, impose demand on local water supply systems.

Industrial water demand may be estimated on the bases of proposed industrial zoning and the type of industries most likely to develop with in the area.

2.7.2 Per capita demand

Per capita demand of the town depends on various factors like standard of living of the costumers, number of population and type of commercial places in a town etc.

The second growth transformation plan(GTP-2) of Ethiopian government Goal 1.2 state that Provide urban water supply access with GTP-2 minimum service level of 100 l/c/day for category-1 towns/cities, 80 l/c/d for category-2 towns/cities, 60 l/c/d for category-3 towns/cities, 50 l/c/d for category-4 towns/cities, up to the premises and 40 l/c/d for category-5 towns/cities within a distance of 250m with piped system for 75% of the urban population.

As urban water supply demand is ever increasing with the rapid urbanization and industrial development, it is becoming a challenge to satisfy the demand only from groundwater sources. Thus, use of hybrid sources both from ground and surface water would be given due attention focusing particularly on the use of dams and reservoirs for multiple use in association with the relevant stakeholders. As per the GTP-2 water supply service level standard, it is required to provide safe water in minimum 25 l/c/d within a distance of 1 km for rural while in urban areas it is required to provide safe water in minimum 100 l/c/d for category 1 towns/cities (towns/cities with a population more than 1 million), 80 l/c/d for category 2 towns/cities (towns/cities with a population in the range of 100,000-1million), 60 l/c/day for category 3 towns/cities (towns/cities with a population in the range of 50,000 -100,000), 50 l/c/d for category 4 towns/cities (towns/cities with a population in the range of 20,000-50,000) up to the premises, and 40 l/c/d for category-5 towns/cities (towns/cities with a population less than 20,000) within a distance of 250 m (MOWIE, 2015).

2.7.3 Climatic and socio-economic adjustment factors

2.7.3.1 Adjustment for climate

In addition to the per capita water demand and mode of services which influence the quantity of water consumption, the climate of the area is also directly related to water consumption.

Table 2.2 Climatic adjustment factors (MOWR, 2006)

Altitude	Factor	Remark
>3300	0.8	
2300-3300	0.9	
1500-2300	1	
500-1500	1.3	
<500	1.5	

2.7.3.2 Adjustment due to Socio-economic Conditions

Population, climate and living standard of the beneficiaries are basic factors for water demand analysis. This needs proper measurement of source yield and reliable socioeconomic data. However, most study documents of town water supply of different settings show similar estimations of population increment, climate and living standard conditions. Area specific estimations were not used for designs and therefore the water amount does not coincide with the socio-economic conditions.

Table 2.3Adjustment factor due to socio-economic conditions (MOWR.2006)

Group	Description	Factor
A	Towns enjoying living standard & with very high potential development	1.1
B	Towns having a very high potential for development but lower living standards at present	1.05
C	Towns under normal Ethiopian conditions	1.0

2.7.4 Modes of Services

Based on the available data obtained from the Bichena Water Supply Service during the field visit in August 2008, five major modes of service were identified for domestic water consumers. The five modes are

- House tap connections (HC);
- Yard tap connections (YCO);
- Neighbor tap Connections (YCS);

- Public fountains (PT);

Table 2.4 Modes of service by percentage for 2014

Mode of Service	Population served in 2014	Remark
HC	0.57%	
YCO	43.96%	
YCS	14.63%	
PT	40.84%	
Total	100.00%	

2.7.4.1 Population Distribution by Mode of Service

The percentage of population to be served by each mode of service will vary with time. The variation is caused by changes in living standards, improvement of the service level, changes in building standards and capacity of the water supply service to expand.

Therefore, the present and projected percentage of population served by each demand category is estimated by taking the above stated conditions and by assuming that the percentage for the house and yard tap users will increase gradually during the project service period while the percentage of shared yard and public tap users will dramatically reduce as more and more people will have private connections as the living standard of people and the socio-economic development stage advance and no user for other sources is expected after commissioning. Table 2.5, 2.6 and 2.7 show mode of service for design period for each year.

Table 2.5 Population percentage distribution by mode of service

Mode of Service	2014	2015	2020	202	2030	2035
HC	0.57	0.57	2.93	6.46	9.12	10
YCO	43.96	43.63	50.47	60.24	67.56	70
YCS	14.63	14.63	13.47	11.74	10.43	10
PT	40.84	40.84	33.13	21.57	12.89	10
Total	100	100	100	100	100	100

Table 2.6 Breakdown of per capita water demand by 2025(MOWR, 2006)

Purpose	Mode of Service			
	HC	YCO	YSC	PT
Total (l/c/d)	50	30	25	20

Table 2. 7 Break down of per capita water demand by 2035(MOWR, 2006)

Purpose	Mode of Service			
	HC	YCO	YSC	PT
Total (l/c/d)	70	40	30	25

2.8 Variation in water uses

Water requirements in the dry season are more than in wet season. The use of water is also more during weekends than working days. More water is also required at rush hours when people come back from work than on normal working hours. Therefore, to satisfy this variation of demand the average day demand is scaled up by certain factors to get the maximum day demand and peak hour demand. These scaled up water demand figures are used to size or determine the capacities of the water supply system like pump stations, rising main and pipe distribution networks. In fixing the capacities of different components of water supply system, it is vital to consider the daily and hourly fluctuation of demand. Hence, the following conditions of demands are considered (ADSWE, 2016).

a) Total average daily water demands.

b) Maximum daily water demands.

c) Peak hourly water demand.

2.8.1 Peak hour demand

The peak hour demand is greatly influenced by the living standard of the population and the size of the town. The peak hour demand is the most prominent figure for the design of the distribution networks.

The peak hour factor (PHF) utilized to calculate the peak hour demand shows similar dependencies as the maximum day factor for the maximum day demand.

The peak hour demand is greatly influenced by town size, mode of service and social activity patterns. Previous studies on hourly variation of demand show the peak hour factor is greater for a smaller population. This taken care of as per the peak daily coefficient figures presented in table below.

Table 2. 8 Peak hour factor (MOWR, 2006)

Population range	Peak hour factor
<20000	2
20001 to 50000	1.9
50001 to 100000	1.8
>100000	1.6

2.8.2 Maximum day demand

The maximum day demand is the highest demand of any one 24 hour period over any specific year. It represents the change in demand with season. This demand is used to design source capacity, riser mains, and service reservoir. The maximum day factor utilized to calculate the maximum day demand is dependent on the population of the town. The deviation of consumption from the average day demand is taken care of as per the maximum daily coefficient figures presented in the Table 2.9.

Table 2. 9 Maximum day factor (MOWR, 2006)

Range	Maximum day factor
Minimum	1
Maximum	1.3

2.10 Design period

The complete water supply project includes huge and costly constructions such as dams, reservoirs, treatment works and network of distribution pipelines. These all works cannot be replaced easily or capacities increased conveniently for future expansions.

While designing and constructing these works, they should have sufficient capacity to meet future demand of the town for number of years. The number of years for which the designs of the water works have been done is known as design period. Mostly water works are designed for design period of 22-30 years, which is fairly good period (Venkateswara, 2005).

3 METHODOLOGIES AND MATERIALS

3.1 Description of the study area

Bichena is found in the Amhara National Regional State. It is presently the capital city of Enemay Administrative District and is located 265 km North of Addis Ababa, the capital city of Ethiopia and 105 km road distance from Debre-Markos, the Capital city of East Gojjam Zone. It is located on the plane area adjacent to the Abay gorge. Bichena Town is locally categorized as woyna-Dega in climatic nature with uni-modal rainy season and mean annual rain fall of 785 mm. The minimum annual temperature is 15.6 ^{o}c and the maximum is 19.4^{o}c averaging to 17.0 ^{o}c. The average terrain elevation of the town is around 2540 masl. Map of the study indicated in Figure 3.1.

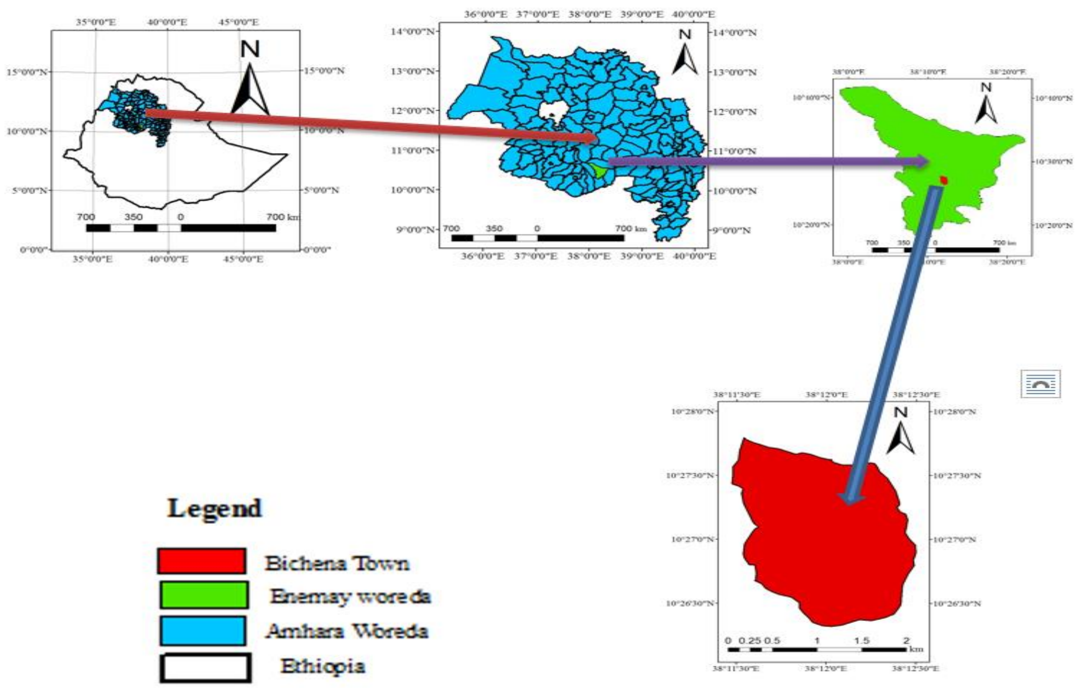

Figure 3.1 Map of the study area

3.2 Materials

For implementation of the research the following equipment's and materials were used for data collection, processing and evaluation.

WaterGemsv8i software to determine velocity and nodal pressure, Arc GIS 9.3 for delineation of the study area, GPS Garmin 72 to check coordinates of points of junction nodes reservoir and sources of town water supply, excel, endnote, calculator, and AutoCAD 2007 were used.

3.2.1 WaterGEMSv8i

WaterGemsv8i (2014) is a versatile hydraulic modeling software package with the advancements in the interoperability, optimization of networks; model building supported with geospatial tools and advantage management tools. Water Gemsv8i is highly efficient and dynamic modeling software which provides the wide regime of analysis and solutions for fire-flow analysis, water quality modeling, energy and capital cost management, etc. Many of the features and functions are common in WaterCADv8*i* and WaterGemsv8i which are streamlined model building, integration with the GIS and AutoCAD functionalities, optimized model calibration, design and its operations. The best part in the WaterGemsv8i is the presentation of obtained results which is very attractive and appealing and can be presented with variety of graphical tools include arc map visualization, thematic mapping, contouring, profiling with color coding and symbology. With the ever increasing number of users WaterGemsv8i has proved one of the most popular and user friendly hydraulic modeling and optimization software package. WaterGemsv8i has strong design algorithm to meet the criteria of accuracy in design of water distribution networks, control of distribution network variables like flow, pressure and velocity along with their optimization (Sonaje, 2015). The major difference betweenWaterGemsv8i andWaterCADv8i is the former allows for integration with ArcGIS. However, WaterCADv8i cannot integrate with ArcGIS. WaterGemsv8i has its own processes the step of Water GemsV8i analysis was showed in Figure 3.2.

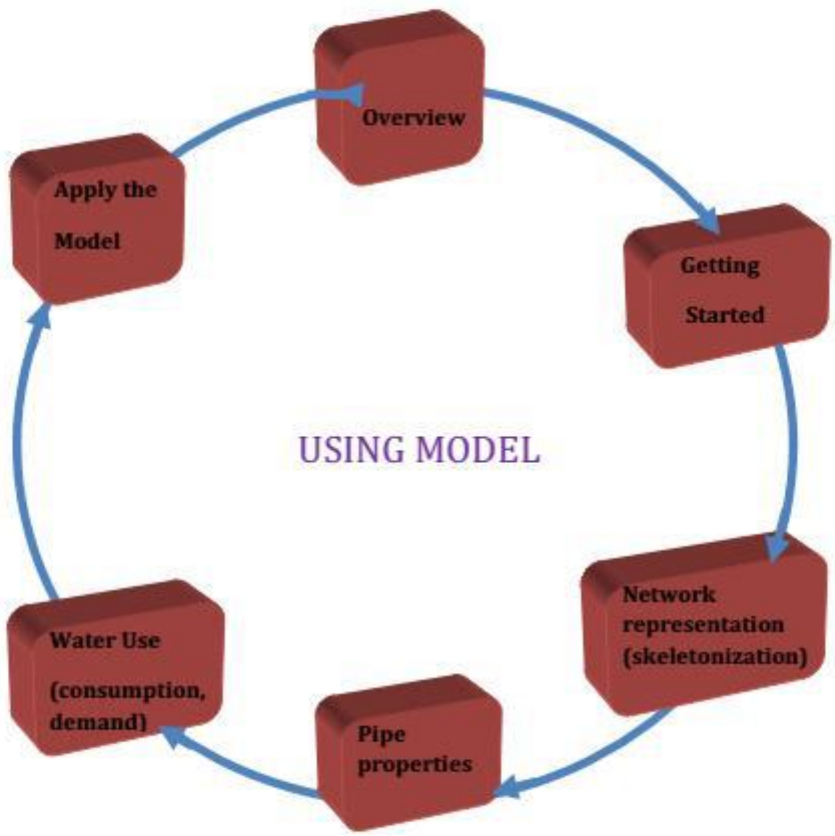

Figure 3.2 Diagrammatical representation modeling process

Source (WaterCAD/GEMs, 2008).

3.3 Source of Data

3.3.1 System Maps

System maps are typically the most useful documents for gaining an overall understanding of a water distribution system because they illustrate a wide variety of valuable system characteristics.

System maps include information such as Pipe alignment, connectivity, material, diameter, the locations of other system components, such as tanks and valves, Pressure zone boundaries, elevations, miscellaneous notes or references for tank characteristics, background information, such as the locations of pipe lines.

3.4 Study variables

The variables needed from WaterGemsv8i include information about the pipes and junctions consisting of either independent or dependent variables.

Independent variables Static variables remain constant during the entire analysis. Static variables necessary for analysis include diameter of pipe length, diameter, and C-factor.

Dependent variables may change during each time step. Dependent variables necessary for analysis are the start and stop node for each pipe, pipe flow, junction demand, outflow, and inflow.

3.5 Study parameter

The hydraulic parameters were nodal pressure and velocity. The type of supply (continuous or intermittent), water pressure, total non-revenue water, per capita supply and extent of metering could be considered as performance indicators for water supply systems. Overall, system performance is function of many parameters some of which are independent (such as physical and chemical characteristics of the water), and some which are closely linked such as pressure levels and flow rates.

3.6 Data collection and evaluation

In order to realize the research two major data gathering techniques were used. These data collection methods are described below.

A) Primary data

Actual field investigation and measurements or survey works including simple observations of town water supply at the sites were used for required data collection in order to know the present condition of the water supply. Data from field survey such as UTM locations were checked by using geographical positioning system (GPS) coordinates.

B) Secondary data

Secondary data were collected from the responsible organization like AWWCE, ANRS-WRDB and Woreda WSSE. Bile data were collected from Water Supply Sewerage Enterprise and aggregated fore different years. Geographical positioning system coordinates were collected from AWWCE. The network layout was first extracted from AutoCAD 2007 drawing and then imported to WaterGemsv8i by modelbulder. The town master plan was taken from town administration office. Water demand for each node was determined by using master plan and counting of each house and multiplying by member of household.

The town water supply data such as pipe length, diameter, material types, reservoir and tank section were collected from the town water supply and sewerage enterprise design document.

3.6 Methods of analysis

The data which were used for the analyses were collected from the past quarter, monthly and annual reports and files kept by responsible organizations for further interpretation and analyses. The data were analyzed by using excel and other software's. The important data for the study includes GPS reading of the tanker, source of water supply, junctions, and reservoir.

The method of analysis was based on nodal pressure and velocity parameters. The standard values of nodal pressure and velocity was identified. The values which were under normal values were taken as sustainable and below and above standard values were taken as unsustainable. In order to determine the sustainability index (SI) for the water supply, reliability, resiliency, and vulnerability performance indicators were calculated. Then overall sustainability was computed to understand water supply sustainability.

3.6.1 Population forecasting

Accurate estimation of water users by particular society is rarely achievable, since water use is practically liable to change. There are different populations forecasting methods .But the result is different from one method to another method. The preference of the method appropriate for particular town needs to consider overall current situations of the targeted town.

For fast growing city, where relatively high economic activity is observed and at the same time continuous expansion of city due to various reasons is experienced, exponential method population forecasting is preferably used. Exponential population forecasting method is expressed as follows;

$$P_n = p_o e^{rn} \quad \text{……………………………………………….3.1}$$

Where, Pn= population at year n;Po= base year population;e = constant e, the base of natural logarithm;r = population growth rate;n =projection year.

According to the information from the town's Municipal Administration, the population of the town in Year 2014 was 28,376 which was projected based on CSA report of 2007.The base year for population projection of Bichena Town was 2014 and population projection was done from 2015 up to 2035.The population projection years was based on design year of water supply distribution system. The growth rate of the study area was taken from annual growth rate of Amhara Towns.

3.6.2 Average daily per capital consumption

The volume of water consumed for different uses has been developed to the town .The annual consumption data has been derived to average daily per capita consumption using the number of population. The average daily per capita consumption of town was derived using the number of population through the following formula.

$$\text{Capital consumption (l/c/d)} = \frac{\text{annual consumption(m3)} * 1000\text{l/m3}}{\text{Population number of Town} * 365} \quad \ldots\ldots\ldots\ldots\ldots\ldots 3.2$$

3.7 Sustainability assessment methods

Sustainability assessment methods are tools for appraising the progress towards a sustainable future. A variety of methods has been used for sustainability assessment of urban water supply systems. Among these methods Statistical, environmental, technical, economic and integrating all are some of them. For this research technical method was used. Sustainability could be assed using sustainability indicators.

3.7.1 Performance assessment

Performance assessment represents a real challenge whose purpose is to guarantee the sustainability of any type of organization, especially in the context of mutation characterized by natural resources depletion, funding cuts and global change (Nafi, 2015).

Performance assessment is currently a well-established practice in the water sector water supply and wastewater collection. Performance indicators are used to assess the performance of the whole service, covering all its sectors of activity (Quadros *et al.*, 2010). Technical performance assessment tools are related to specific aspects of the system (e.g. hydraulic behavior). The technical sustainability of a water distribution system is measured using the sustainability index methodology which is based on the reliability, resiliency and vulnerability performance criteria.

The performance assessment is the key towards sustainability, where performance assessment can be defined as “any approach that allows for the evaluation of the efficiency or the effectiveness of a process or activity through the production of performance measure (Alegre and Coelho, 2012).

3.7.2 Sustainability indicators

The sustainability indices could be done based on performance indicators including reliability, resiliency and vulnerability. Some literature investigated the relationship between urban form and the performance of a water distribution system.

Performance measurement can be defined as the process of quantifying the effectiveness and efficiency of actions. It aims at helping decision makers to build strategies by monitoring performance trends and the effectiveness of past or potential actions.

According to Lundin (2003) Indicators are pieces of information, which summarize important properties, visualize phenomena of interest, quantify trends and communicate them to relevant target groups. They are useful tools in decision making when additionally.

a) Provide information for spatial comparison,

b) Provide early warning information and,

c) Anticipate future conditions and trends.

3.7.2.1 Sustainability Index Calculation

Recently, water resources sustainability has been measured using reliability, resiliency and vulnerability performance indicators. Numerous investigators have applied these performance indices differently in the literature. Tabesh and Saber (2012) proposed a model using hydraulic (i.e. pressure index, pressure performance index, velocity performance index and reliability index), physical, and empirical indices for rehabilitation of water distribution networks. A sustainability index (SI) is a term that indicates the performance of a water system with respect to predetermined thresholds of a satisfactory state (Loucks, 1997).

Mathematically the satisfactory and unsatisfactory states for velocity and nodal pressures scored 1 for satisfactory and 0 for unsatisfactory conditions.

$$P_{j;t} = \begin{cases} \text{unsatisfactory (o)} & (P_{j;t} < P_{min} \vee p_{j;t} > P_{max} \\ \text{Satisfactory (1)} & P_{j;t} \geq P_{min} \wedge P_{j;t} \leq P_{max} \end{cases}$$

Where Pj, t is the pressure at node j in at time t; Pmin is the minimum pressure; and P max is the maximum pressure.

For velocity the same formula was used by substituting velocity in pressure in the formula.

Vulnerability (VUL) is the magnitude or duration of an unacceptable state of WDS in a certain time scale. Kay (2000) stated that the vulnerability could be measured by dividing the cumulative extent of unsatisfactory values to the sum of all values in the simulation period. This evaluation method is also used by Huizar . *et al.*,(2011) in order to create a decision support system for water supply sustainability. In this study, vulnerability is defined as

$$VUL_k = \frac{\sum \text{unsatisfactory values}}{\sum \text{all values}} \quad \ldots\ldots 3.3$$

Where k refers to pressure or velocity

The SI is a weighted combination of reliability, resiliency, and vulnerability which may change over time and space (Loucks,1997). The following definitions of reliability, resiliency, and vulnerability follow the work of (Hashimoto *et al.*, 1982). Reliability (REL) is the probability that the WDS is in a satisfactory state defined as

$$REL_k = \frac{\text{times satisfactory occurs}}{\text{total of time steps}} \quad \ldots\ldots 3.4$$

Where k refers to pressure or velocity

Resiliency (RES) represents how fast the system recovers from a failure defined as

$$RES_k = \frac{\textbf{times of satisfactory follows unsatisfactory}}{\textbf{total of times unsatisfactory occurs}} \quad \ldots\ldots 3.5$$

Where k refers to pressure or velocity

Sustainability index then can be calculated by the following formula

$$SI = [REL*RES*(1-VUL)]^{1/3} \quad \ldots\ldots 3.6$$

The main feature of the SI is that it ranges from 0 (the lowest degree of sustainability) to 1 (highest degree of sustainability). Another property is that if any one of the performance criteria is zero then the overall SI will be zero.

Table 3.1 Sustainability range based on sustainability index (Aydin, 2014)

SI ranges	State
0-0.25	Unacceptable
0.25-0.5	Medium but unacceptable
0.5-0.75	Acceptable
0.75-1	Ideal

3.8 Skeletonization

Skeletonization is the process of selecting for inclusion in the model only the parts of the hydraulic network that have a significant impact on the behavior of the system. Attempting to include each individual service connection, gate valve, and every other component of a large system in a model could be a huge undertaking without a significant impact on the model results. Capturing every feature of a system would also result in tremendous amounts of data, enough to make managing, using, and troubleshooting the model an overwhelming and error-prone task. Skeletonization is a more practical approach to modeling that allows the modeler to produce reliable, accurate results without investing unnecessary time and money.

Skeletonization should not be confused with the omission of data. The portions of the system that are not modeled during the skeletonization process are not discarded; rather, their effects are accounted for within parts of the system that are included in the model (AWWA, 2012).

Skeletonization guidelines: There are no absolute criteria for determining whether a pipe should be included in the model, but it is safe to say that all models are most likely skeletonized to some degree. Water distribution networks vary drastically from one system to another, and modeling judgment plays a large role in the creation of a solution. For a small diameter system, such as household plumbing or a fire sprinkler system, small differences in estimated flow rate may have perceptible effects on the system head losses. For a large city system, however, the effects of water demanded by an entire subdivision may be insignificant for the large-transmission main system.

After the network imported in to Water Gems V8i software the pipes below 66 mm diameter were skeletonized by using Skelebrator. This was done to reduce network complexity and to save time and resource.

3.9 Water distribution system simulation

The term simulation generally refers to the process of imitating the behavior of one system through the functions of another. In this cause the term simulation refers to the process of using a mathematical representation of the real system, called a model.

Network simulations, which replicate the dynamics of an existing or proposed system, are commonly performed when it is not practical for the real system to be directly subjected to experimentation or for the purpose of evaluating a system before it is actually built (WaterCAD/GEMs, 2008).

3.9.1 Types of simulations

After the basic elements and the network topology are defined, further refinement of the model can be done depending on its intended purpose. There are various types of simulations that a model may perform, depending on what the modeler is trying to observe or predict. The two most basic types are

1 **Steady-state simulation:** Computes the state of the system (flows, pressures, pump operating attributes, valve position, and so on) assuming that hydraulic demands and boundary conditions do not change with respect to time. It is important to know pressure and flow.

2 Extended-period simulations (EPS): Determines the quasi-dynamic behavior of a system over a period of time, computing the state of the system as a series of steady-state simulations in which hydraulic demands and boundary conditions do change with respect to time. This is important to water quality parameters.

3.9.1.1 Steady-State Simulation

As the term implies, steady-state refers to a state of a system that is unchanging in time, essentially the long-term behavior of a system that has achieved equilibrium. Tank and reservoir levels, hydraulic demands, and pump and valve operation remain constant and define the boundary conditions of the simulation.

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

Real water distribution systems are seldom in a true steady state. Therefore, the notion of a steady state is a mathematical construct. Demands and tank water levels are continuously changing and pumps are routinely cycling on and off. A steady-state hydraulic model is more like a blurred photograph of a moving object than a sharp photo of a still one. However, by enabling designers to predict the response to a unique set of hydraulic conditions (for example, peak hour demands or a fire at a particular node), the mathematical construct of a steady state can be a very useful tool.

Steady-state simulations are the building blocks for other types of simulations. Once the steady-state concept is mastered, it is easier to understand more advanced topics such as extended-period simulation, water quality analysis, and fire protection.

Steady-state models are generally used to analyze specific worst-case conditions such as peak demand times, fire protection usage, and system component failures in which the effects of time are not particularly significant. Figure 3.3 express WaterGemsv8i steady state procedure.

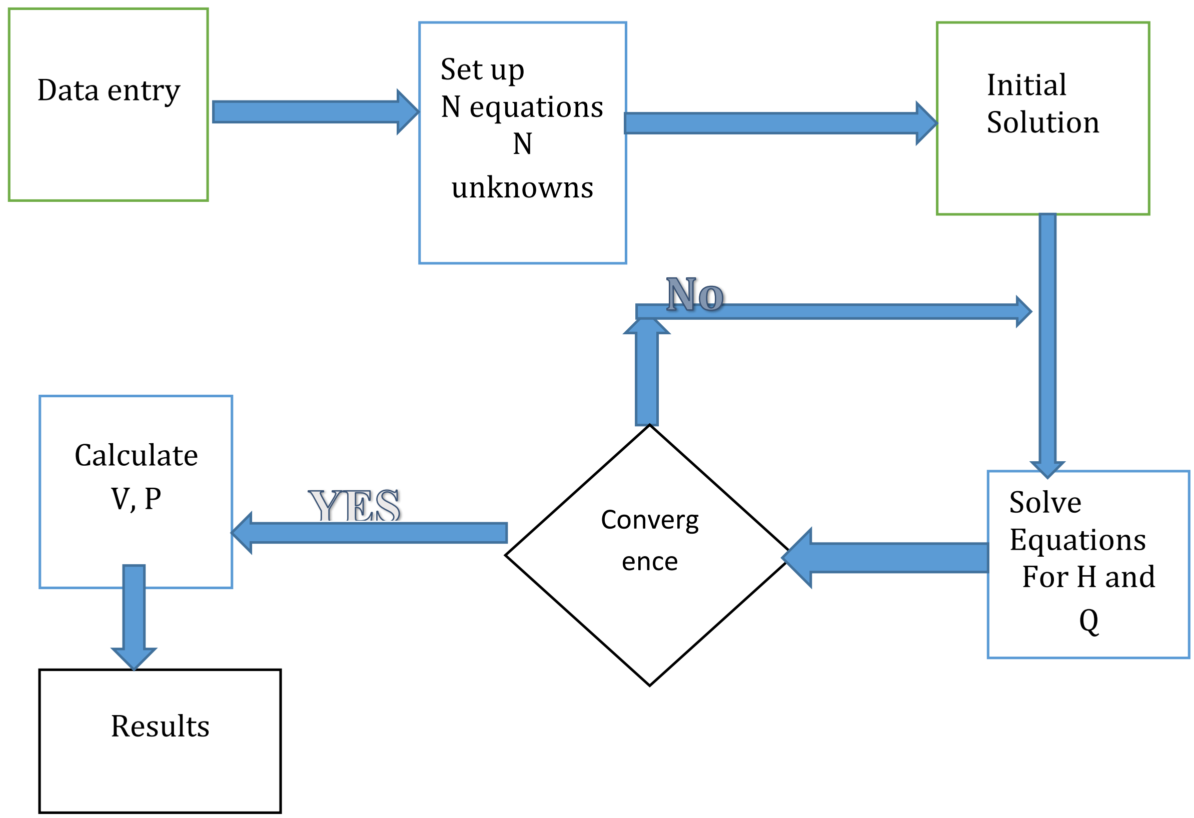

Figure 3.3 Flow chart for steady state simulation

Source (WaterCAD/GEMs, 2008)

3.9.1.2Extended-Period Simulation

The results provided by a steady-state analysis can be extremely useful for a wide range of applications in hydraulic modeling. There are many cases, however, for which assumptions of a steady-state simulation are not valid, or a simulation is required that allows the system to change over time. For example, to understand the effects of changing water usage over time, fill and drain cycles of tanks, or the response of pumps and valves to system changes EPS is needed. It is important to note that there are many inputs required for an extended-period simulation. Due to the volume of data and the number of possible actions that a modeler can take during calibration, analysis, and design, it is highly recommended that a model be examined under steady-state situations prior to working with extended period simulations. Once satisfactory steady-state performance is achieved, it is much easier to proceed into EPS.

EPS Calculation Process: Similar to the way a film projector flashes a series of still images in sequence to create a moving picture, the hydraulic time steps of an extended-period simulation are actually steady-state simulations that are strung together in sequence. After each steady-state step, the system boundary conditions are reevaluated and updated to reflect changes in junction demands, tank levels, pump operations, and so on. Then, another hydraulic time step is taken, and the process continues until the end of the simulation. ESP steps described in Figure 3.4.

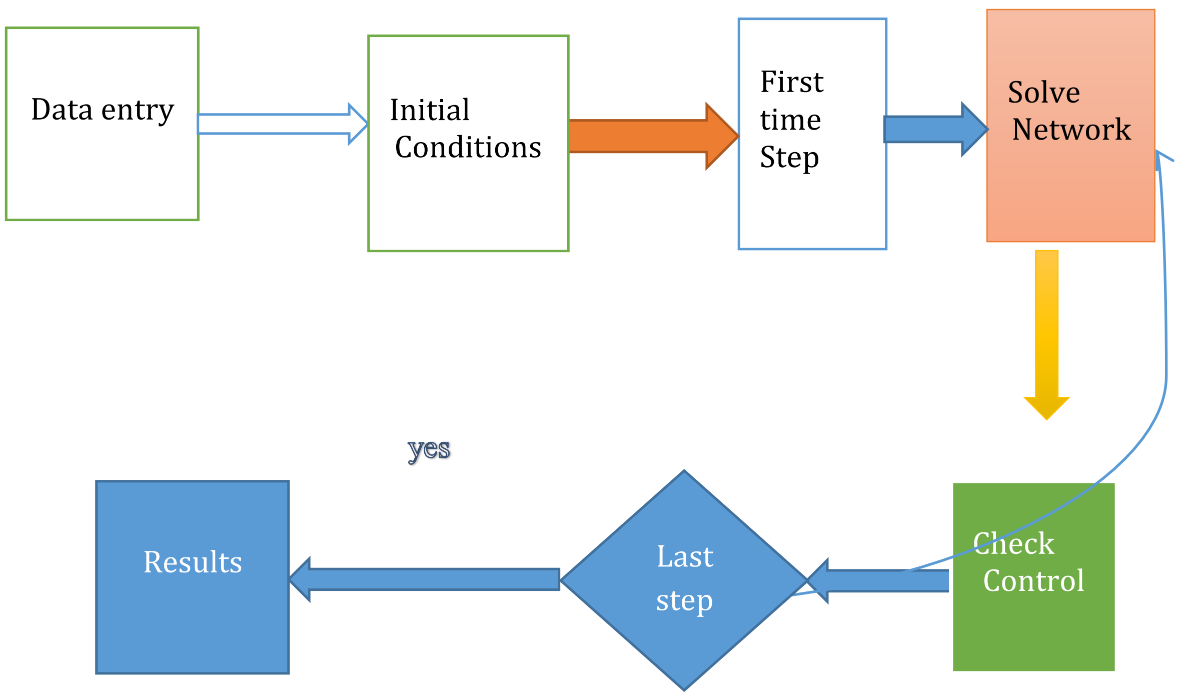

Figure 3.4 Flow chart for extended period simulation

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

When modeling emergencies or disruptions that occur over the short-term, however, it may be desirable to model only a few hours into the future to predict immediate changes in tank level and system pressures. For water quality applications, it may be more appropriate to model duration of several days in order for quality levels to stabilize.

Even with established daily patterns, a modeler may want to look at simulation duration of a week or more. For example, consider a storage tank with inadequate capacity operating within a system. The water level in the tank may be only slightly less at the end of each day than it was at the end of the previous day, which may go unnoticed when reviewing model results. If a duration of one or two weeks is used, the trend of the tank level dropping more and more each day will be more evident.

First the Steady-State Simulation was done and extended period simulation was simulated next in order to achieve complete simulation.

3.10 System design criteria

The computer model predicts the performance of the distribution system under various demand conditions. To identify the deficiencies, the model-predicted performance is compared to the established design and operational standards. Inadequate system pressures generally indicate deficiencies in a system. These deficiencies are caused by any of the model components including piping, pumping, and storage or caused by inaccuracies in the assumed system operating conditions (AWWA, 2012).

3.10.1 Pressure design Criteria analysis

When assessing the adequacy of a system, the first parameter to check is the predicted pressure. There are generally three design pressures that are defined for each community: maximum pressure, minimum pressure during peak hour, and minimum pressure during a fire flow. The range of pressure fluctuations at a single point experienced over a 24-hour period should also be kept to less than 20 or 30 psi (138 or 207 kPa). The maximum pressure refers to the maximum pressure that customer’s experience.

It is often in the range of 90–110 psi (620–759 kPa).The minimum pressure during peak hour refers to minimum pressure at customers' taps during normal system operation. This value is typically in the range of 35–50 psi (241–345 kPa) and ensures that there is adequate pressure to the second story fixtures within a property if internal plumbing is configured correctly (AWWA, 2012).

Ethiopian guideline criteria for the minimum and maximum operating pressure value in the distribution network were 15m to 70m respectively (MOWE, 2006). Maximum pressure limitations are required to reduce the additional cost of the pipe, strengthening necessary due to the high pressure.

According to urban water design criteria (MOWE, 2006) the operating pressures in the distribution network shall be as follows:

Table 3.2 Pressure range (MOWR, 2006)

Range	Normal Conditions	Exceptional Conditions
Minimum	15 m water head	10 m water head
Maximum	60 m water head	70 m water head

4 RESULTS AND DISCUSSION

4.1Water source of Bichena Town

The source of water supply was ground water which was preferable source than surface water in terms of quality because ground water is free from surface pollutions and uncontaminated than surface. Ground water is only affected by chemical pollution. The problems in ground water investigation are the zones of occurrence and recharge. But Bichena Town is situated in the western plateau, an area which the hydro geological map of Ethiopia classifies as "Highland". It is an area where there is wide spread moderate to large quantities of ground water of good chemical quality (TDS 0-1500ppm). The drilling result from existing borehole reported yield show that the aquifer zones are fractures and weathered zones between different flow layers and flow porosity which is typical of basaltic lava flows.

Aquifers in escarpment areas and highlands host low fluoride water. Degradation of the recharge areas affect the infiltration of water into the ground thereby decreases the amount of water in the source. Degradation also favors high runoff and then flooding which can have a damaging effect on physical structures at the water source.

4.2 Population projection

In order to forecast the population for the study area based on last population and housing census report exponential population projection method was used. Bichena Town population for 2015 was 29623 and for 2035 it was estimated to be 61716 as presented in the Table 4.1.

Table 4.1 Population projection of Bichena Town

Year	2014	2015	2020	2025	2030	2035
Annual growth rate (%)	Base population	4.30	4.10	4.00	3.80	3.7
Population urban	28376	29623	36290	44060	52120	61716

4.3 Water demand analyses

In the study area water demand is rapidly increasing due to urbanization effect and population increase. Additionally the area is fast growing town and the population of the town is increase from year to year. The amount of water supplied to the system was lower than the required due to rapid population growth and urbanization effect. That means demand exceeds available production capacity. According to the design period from 2015 up to 2025 is stage one and from 2026 up to 2035 stage two. Based on the Gide Line of Ethiopian MOWR per capita demand of the study area was calculated as the base by mode of service indicated in the Table 4.2.

Table 4.2 Projected per capita demand by mode of service (2015-2035)

Mode of Service	2015	2020	2025	2030	2035
HC	50	50	50	70	70
YCO	30	30	30	40	40
YCS	25	25	25	30	30
PT	20	20	20	25	25

By using Table 4.2 as the base of other water demand calculation the water demand was projected from 2014-2035 by including non-revenue water. As shown in Table 4.3 total domestic water demand was forecasted by each mode of service throughout design period. The total domestic water supply demand for 2015 year was 749 m^3/d.

Table 4.3 Population and domestic demand water projection

Description	Unit	2014	2015	2020	2025	2030	2035	Remark
Growth rate	%		4.30%	4.10	4.00	3.8	3.19	
Population	no	28,376	29,623	36290	44060	52120	61716	
HC	%	0.57	0.57	2.93	6.46	9.12	10.00	
YCO	%	43.96	43.96	50.47	60.24	67.56	70	
YSC	%	14.63	14.63	13.47	11.74	10.43	10	
PT	%	40.84	40.84	33.13	21.56	12.89	10	
Population served by								
HC	no	162	169	1063	2846	4753	6172	
YCO	no	12,474	13,022	18316	26542	35212	43201	
YSC	no	4151	4334	4888	5173	5437	6172	
PT	no	11589	12098	12023	9499	6718	6172	
Per capita demand								
HC	l/c/d		50	50	50	70	70	
YCO	l/c/d		30	30	30	40	40	
YSC	l/c/d		25	25	25	30	30	
PT	l/c/d		20	20	20	25	25	
Total domestic demand	m^3/d		749	965	1258	2072	3024	

4.3.1 Socio economic and climatic adjustment

Bichena town is classified as a town of "high potential growing towns under normal Ethiopian conditions" and is therefore, categorised as a medium town and was given an adjustment factor of 1.05 for climatic adjustment factors. As well as it is found in an altitude on range 2300-3300 masl thus, an adjustment factor of 0.90 was taken.

Based upon these adjustment factors domestic water demand was 708 $m^{3/}$d for the year 2015 and 2858 $m^{3/}$d for 2035.the whole adjusted domestic water demand presented in Table 4.4.

Table 4.4 Socio-economic and climatic adjusted demand (2015-2035)

Year	Unit	2015		2020	2025	2030	2035
Climate Adjustment Factor	-	0.9		0.9	0.9	0.9	0.9
Socio-Economic adjustment Factor	-	1.05		1.05	1.05	1.05	1.05
Total domestic demand	m^3/d	749		965	1258	2072	3024
Adjusted total domestic demand	$m^{3/}$d	708		912	1189	1958	2858
	l/s	8.19		10.56	13.76	22.66	33.07

After the domestic water demand was projected none revenue water, public and commercial demand and industrial water demand were computed in order to identify total water demand of the study area. At present there are no industries in Bichena town. The development plan of the town has allocated areas for industrial (manufacturing) development but it is not known when these will occur. The water demand for small scale cottage industries like edible oil production and other workshops were considered 5% of the domestic water demand. For Bichena Town water supply for public and commercial water demand 10% was taken. The current borehole supply only 596.16 m^3 /day but the demand was 957 m^3/day for 2015. This indicates that there was shortage of water in the town. Bichena town water supply demand exceeds supply in the water distribution system. Table 4.5 show total water demand of the study area in the design period.

Table 4.5 Total water demand of Bichena Town (2015-2035)

Demand	Unit	2015	2020	2025	2030	2035
Domestic demand	m^3/d	708	912	1189	1958	2858
Public and Commercial	m^3/d	71	91	119	196	286
Industrial demand	m^3/d	36	46	60	98	143
Un-Accounted for water	m^3/d	142	137	179	353	572
Total Bichena demand	m^3/d	957	1186	1547	2605	3859

For the research peak hour factor is 1.9 because of population range of the study area is 20001-50000.The peak hour demand and maximum day demand was projected based up on peak factor of the town. On this particular research the maximum day demand factor of about 1.15 was adopted because maximum day demand should be at range of 1-1.3. The maximum day demand of 2015 was 1101 m^3/d and peak hour demand 1818 m^3/d.

Table 4.6 Adjusted demand of the town

Description	2015	2020	2025	2030	2035
Total demand (m^3/d)	957	1186	1547	2605	3859
Peak hour demand factor	1.9	1.9	1.9	1.9	1.9
Peak hour demand(m^3/d)	1818	2253	2939	4950	7332
Maximum day demand factor	1.15	1.15	1.15	1.15	1.15
Maximum day demand demand(m^3/d)	1101	1364	1779	2996	4438

4.4 Average daily per capita consumption

For the year 2015 per capita consumption was 13.3 l/p/d .But World Health Organization minimum quantity standard which sated as 20 l/c/d with in 0.5km radius. The per capita also lower than Ethiopian GTP-2 plan per capita which is 50 l/c/d given to the study area.

The average per capita consumption was very low while compared with the country standard used for design purpose 50 l/c/d as per GTP-2 goal. According to Melaku Abebaw (2015) Debre-Markos Town for the year 2014 was 23.79 l/c/d. Even though this was below the required level, Bichena Town per capita was under Debre-Markos town. This show that how much Bichena town per capita was underneath value. A household needs a minimum of 150 l/ day and for good sanitation up to 600 l/ day (UN-HABITAT, 2003). Obviously domestic consumptions in cities differ mainly due to climate, standard of living, household size, etc. But from this study it can be concluded that the per capita water usages of the study areas was rather very low and needs to be improved.

4.5 System design criteria

Design criteria define system capabilities by specifying the performance requirements of the system components. Thus, whether the objective of the analysis is the design of a new system or improvements to an existing system, the design criteria define the potential solutions and are the standard against which system performance, both observed and predicted, is compared to determine sufficiency of service.

Bichena town water supply entails the total of 10.3 km pipe. This is not all water supply network because the water supply network skeletonized below 66 mm in the study layout. Majority of pipes were HDPE which covers 10 km from the total of pipe length. Each diameter and type of material length coverage indicated in the table 4.8 below.

Table 4.7 Pressure pipes inventory

Diameter (mm)	Length (HDPE) (m)	Length (Ductile Iron) (m)	Length (All Materials) (m)	Volume (ML)
79.2	5,542	0	5,542	0.03
96.2	22	0	22	0.00
96.8	2,362	0	2,362	0.02
141.0	1,978	0	1,978	0.03
200.0	54	0	54	0.00
250.0	155	0	155	0.01
350.0	0	155	155	0.01
450.0	0	63	63	0.01
All Diameters	10,114	219	10,333	0.11

4.5.1 Pressure design Criteria analysis

Most pressure of water supply distribution system was under Ethiopian standard ranges 15 m of water head up to 70 m of water head.

From the study area result, water supply distribution system pressure was extending from 12 m of water to 44 m of water. According to this study, pressure ranges full fill the criteria of Ethiopian urban water supply design guideline criteria maximum and minimum requirements. Pressure was increase as elevation decrease and vice versa. According to the study results high pressure was found in low elevation areas. As indicated in the Figure 4.1 pressure and elevation has indirectly relationship by taking sample from the water supply junctions.

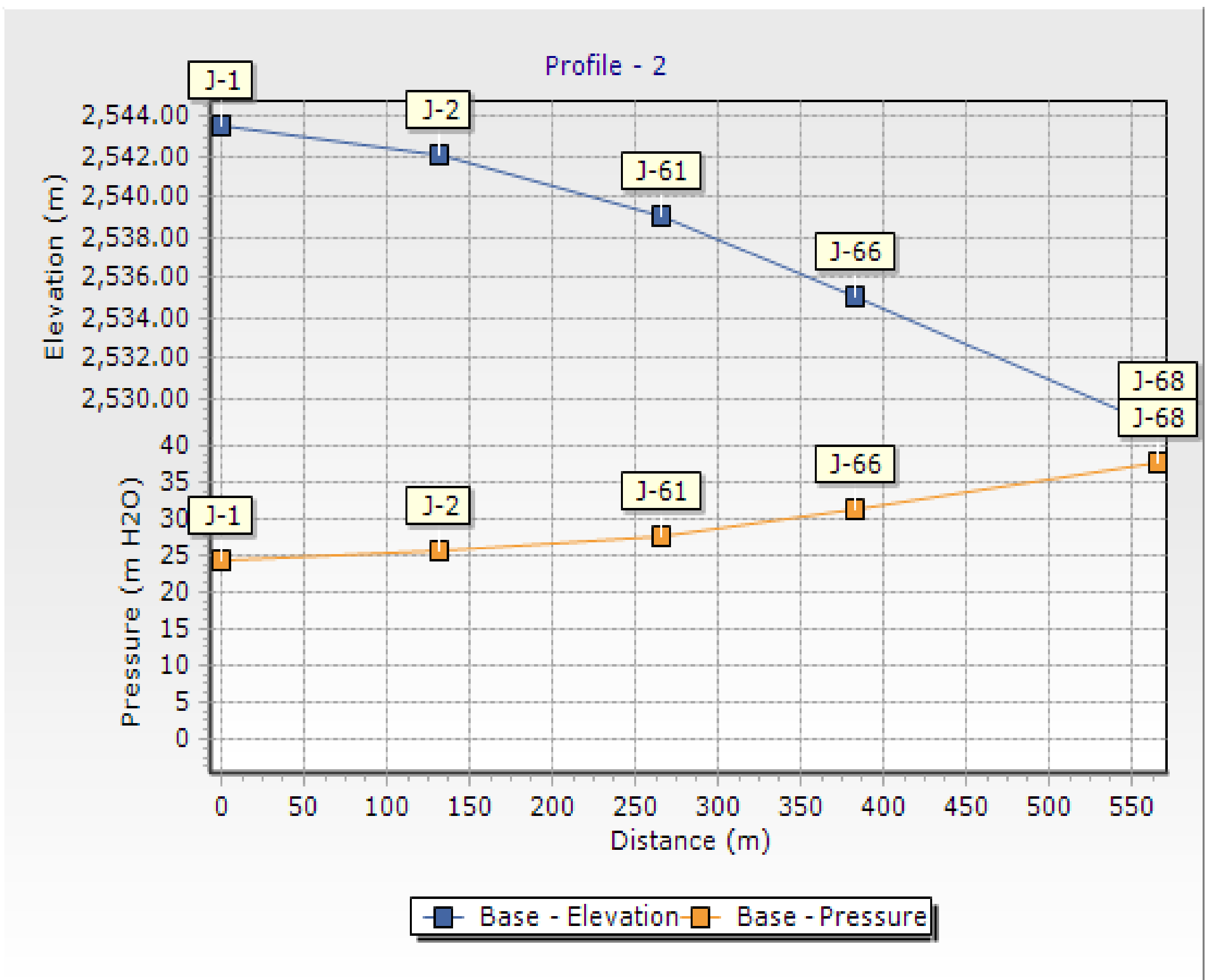

Figure 4.1The relationship of pressure with elevation

Figure 4.2 show rough connection of pressure and elevation however, Figure 4.3 explain each area of water supply elevation. Figure 4.3 was used to compare pressure with elevation which was indicated in Figure 4.3. Pressure and elevation were explained by couture of pressure and elevation. As indicated in the couture map in Figure 4.2 from right to left the amount of pressure decrease. This decrease indicate that the elevation of the ground increases from right to left. The contour of the elevation was shown in the Figure 4.3.

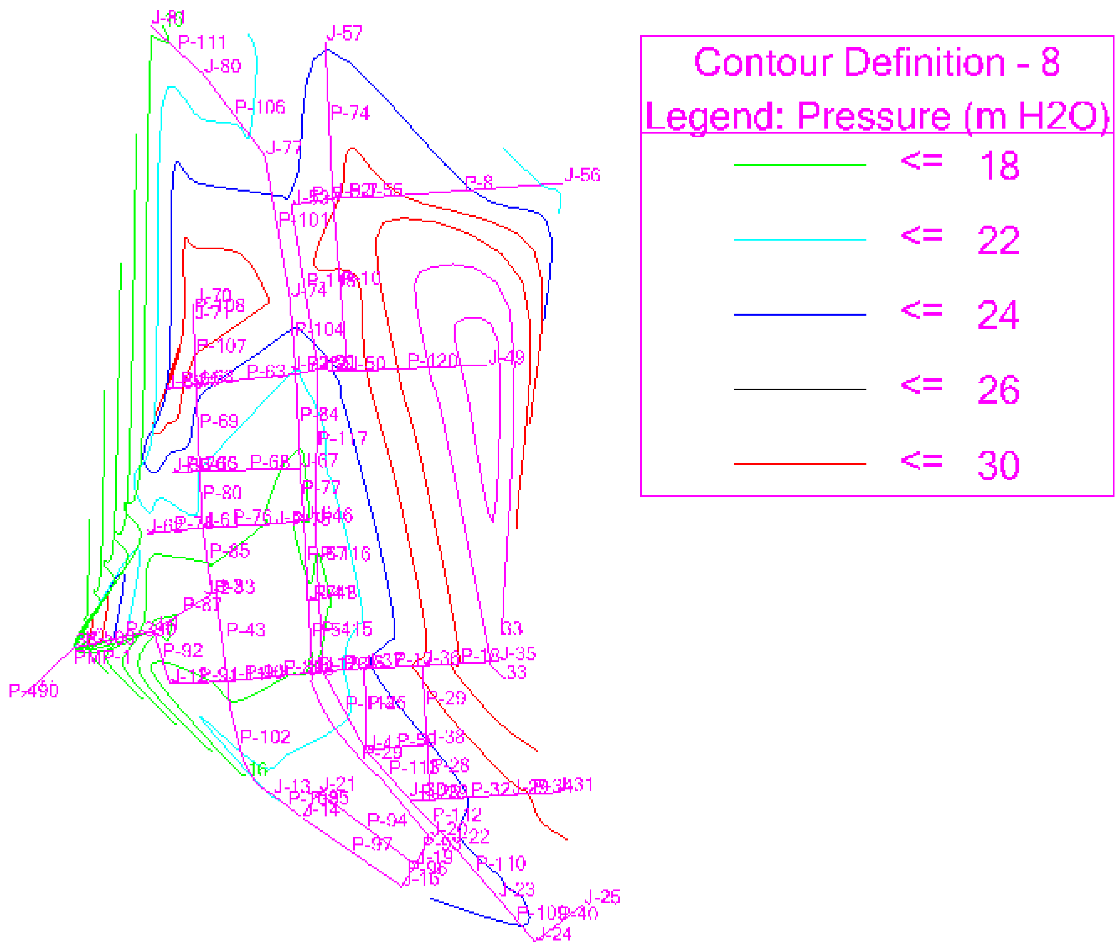

Figure 4.2 Couture of pressure for Bichena Town water supply

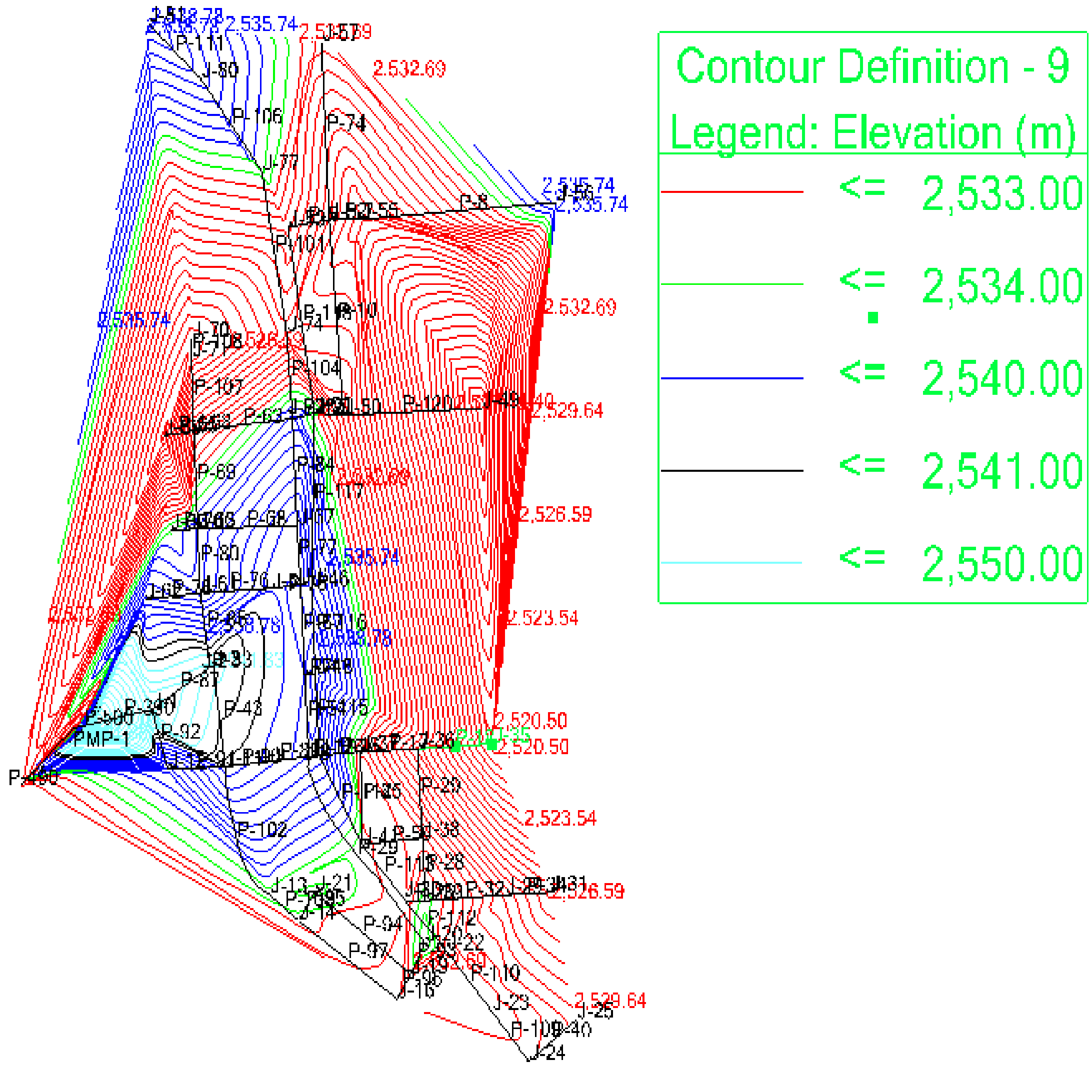

Figure 4.3 Elevation profile of Bichena Town

Figure 4.4 show pressure for each junction by color coding analysis .Based on the figure shown most pressure values were lower than 30 m of water and greater than 10 m of water. However the detail description pressure value of each junction listed in the appendix A.

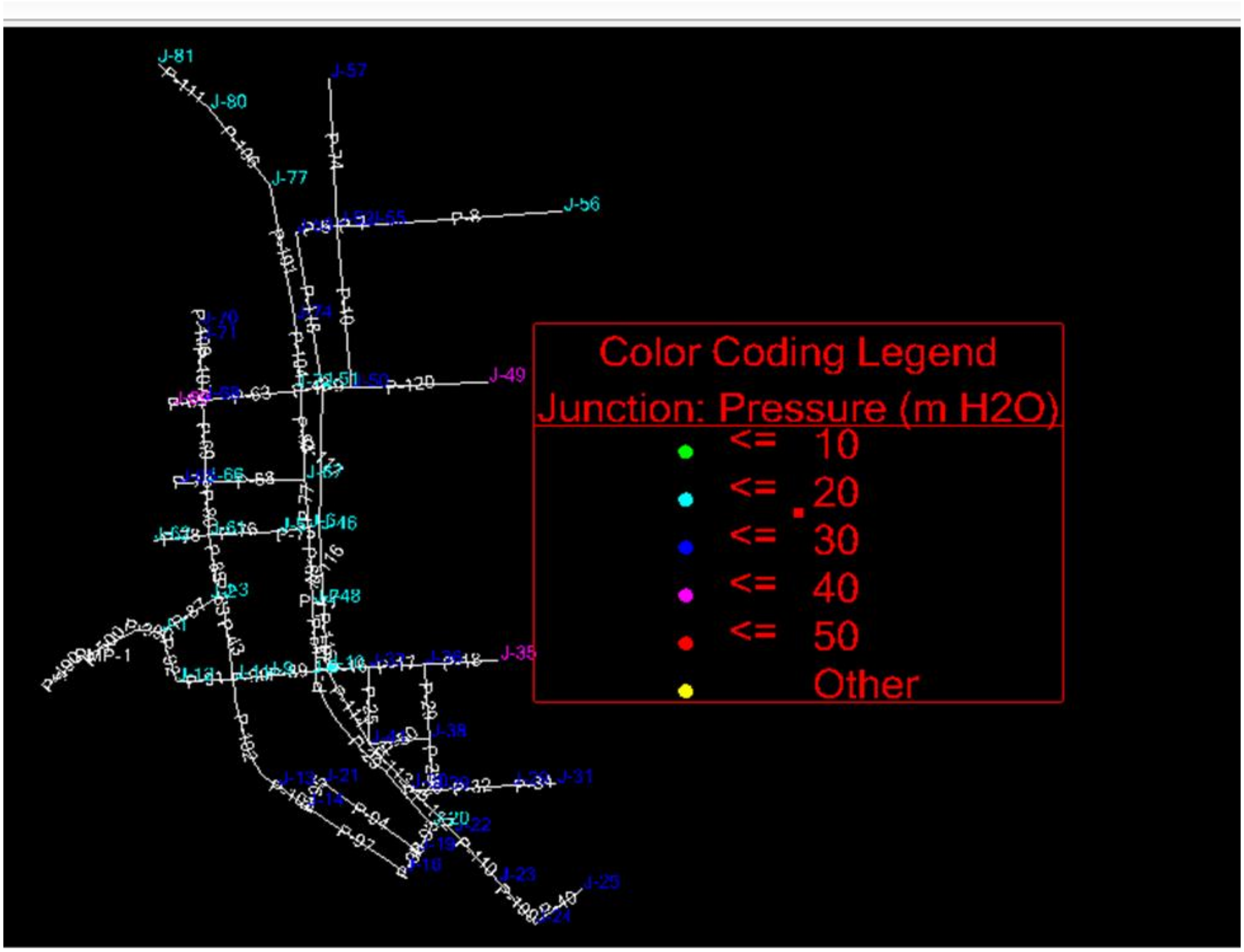

Figure 4.4 Pressure profile of Bichena Town water supply

4.4.2 Velocity design Criteria analysis

For the study area 96 % of velocity is not in the suitable range based on Ethiopian urban water supply design guideline criteria. Velocity lower than 0.6 m/s solid materials settled and have an effect on water quality. But velocity greater than 2 m/s could erode the pipe. In this study water quality effect is great but no erodible effect. Velocity out of the normal value has its own effect on water supply distribution system. Minimum velocity is a cause to water stagnation causing sedimentation and bacteriological growth in the conduits on the other hand maximum velocity increase head losses as well as water hammer. Water hammer was minimal. Bichena town water supply distribution system has an indicator of water quality problem because 96 % of pipes in the distribution system have velocity that causes to water quality problem because bacterial growth and sedimentations happen in low velocity pipe water supply systems. The detail of velocity result was shown in the appendix. Table 4.10 show summary of the all velocity in to for velocity categories to give analysis based on the effect of range. From pipe layout 65% of pipes has very low and sedimentation effect on water supply system.

Table 4.8 Velocity for water supply distribution system

Velocity(m/s)	Number	Percentage	Effect
0-0.1	44	65	Very low and sedimentation happen
0.1-0.6	21	31	Sedimentation happen
0.6-2	3	4	Acceptable level
>2	0	0	Head loss happen

The velocity of water supply distribution system pipes of velocity were described in Figure 4.5 by color coding method. The Figure 4.5 point out velocity where the velocity was high or low.

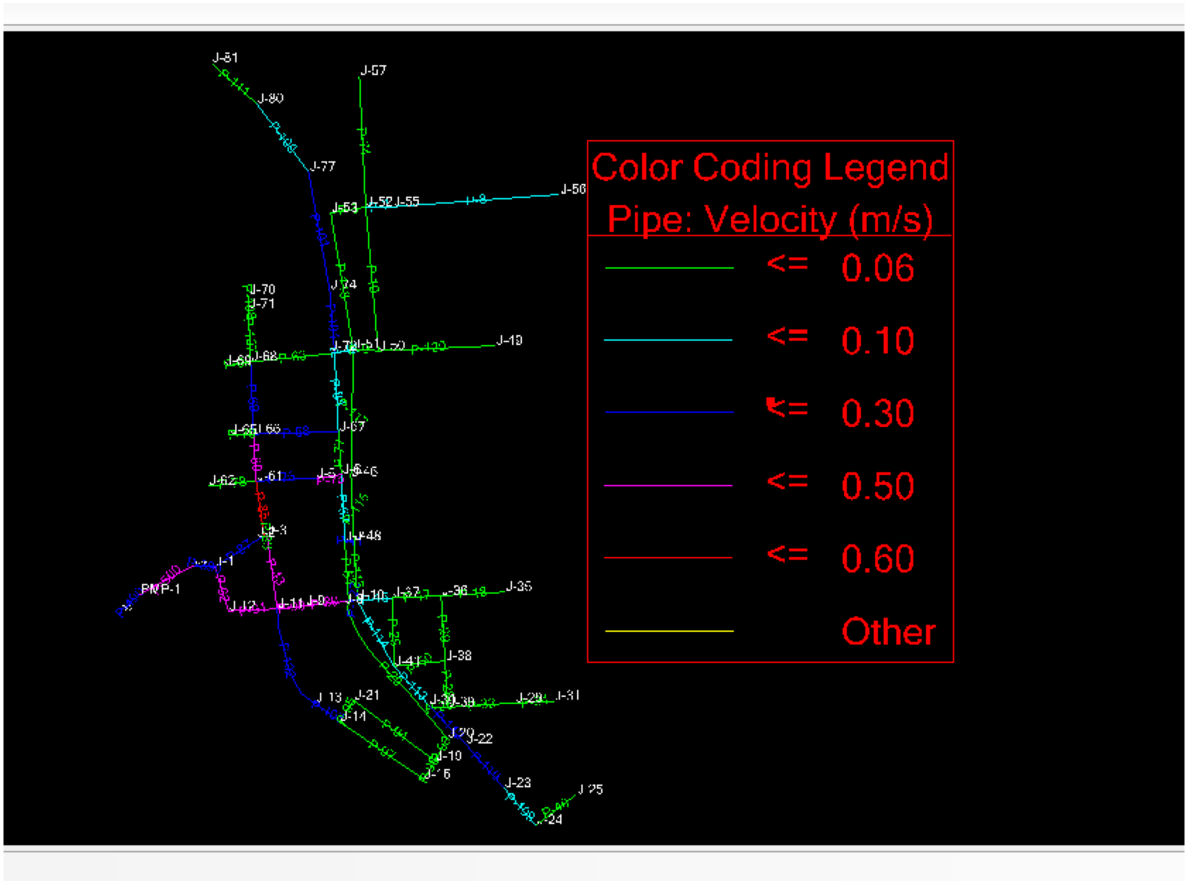

Figure 4.5 Velocity profile of Bichena Town water supply

4.5 Performance index analysis

Each index were computed by reliability, vulnerability and resilience values. As shown Table 4.12 the velocity was more susceptible than pressure. After reliability, vulnerability and resilience calculated pressure and velocity were computed.

Table 4.9 Performance indicators for Bichena Town

	Pressure	Velocity	Average
Vulnerability	0.045	0.074	0.059
Reliability	0.92	0.015	0.47
Resiliency	0.75	0.015	0.38

4.6 Sustainability analysis

Sustainability based up on velocity sustainability indicator was unacceptable value which was 0.061 but most junction were in normal pressure range .The overall sustainability was undesirable, the value was 0.46. Sustainability indexes were classified as unacceptable, medium but unacceptable and acceptable based on SI.

Based on the classification the overall sustainability index was 0.46, but 0.061 for velocity and 0.86 for pressure. The Overall sustainability index was computed by taking average value of velocity sustainability index and pressure sustainability index. Water should be sustainable if it serves enough amount of water to the customer with appropriate water quality standards. But in the cause of study area amount of water supplied to the customers was much lower than amount of water needed to consumers.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSION

To assess sustainability of Bichena water supply distribution system WaterGemsv8i was used. Water demand was forecasted by using per capita demand by each mode of service. Velocity based hydraulic performance evaluation indicated that acceptable minimum and maximum velocity have not been meet. As a result, the distribution system is exposed to risks of pipe sedimentation and the consequences is water quality problem.

The per capita of Bichena town was 13.3 l/c/d which was lower than WHO (2008) standard as well as GTP- 2 minimum plan standard. Normally the analysis of WaterGemsv8i hydraulic result indicated that the current hydraulic performance of the water supply system is not in suitable situation and not sustainable based on sustainable index calculation.

Supply of the area was lower than the demand of the consumers and sustainability index was under undesirable value. Also it was showed that the town water supply performance was low. In general, the simulated hydraulic result indicated that the current sustainability of Bichena Town water supply was not suitable. Because based on result s velocity based sustainability was very low and demand was not satisfied. The distribution system is prone to exposed to low velocity.

5.2 RECOMMENDATIONS

Socioeconomic wellbeing of the people in the town could be developed when water supply system service is in allowable situation. Improving the existing water supply service in the town in terms of quantity, reliability and sustainability means upgrading performance of water supply distribution system. In order to control and reduce water loss and increase water supply production to Bichena Town the following measures should be taken.

Since budgets are not covered by only towns' water supply offices both Ministry Of Water Irrigation and Electric as well as the Regional Water Resources Development Bureau take mitigation measure to reduce water supply shortage in Bichena.

Increasing pumping hour of the submersible pump should be taken up to its capacity may reduce water demand shortage. So as to alleviative water scarcity in the water supply production additional borehole should be drilled. Demand management should manage the demand by controlling waste or loss from pipe leakage and consumption through the use of meters and tariffs that are set in accordance with the volume of water consumption. Since velocity of water supply of the study area was low and affect water quality of the distribution system, pipe size should be modified. Subsequently sustainability assessment is broad that encompass any aspects, further study should be conducted including water quality parameters and other sustainability assessment methods such as social and economic assessment methods. Loss could be reduced by giving awareness to the customers. In order to make continuous of ground water yield artificial recharge should be done.

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APPENDIXS

A Flex Table: Junction Table

Current Time: 0.000 hours

Label	Elevation (m)	Zone	Demand (L/s)	Demand Collection	Pressure (m H2O)
J-1	2,543.41	<None>	0	<Collection: 1 items>	20
J-10	2,537.95	<None>	0	<Collection: 1 items>	25
J-11	2,539.88	<None>	0	<Collection: 1 items>	23
J-12	2,536.11	<None>	0	<Collection: 1 items>	27
J-13	2,533.61	<None>	0	<Collection: 1 items>	29
J-14	2,532.90	<None>	1	<Collection: 1 items>	30
J-16	2,531.58	<None>	0	<Collection: 1 items>	31
J-19	2,532.31	<None>	0	<Collection: 1 items>	31
J-2	2,542.04	<None>	0	<Collection: 1 items>	22
J-20	2,534.45	<None>	0	<Collection: 1 items>	29
J-21	2,534.14	<None>	0	<Collection: 1 items>	29
J-22	2,531.87	<None>	0	<Collection: 1 items>	31
J-23	2,532.05	<None>	0	<Collection: 1 items>	31
J-24	2,531.05	<None>	0	<Collection: 1 items>	32
J-25	2,529.96	<None>	0	<Collection: 1 items>	33
J-29	2,528.90	<None>	0	<Collection: 1 items>	34
J-3	2,541.54	<None>	0	<Collection: 1 items>	22
J-30	2,532.15	<None>	0	<Collection: 1 items>	31

J-31	2,526.42	<None>	0	<Collection: 0 items>	37
J-35	2,520.04	<None>	0	<Collection: 0 items>	43
J-36	2,527.07	<None>	0	<Collection: 1 items>	36
J-37	2,532.11	<None>	0	<Collection: 1 items>	31
J-38	2,531.70	<None>	0	<Collection: 1 items>	31
J-39	2,533.70	<None>	0	<Collection: 1 items>	29
J-41	2,532.90	<None>	0	<Collection: 1 items>	30
J-46	2,537.67	<None>	0	<Collection: 1 items>	25
J-48	2,539.89	<None>	0	<Collection: 1 items>	23
J-49	2,514.40	<None>	0	<Collection: 1 items>	49
J-5	2,539.32	<None>	0	<Collection: 1 items>	24
J-50	2,530.09	<None>	0	<Collection: 1 items>	33
J-51	2,534.35	<None>	0	<Collection: 1 items>	10
J-52	2,528.48	<None>	0	<Collection: 1 items>	35
J-53	2,531.06	<None>	0	<Collection: 1 items>	32
J-55	2,526.13	<None>	0	<Collection: 1 items>	37
J-56	2,536.00	<None>	0	<Collection: 1 items>	27
J-57	2,531.77	<None>	0	<Collection: 1 items>	31
J-6	2,539.16	<None>	0	<Collection: 1 items>	24
J-61	2,535.63	<None>	0	<Collection: 1 items>	28
J-62	2,537.10	<None>	0	<Collection: 1 items>	26
J-65	2,533.81	<None>	0	<Collection: 1 items>	29
J-66	2,535.20	<None>	0	<Collection:	28

				1 items>	
J-67	2,539.34	<None>	0	<Collection: 1 items>	24
J-68	2,530.53	<None>	0	<Collection: 1 items>	33
J-69	2,524.01	<None>	0	<Collection: 1 items>	39
J-7	2,538.78	<None>	0	<Collection: 1 items>	24
J-70	2,524.89	<None>	0	<Collection: 1 items>	38
J-71	2,525.10	<None>	0	<Collection: 1 items>	38
J-72	2,535.34	<None>	0	<Collection: 1 items>	28
J-74	2,528.78	<None>	0	<Collection: 1 items>	34
J-77	2,534.03	<None>	0	<Collection: 1 items>	29
J-8	2,538.44	<None>	0	<Collection: 1 items>	25
J-80	2,537.32	<None>	0	<Collection: 1 items>	26
J-81	2,538.89	<None>	0	<Collection: 1 items>	24
J-9	2,539.47	<None>	0	<Collection: 1 items>	24

Y (m)	X (m)
1,155,225.42	412,220.64
1,155,140.13	412,581.15
1,155,118.87	412,378.32
1,155,114.00	412,254.96
1,154,881.60	412,474.16
1,154,833.08	412,536.66
1,154,688.03	412,748.90
1,154,733.67	412,778.38
1,155,303.91	412,344.93
1,154,792.15	412,808.54
1,154,887.28	412,571.98
1,154,776.59	412,855.82
1,154,665.20	412,953.15
1,154,571.47	413,032.80
1,154,649.21	413,135.35

1,154,881.00	412,981.36
1,155,303.97	412,353.18
1,154,870.29	412,766.67
1,154,885.55	413,078.64
1,155,161.73	412,954.56
1,155,151.99	412,793.24
1,155,146.88	412,670.57
1,154,987.24	412,803.36
1,154,870.25	412,810.08
1,154,974.12	412,673.52
1,155,452.25	412,565.08
1,155,289.81	412,573.11
1,155,784.52	412,930.96
1,155,450.23	412,482.92
1,155,771.80	412,634.01
1,155,775.92	412,570.71
1,156,135.43	412,602.68
1,156,120.80	412,514.05
1,156,136.02	412,671.25
1,156,167.37	413,092.90
1,156,466.44	412,586.25
1,155,458.61	412,541.26
1,155,442.26	412,325.15
1,155,429.76	412,204.19
1,155,558.28	412,259.17
1,155,560.95	412,318.95
1,155,567.17	412,533.24
1,155,743.85	412,311.02
1,155,733.13	412,245.25
1,155,289.66	412,549.70
1,155,913.21	412,306.49
1,155,878.22	412,305.77
1,155,765.66	412,523.89
1,155,925.69	412,511.22
1,156,225.19	412,457.65
1,155,138.18	412,559.00
1,156,396.93	412,326.15
1,156,499.67	412,212.37
1,155,126.56	412,449.61

FlexTable: Pipe Table

Current Time: 0.000 hours

ID	Label	Length (Scaled) (m)	Start Node	Stop Node	Diameter (mm)	Material
121	P-5	90	J-53	J-52	96.8	HDPE
122	P-74	331	J-52	J-57	79.2	HDPE
123	P-7	69	J-52	J-55	79.2	HDPE
126	P-8	423	J-55	J-56	79.2	HDPE
129	P-9	63	J-51	J-50	141.0	HDPE
130	P-10	365	J-50	J-52	79.2	HDPE
145	P-16	90	J-10	J-37	79.2	HDPE
147	P-17	123	J-37	J-36	96.8	HDPE
148	P-18	162	J-36	J-35	79.2	HDPE
160	P-25	173	J-41	J-37	79.2	HDPE
161	P-26	43	J-30	J-39	79.2	HDPE
162	P-28	117	J-39	J-38	79.2	HDPE
163	P-29	165	J-38	J-36	79.2	HDPE
166	P-32	172	J-39	J-29	79.2	HDPE
169	P-34	97	J-29	J-31	79.2	HDPE
179	P-40	129	J-24	J-25	79.2	HDPE
187	P-43	187	J-11	J-3	79.2	HDPE
197	P-50	130	J-41	J-38	79.2	HDPE
200	P-54	152	J-8	J-7	141.0	HDPE
207	P-63	214	J-72	J-68	96.8	HDPE
208	P-65	67	J-68	J-69	79.2	HDPE
210	P-67	169	J-7	J-6	141.0	HDPE
212	P-68	214	J-67	J-66	96.8	HDPE
213	P-69	183	J-66	J-68	79.2	HDPE
214	P-70	60	J-66	J-65	79.2	HDPE
219	P-75	59	J-6	J-5	79.2	HDPE
220	P-76	158	J-61	J-5	96.8	HDPE
221	P-77	109	J-6	J-67	141.0	HDPE
222	P-78	122	J-61	J-62	79.2	HDPE
224	P-80	119	J-61	J-66	96.8	HDPE
229	P-83	8	J-3	J-2	250.0	HDPE
230	P-84	199	J-67	J-72	141.0	HDPE
231	P-85	140	J-2	J-61	96.8	HDPE
232	P-87	147	J-1	J-2	250.0	HDPE
233	P-89	110	J-9	J-8	96.8	HDPE
235	P-90	72	J-11	J-9	96.8	HDPE
236	P-91	123	J-12	J-11	79.2	HDPE
237	P-92	117	J-1	J-12	79.2	HDPE
238	P-93	66	J-20	J-19	79.2	HDPE

239	P-94	257	J-19	J-21	79.2	HDPE
240	P-95	65	J-21	J-14	79.2	HDPE
241	P-96	54	J-19	J-16	79.2	HDPE
242	P-97	257	J-16	J-14	79.2	HDPE
246	P-101	304	J-74	J-77	79.2	HDPE
248	P-103	79	J-13	J-14	79.2	HDPE
251	P-104	161	J-72	J-74	96.8	HDPE
257	P-106	216	J-77	J-80	79.2	HDPE
258	P-107	134	J-68	J-71	79.2	HDPE
259	P-108	35	J-71	J-70	79.2	HDPE
265	P-109	123	J-23	J-24	79.2	HDPE
266	P-110	148	J-22	J-23	79.2	HDPE
267	P-111	153	J-80	J-81	79.2	HDPE
268	P-112	129	J-30	J-22	96.8	HDPE
269	P-113	139	J-41	J-30	141.0	HDPE
270	P-114	190	J-10	J-41	141.0	HDPE
271	P-115	150	J-10	J-48	141.0	HDPE
272	P-116	163	J-48	J-46	141.0	HDPE
273	P-117	324	J-46	J-51	141.0	HDPE
274	P-118	350	J-51	J-53	96.8	HDPE
281	P-120	297	J-50	J-49	141.0	HDPE
293	P-123	22	J-8	J-10	96.2	HDPE
329	P-102	267	J-11	J-13	79.2	HDPE
332	P-29	436	J-8	J-20	96.8	HDPE
336	P-42	48	J-72	J-51	96.8	HDPE
337	P-41	23	J-7	J-48	141.0	HDPE
357	P-390	124	TANK	J-1	200.0	HDPE
374	P-490	142	R-8	PMP-1	160.0	HDPE
375	P-500	417	PMP-1	TANK	160.0	Ductile Iron

Hazen-Williams C	Flow (L/s)	Velocity (m/s)	Has Check Valve?
150.0	0	0.05	False
150.0	0	0.02	False
150.0	0	0.10	False
150.0	0	0.08	False
150.0	0	0.03	False
150.0	0	0.06	False
150.0	0	0.08	False
150.0	0	0.03	False
150.0	0	0.00	False
150.0	0	0.02	False
150.0	0	0.01	False
150.0	0	0.03	False
150.0	0	0.03	False

150.0	0	0.02	False
150.0	0	0.00	False
150.0	0	0.05	False
150.0	-2	0.44	False
150.0	0	0.04	False
150.0	1	0.04	False
150.0	0	0.05	False
150.0	0	0.05	False
150.0	-1	0.08	False
150.0	-1	0.19	False
150.0	1	0.18	False
150.0	0	0.01	False
150.0	-2	0.36	False
150.0	2	0.26	False
150.0	0	0.02	False
150.0	0	0.02	False
150.0	2	0.32	False
150.0	-2	0.05	False
150.0	1	0.09	False
150.0	4	0.60	False
150.0	7	0.14	False
150.0	3	0.35	False
150.0	3	0.36	False
150.0	2	0.35	False
150.0	2	0.43	False
150.0	0	0.03	False
150.0	0	0.03	False
150.0	0	0.06	False
150.0	0	0.04	False
150.0	0	0.05	False
150.0	1	0.16	False
150.0	1	0.21	False
150.0	1	0.13	False
150.0	0	0.09	False
150.0	0	0.04	False
150.0	0	0.03	False
150.0	0	0.08	False
150.0	1	0.11	False
150.0	0	0.05	False
150.0	1	0.11	False
150.0	1	0.07	False
150.0	1	0.08	False
150.0	-1	0.04	False
150.0	1	0.05	False

150.0	1	0.03	False
150.0	0	0.06	False
150.0	0	0.01	False
150.0	1	0.17	False
150.0	1	0.23	False
150.0	0	0.05	False
150.0	1	0.09	False
150.0	2	0.11	False
150.0	9	0.29	False
130.0	36	1.80	False
130.0	36	1.80	False