



PERFORMANCE EVALUATION OF URBAN WATER SUPPLY  
SYSTEM; A CASE OF JIGJIGA TOWN,  
SOMALI REGIONAL STATE, ETHIOPIA

MSc. THESIS

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HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

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PERFORMANCE EVALUATION URBAN WATER SUPPLY  
SYSTEM A CASE OF JIGJIGA TOWN, SOMALI REGIONAL  
STATE. ETHIOPIA

BY

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MASTER OF SCIENCE IN WATER RESOURCE ENGINEERING AND  
MANAGEMENT

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## ADVISORS' APPROVAL SHEET

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This is to certify that the thesis entitled "PERFORMANCE EVALUATION URBAN WATER SUPPLY SYSTEM A CASE OF JIGJIGA TOWN, SOMALI REGIONAL STATE. ETHIOPIA" submitted in partial fulfillment of the requirements for the degree of Master (MSc) with specialization in Water Resource Engineering and Management, the Graduate Program of the Department of Water resource and Irrigation Engineering, and has been carried out by ABDURAHMAN ALI AHMED. ID. No. GPWREM/0001/12, under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

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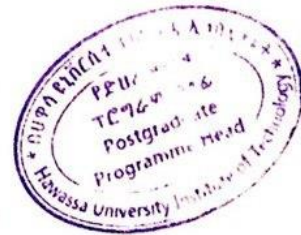
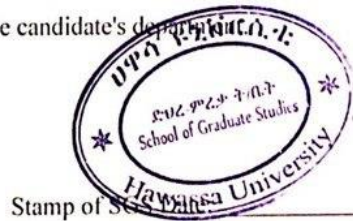
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## **DECLARATION**

I hereby declare that this MSc. thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this dissertation have been duly acknowledged.

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## ABSTRACT

In most developing countries, such as Ethiopia, problems with urban water supply and demand are common. The purpose of this thesis was to assess the present urban water delivery system in Jigjiga Town with the major goals of identifying issues with the Jigjiga Town water system by evaluating the current status of the town's water supply system, evaluating the WSS hydraulic performance, and finally propose corrective solutions. The present situation was assessed using the gap between the town's supply and demand by forecasting its population, while water losses were calculated using the difference between production and consumption data. In addition, WaterGEMS software was utilized to construct the model in order to examine the current water supply and distribution system. The model was used to adjust the high and low-pressure zones at junctions, as well as the velocity through the pipe. To explore the system model, the model was run for steady-state simulation and extended period simulation. According to the results of the research, the Town's water supply just covers 64% of demand. This result indicates the prevalence of demand-supply gap. Furthermore, the average loss from three years of production and consumption observation was 36 %. Moreover, the system has issues of over and under pressure, with utmost pressure occurring at extended period simulation (EPS) at PHD being 69mH<sub>2</sub>O, which is under the suggested range, and 83.5 % (182 points) of the velocity in the pipes being less than 0.5m/s. To deal with these issues, additional pumps must be installed to enhance production, existing well sources must be rehabilitated, and the capacity of the distribution pipeline must be increased by installing new pipes.

Keywords: WaterGEMS Model, Demand-Supply level, Hydraulic performance, Water Coverage, Water Loss

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## **LIST OF ACRONMYS/ABBREVIATIONS**

AD	Average Day Demand
AL	Apparent Loss
CSA	Central Statistical Agency
DCI	Ductile Iron Pipe
DD	Domestic Demand
DN	Nominal Diameter
E.C	Ethiopian Calendar
EPS	Extended Period Simulation
FDRE	Federal Democratic Republic of Ethiopia
GIS	Geographic Information System
GPS	Geographical Positioning System
HC	House Connection
HTU	House Tap User
JJU	Jigjiga University
L/S	Liter per second
M/S	Meter per Second
MDD	Maximum Day Demand
MoWE	Ministry of Water and Energy
MOWR	Ministry of Water Resource
NDD	Non- Domestic Demand
NRW	Non-Revenue Water
NTU	Neighborhood Tap User

O&M	Operation and Maintenance
PHD	Peak Hour demand
PTU	Public Tap User
PVC	Polyvinyl Chloride
RL	Real Loss
SRS	Somali Regional State
SRSWRDB	Somali Regional State Water Resource Development Bureau
UAC	Unbilled Authorised Consumption
WL	Water Loss
WRC	Water Resource Commission
WSS	Water Supply System
WSSJT	Water Supply System in Jigjiga Town
WWDSE	Water Work Design and Supervision Enterprise
YTU	Yard Tap User

# 1. INTRODUCTION

## 1.1 Background of the Study

A sustainable water supply has been a requirement for humans and all living creatures since the beginning of time. The development of water delivery infrastructure has therefore become the most significant public and private utility for this aim. Every year, a huge amount of money is spent throughout the world to develop, upgrade, and maintain this utility in order to ensure that there is sufficient water supply that is safe to drink and use.

Water is one of life's most basic necessities. Water is required for the survival of all living beings like Drinking, food preparation, irrigation, and industry. Although water covers more than 70% of the Earth's surface, fresh water accounts for less than 1% of that resource, and it is not uniformly distributed throughout the globe. More than one billion people (1,000 million) throughout the world, primarily in poor nations, do not have access to safe drinking water. Apart from water shortage, several additional problems face many regions of the world in ensuring a safe, sufficient, and consistent water supply(OpenWASH, 2016).

The Ministry of Water, Irrigation & Energy (MoWIE) of the Federal Democratic Republic of Ethiopia (FDRE) has developed a water policy that includes water supply and sanitation to promote rapid development of water supply for human and livestock consumption, industrial and alternative uses in terms of convergence, quantity, reliable and acceptable quality, taking current and future realities into consideration. It also highlights the need of providing appropriate, dependable, and efficient facility and sanitation services in order to improve the Ethiopian people's well-being and productivity, as well as their concrete contribution to the economy. In our region, water distribution system planning is imposed using universal design factors that ignore the effects of local conditions, requiring the design parameters to be altered to meet water requirements.

According to the report of Ministry of Health, Water and Energy, access to safe drinking water increased from 23.1% in 1998 to 68.5% in 2012. However, millions of people in urban and rural areas have not been getting safe drinking water from an improved water source (Debela & Muhye, 2017).

The only promising water resource for Jigjiga Town water supply project is groundwater. In the existing system, there are about 25 boreholes drilled so far around the city, but out of the total only 22 boreholes are functioning properly supplying only less than 52 l/sec.

The yield of the boreholes is decreasing from time to time. 8 more were also drilled and connected to the system at Jerer valley about 23km far from the city to the south direction and connected to the system via 3,000m<sup>3</sup> Reservoir which is located to the South-East direction along the Asphalt road from Jigjiga Town to Degahabour and about 75 l/sec water is being supplied from this Jerer well field. The water quality of the boreholes is also deteriorating.

Provision of the unpolluted water system is one in all the most important factors that greatly contribute to the socio-economic transformation of the community around the project space by raising the living standard, health and thereby increasing productivity. so as to confirm the availability of water sufficiently and qualitatively, it becomes imperative in fashionable society, to arrange and build suitable water system schemes, which can give safe drink to the varied sections of the community in accordance with their demands and needs.

In 1975, Jigjiga water Supply was, designed the old distribution system. As the city's population has grown, the quantity of water has been insufficient for the residents, and the city is presently facing a serious water crisis. The public water fountains and household taps are frequently dry. In the city, water vending is popular, and a 25 litter container (Jerrycan) costs around 40 birr. In this location, there is no perennial stream. Although there is a dam

near the city, the accessible water in the dam reservoir is not treated. As a result, it is exclusively utilized for animals and other purposes.

The persistent and frequent failure of the Jigjiga Town water delivery networks has become one of the most urgent issues in the water supply sector, requiring quick attention.

The primary Objective of this thesis is the performance evaluation of the existing urban water supply system in Jigjiga Town and in order to do that we have to look to different perspectives. The first one, we have to evaluate the situation of the water supply & distribution system and coverage of the city by considering its Demand-Supply analysis which is affected by its population increase. And the second one we have to assess the Hydraulic performance which relate to the efficient delivery of water which is measured in terms of pressure, flow rate, velocity, etc. which is done by using analysis Software known as WATERGEMS.

## 1.2 Problem Statement

Jigjiga Town gets potable water supply system since a long time ago. Even though distributing the available water and water loss from a utility's delivery system is a growing management problem in Ethiopia, there are few studies conducted on the existing water utilities in the country related to performance evaluation, water loss and coverage.

Jigjiga Town is facing difficulties with water supply and demand. Due to growing population and expanded commercial activity in and around the area, Jigjiga Town is currently facing a dramatic water supply shortage. The majority of existing system network layouts is not correctly set out, creating challenges for maintenance, transfer, and replacement of old or damaged pipes if necessary. According to the water supply bureau expertise, all water supply network pipelines were established before the existing road access and residential building were built. Water distribution pipes can currently be found beneath drainage lines, toilets, ditches, and buildings, as well as in the residential building compound.

As a result of these issues, the hydraulic network's performance has degraded, and water supply coverage has decreased, according to information acquired from the Municipality's water service office.

Previously, Jigjiga Town water supply system pipe network was designed for residential demand limited to a very small area of the town, but with the construction of new small and light industries, commercials, institutions, and multiple residential houses and services, the supply coverage area has dramatically expanded. Additionally, extra demand loads from neighboring border Kebeles along the water source line are incorporated in the systems, which were not previously addressed when the current water supply was constructed. The water supply and demand are incompatible.

The existing source of Jigjiga Town water supply system is from "Jerer valley". The water supply implemented to give service for the people of the Town as well as the communities

along the main pipeline and surrounding rural community of the Town. However, throughout time, the Jigjiga Town water supply system encountered major problems. Hence, the water supply system doesn't provide the intended demand to the community.

The system's weaknesses and strengths are not recognized. The water utility is losing money as a result of the loss of water. It is unknown how much water is lost from the water supply delivery system or where it is lost. There are kebeles in the town that are outside the reach of distribution pipes, as well as kebeles that have distribution pipes but are frequently without water. Due to a lack of water, the Jigjiga municipal water utility had difficulty distributing the limited water evenly among the population. Along from that, inadequate management of existing infrastructure assets contributes to increased water supply losses.

This research will analyze the distribution system performance, assess areas with excessive water losses, and determine how much water is lost on an annual basis in order to assess the state of Jigjiga Town's water supply system.

## **1.3 Objectives of the study**

### **1.3.1 Main objectives**

The main objective of this study was evaluated the hydraulic performance of Jigjiga Town water supply distribution system.

### **1.3.2 Specific objectives**

The specific objectives of the research include:

- ❖ To assess overall water loss (unaccounted for water) at the city level, to identify likely causes of water losses.
- ❖ To evaluate the water supply distribution coverage of the Town.
- ❖ To evaluate the hydraulic performance of the water supply system of the Town

#### **1.4 Significance of the study**

Since the research focuses on evaluating the performance of water supply Jigjiga Town, it is expected to increase the knowledge and up to date information on urban water supply systems. It is also used to show the level of water supply system with in the area and the shortage of water with in the Town will be solved, as a result, the socio-economic and the health status of the people is become improved.

Also, it helps future researchers to use this study as a reference. Furthermore, it will help to give suggestions and recommendations in order to improve the status of the water supply system and to achieve a prospect to the population in Jigjiga Town by getting the Demand they need.

#### **1.5 Scope of the study**

The goal of this research is to assess the performance urban water supply system, specifically in Jigjiga town. And it largely focuses on measuring the hydraulic performance, water coverage, and water loss of the water supply distribution system. Bentley WaterGEMS is used for hydraulic network analysis and water loss calculated production and consumption three times in a row. The system's performance was studied during peak and low consumption hours, and its performance was evaluated based on hydraulic parameters.

## **2. LITERATURE REVIEW**

### **2.1 Water Supply Concepts**

Worldwide, over one billion people lack access to an adequate water supply; more than twice as many lack basic sanitation(Institute of Medicine, 2009).

A safe, reliable, affordable, and easily accessible water supply is essential for good health. Yet, for several decades, about a billion people in developing countries have not had a safe and sustainable water supply. It has been estimated that a minimum of 7.5 liters of water per person per day is required in the home for drinking, preparing food, and personal hygiene, the most basic requirements for water; at least 50 liters per person per day is needed to ensure all personal hygiene, food hygiene, domestic cleaning, and laundry needs. This domestic water consumption is dwarfed by the demands of agriculture and ecosystems, even in wealthy countries where per capita domestic water consumption greatly exceeds these figures. To cover all these requirements and to avoid water stress, experts generally agree that about 1,000 cubic meters of freshwater per capita per year is needed.(Hunter et al., 2010)

Water access in urban places is better than in rural areas of sub-Saharan Africa, where only 56% of the population currently has access to improved sources(Dos Santos et al., 2017).

Sub-Saharan countries are among those most threatened by water stress, in view of the likelihood of extreme variability, seasonality, and decreasing stream-flows that are predicted to occur in the coming decades (Arsiso et al., 2017).

Water supply services in Ethiopia are among the lowest in Africa For instance, As a result, access to improved water supply increased from about 19 percent to 52.5 percent between 1996 and 2007.(Hundie & Abdisa, 2016)

## 2.2 Water Loss and Leakage

Water Loss & Leakage is a general phenomenon in all the water supply systems in the world that occurs in all water distribution networks, since the connection will not be perfect regarding to the material quality, workmanship, Lack of maintenance & Operation, etc.

Due to this reason, an amount that reaches to 10% of the total production is allowed to be loss in the entire system, if the loss is <10% the NRW levels and action needed is Acceptable, monitoring and control, if it's between 10-25% the level is Intermediate and could be reduced, and finally if its >25% it's a matter of concern and emergent reduction is needed(Allan Lambert, 2003).

Individual meter readings for each customer should exactly equal the amount of water measured from the treatment facility. However, in practice, this is not the case. So while inflow equals outflow, not all outflows are metered. These "missing" flows are known as unaccounted-for water (UFW).

There are several reasons why the total amount of water generated by the utility may be less than the sum of all metered customer consumption. The most frequent causes of differences include leakage, measurement mistakes, and unmetered use. Customer demands and unaccounted-for water should ideally be assessed separately.

Water distribution systems across the world are aged and degrading, while demand on these systems, and hence on natural water supplies, is growing all the time. Water distribution system losses are at alarmingly high levels in many towns and cities throughout the world. Physical losses (leaks), illegitimate use, unmetered consumption, and under-registration of water meters are all examples of water losses. Leakage accounts for a significant portion of overall water losses, sometimes exceeding 70%(WHO, 2001).

Leakage or real loss (RL) in pipelines, storage reservoirs, and customer connections, or apparent loss (AL) due to customer meter underregistration, data handling and billing problems, or unauthorized usage, are all examples of WL(A. Lambert & Hirner, 2000).

### 2.2.1 Non-Revenue Water

The sum of the volume of WL and the volume of unbilled authorised consumption (UAC), which is the authorised use that has no revenue, such as water used for firefighting or network cleaning, is called non-revenue water (NRW)(AL-Washali et al., 2019).

Non-Revenue Water is defined as the difference between system input volume and billed authorized usage, and it includes the following:

- ❖ Unbilled Authorized Consumption (mostly a minor component of water balance).
- ❖ Apparent Losses
- ❖ Real Losses

According to (Kingdom et al., 2006), its estimated that \$141 billion is spend for the NRW in the water utilities in every year, by which third of it occurs in the developing world. And about 45 billion cubic liters of water is lost daily in the developing countries through water leakages in the distribution system which will be enough to serve approximately 200 million people if was maintained and operated correctly. Similarly, close to 30 million cubic meters are delivered every day to customers, but are not invoiced because of pilferage, employees' corruption, and poor metering which led the capacity of developing countries to become financially viable.

Unavoidable annual real loss(UARL): This category indicates the system's permissible volume of real losses, which estimates the amount of leaks that are undetected or uneconomical to fix during the year. This can help to assess the sustainability of real loss minimization (provides better understanding of real loss components)

Table 2-1: World Bank Institute Banding system to interpret ILIs

General description of real loss performance management categories	Developing countries	Developed countries	BAND
	ILI Range	ILI Range	
Further loss reduction may be uneconomic unless there are shortages; careful analysis is needed to identify cost effective improvement	< 4	< 2	A
Potential for marked improvements; consider pressure management, better active leakage control practices, and better network maintenance	4 to <8	2 to <4	B
Poor leakage record; tolerable only if water is plenty and cheap; even then analyze level and nature of leakage and intensify leakage reduction efforts	8 to <16	4 to <8	C
Very inefficient use of resources; leakage reduction programs imperative & high priority	16 or more	8 or more	D

Table 2-2: Water balance showing NRW components (Source: IWA,2000)

System Input Volume	Authorized Consumption	Billed Authorized Consumption	Billed Metered Consumption (including water exported)	Revenue Water	
					Billed Non-metered Consumption
	Authorized Consumption	Unbilled Authorized Consumption	Unbilled Metered Consumption	Non-Revenue Water	
			Unbilled Non-metered Consumption		
	Water Losses	Apparent Losses	Unauthorized Consumption		
			Metering Inaccuracies		
		Real Losses	Leakage on Transmission and/or Distribution Mains		
			Leakage and Overflows at Utility's Storage Tanks		
	Leakage on Service Connections up to Customers' Meters				

### 2.2.2 Pressure and leakage

In some countries – notably Japan and the UK – the importance of managing distribution systems to minimise excess pressures is widely recognised as a fundamental aspect of leakage management strategy. International data on pressure:leakage relationships demonstrates that leakage in distribution systems is usually much more sensitive to pressure

than would be predicted by the 'square root' relationship, with different components of leakage responding differently to pressure. An understanding of pressure and leakage relationships is therefore fundamental to a systems approach to leakage control (Allan, 2000).

One of the major factors influencing leakage is pressure in the distribution system. In the past, the conventional view was that leakage from water distribution systems is relatively insensitive to pressure (Van Zyl & Clayton, 2007).

“In many water network systems, even though the total demand and the total loss of water can be known rather easily, information about the possible influence of local pressure upon demand is sadly lacking that as a result creates difficulty to assess and compare the demand and loss of water in its spatial distribution. Pressure Distribution system on the one hand contributes to the increase of leakage, when its more, and on the other hand when it is low contributes to the shortage of water that as a result causes for unequal distribution of water among residents.”

### **2.3 Global and Ethiopia Water Supply Coverage**

Water supply coverage provides a picture of a given country or town water supply status and allows comparing one country to others, as well as inter and intra-city distribution within a specific country. The percentages of the population with or without a piped water connection are a useful indicator for comparing water supply coverage in urban areas.

90% of the world's population (6.8 billion people) used basic drinking water services in 2017, rising from 82 percent (5 billion people) in 2000. Global coverage will be approximately 96 percent in 2030 if present trends continue, falling short of universal access. Between 2000 and 2017, urban coverage grew slightly from 95 to 97 percent, while rural coverage climbed from 69 to 81 percent, narrowing the urban-rural coverage "gap" by ten

percentage points. Since 2000, a quarter of the present population in Sub-Saharan Africa has obtained access to at least basic drinking water (UNICEF, 2019)

Although water supply coverage is greater in urban areas than in rural areas, actual water supply coverage in developing countries in general, and African cities in particular, is relatively low when compared to demand. According to the Global Water Supply and Sanitation Assessment 2000 Report, 43 % capital cities have a house connection or yard tap, % served by a public tap, and 31 % of the population remains un-served (WHO, 2000)

### **2.3.1 Jigjiga Town Water Supply Coverage**

water supply system for Jigjiga Town is from two well fields. The major source is located in the south of the town called Jerer well field and the other found in the north of the town called Qordere. The water abstracted from jerer well field boreholes are pumped to 3000m<sup>3</sup> services reservoir through about 16kms long DN400mm DCI raising main by two pumping stations and then the water from the service reservoir is arrive at Town distribution networks by gravity. The water abstracted from the existing northern well field(Qordere) boreholes will be collected in to the 200m<sup>3</sup> wet well or collection chamber and pumped to 1000m<sup>3</sup> services reservoir and then the water from the 1000m<sup>3</sup> reservoir is arrive at Town distribution networks by gravity.

### **2.4 Water Distribution System**

The purpose of distribution system is to deliver water to client with applicable quality, amount and pressure. Distribution system is employed to explain jointly the facilities want to provide water from its supply to the purpose of usage.

The distribution network, which includes mostly of pipes, pumps, junctions (nodes), valves, fittings, and storage tanks, is responsible for distributing water from the source or treatment facilities to its users at usable pressures. The effective operation of water distribution

networks is closely connected to the well-being of the inhabitants in modern civilizations (Anore, 2020).

The water quality in the distribution pipelines should not degrade also water with adequate pressure head to all of the intended locations, Should be able to provide the required volume of water during a firefighting operation, Distribution pipes should be at least one meter distant from or above sewage lines. (Adeosun, 2014).

#### **2.4.1 Layout of Distribution System**

In order to follow the road layouts, distribution pipes are usually placed beneath the road pavements. Pipe networks classified into four categories: grid, ring, radial, and dead end systems.

The Grid Iron System that is the commonest system is appropriate for cities with rectangular layout, wherever the water mains and branches are ordered in rectangles.

the benefits of this technique together with that the water is kept in smart circulation because of the absence of dead ends and also break down in some section doesn't affects the system. However, the precise Calculation of sizes of pipes isn't attainable because of provision of valves on all branches.

The second sort that is that the Ring System, the availability main is set right along the peripheral roads and sub mains diversify from the mains. Thus, this technique conjointly follows the grid iron system with the flow pattern similar in character to it of dead finish system. So, determination of the dimensions of pipes is straightforward. conjointly the water is often equipped to any purpose from a minimum of 2 directions. In the Radial System, the distribution is split into completely different zones. The water is wired into the distribution reservoir unbroken within the middle of every zone and therefore

the pipes are formed radially ending towards the boundary. Its benefits embrace fast service and calculate the pipe sizes.

While the Dead Finish System that is that the final one and also the only 1 that is applicable to my town, is appropriate for recent cities and cities having no definite pattern of roads. the benefits of this method embrace, its comparatively low-cost and determination of discharges and pressure is less complicated because of less range of valves. however, because of several dead ends, stagnation of water happens in pipes.

#### 2.4.2 Methods of Distribution

Water is distributed to the consumers in several different ways as local condition or other consideration may dictate. The methods are:

##### **I) Gravity distribution:**

This is feasible when the source of supply is a lake or impounding reservoir located at a high enough elevation above the city to keep the mains under pressure. If the conduit running from the source to the city is large enough and well protected against accidental breakage, this is the most dependable approach.

##### **II) By pumping with storage:**

This is the most common approach in practice; excess water produced during periods of low demand is kept in elevated tanks. During periods of high demand, stored water is used to fulfill the demand.

The method allows fairly uniform rate of pumping and hence is economical, as in this case the pumps may be operated at their rated capacity. As some allowance is kept for the fire reserve and the storage for break down it is also a fairly reliable method of water supply.

##### **III) Direct pumping:**

In this method pumps are used for supplying water without any storage. The water is forced in the main and then to the consumers. It is the least desirable system. As

consumption varies, the pressure in the main is likely to fluctuate.

Power failure would result complete interruption in water supply. If pumping is done electrically the peak power consumption of water plant likely to occur during high current consumption and this increase power costs.

## 2.5 Principles of pipe network Hydraulics

Flow in a pipe network satisfies two basic principles The Governing principles for flow in pipe systems under steady conditions are conservation of mass and energy.

### a. Conservation of mass

The rate of storage in a system is equal to the difference between the inflow and outflow to the system under a steady state condition. Although tank storage may fluctuate over time in pressurized water distribution networks, no storage may occur inside the pipe network. For a junction node, the input and outflow must balance in a pipe (Lansey & Mays, 2000),

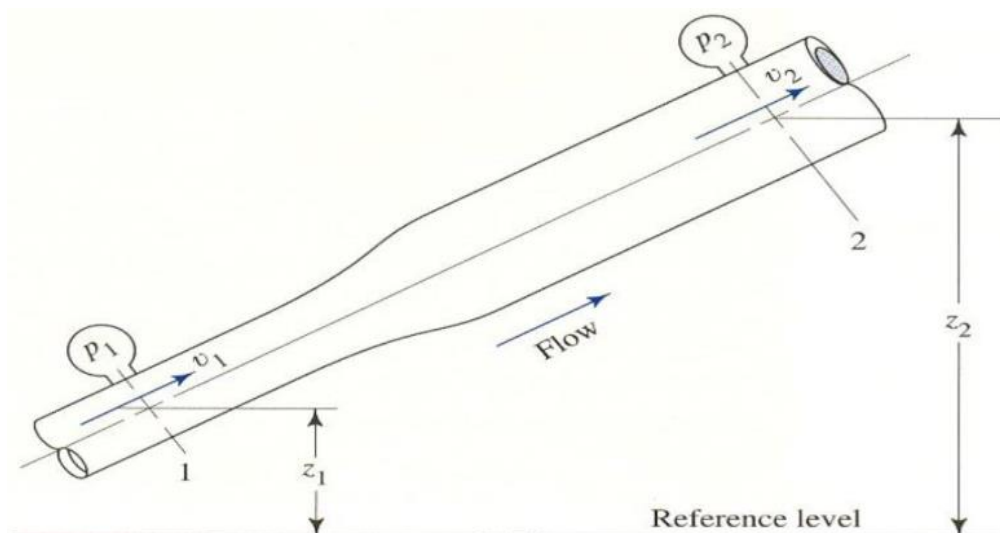


Figure 2-1: Conservation of mass diagram (continuity law)(Hopkins, 2012)

$$\text{Mass of fluid at section 1} = \text{Mass of fluid at section 2}$$

Principle of conservation of mass

$$A_1V_1 = A_2V_2 = Q_1 = Q_2 \dots \text{eqn(1)}$$

Where,  $V$  = average velocity (m /sec);  $A$  = cross-sectional area (m<sup>2</sup>) and  $Q$  = Discharge (m<sup>3</sup>/sec).

### b. Energy Conservation

Conservation of energy declares that the difference in energy between two points is equal to the frictional and minor losses and the energy added to the flow in components between these points.

While “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” (Bernoulli, 1738 cited in” (Walski et al., 2003). As a result, the difference in energy between any two points in a connected network is equal to the energy gains from pumps, as well as energy losses in pipes (frictional head loss) and energy losses in bends and fittings (minor head loss) that occur in the journey between them (Walski et al., 2003).

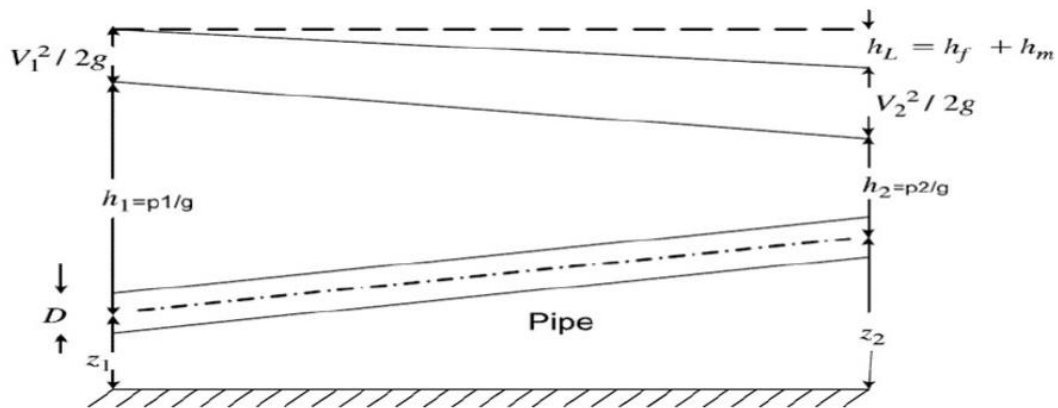


Figure 2-2: Conservation of energy(Hopkins, 2012)

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + Z_2 + HL \dots \text{eqn(2)}$$

Where,  $P$  = Pressure (mwc);  $V$  = Velocity (m/sec);  $z$  = Elevation (m);  $g$  = gravitational acceleration constant (m/s<sup>2</sup>);  $\gamma$  = Specific weight of water (kg /m.) and  $HL$  = Head losses (m).

## **2.6 Hydraulic Performance Evaluation of urban water supply distribution system**

Performance of a water distribution network can be defined as ability to deliver a required quantity of water under sufficient pressure and an acceptable level of quality during different operational situations (Tabesh & Dolatkahi, 2006).

To evaluate the performance of water supply systems in terms of water production and demand is important to deliver sufficient amount and enough quality of water. A good distribution system should be capable of supplying water at all proposed place within the town with sufficient pressure head and the required amount of water for various types of demand (GARG, 2006)

Performance indicators are some types of water supply performance measurement that you can know the level of water supply and distribution efficiency by using different types of indicators including Indicators for assessing users, Opinions & Satisfaction. It includes user satisfaction, Roles and responsibilities, complaints dealt with and etc. Hydraulic performance of water distribution systems under the action of cyclic pumping; the results show that the network under consideration is exposed to relatively high-pressure values throughout. The velocity of the water through the network attained also high values. These high values of pressure and velocity have negative effects on the performance of the network (Zyoud, 2003)

### **2.6.1 Hydraulic Performance**

In water distribution system there are different pipelines those are connected to deliver water from main line to houses. The amount of water withdraw rate from the service connection varies in an arbitrary manner and the maximum withdrawal rate occurs in morning and evening. For the analysis and design of a pipe network, this maximum withdrawal rate is

considered. Therefore, the hydraulic performance and its parameters determined maximum hourly and daily demand of water discharge (P. K. S. A. K. Sharma, 2008). Water distribution systems are made up of a network of smaller to wider pipes with multiple connections that deliver water to customers directly. Pump station, reservoir, and accessories, anchorages and valve chambers, as well as other appurtenances (valves, hydrants, and water meters) can be added in the system to increase the water supply distribution system service level(Trifunović, 2006).

Water production may be described in terms of system input, with the input discharge equal to the sum of the withdrawals in a single-input system. The input system parameters are the nodal discharge or withdrawal and system pressure heads. The system must be analyzed in order to get input point discharges, pipe discharges, and nodal pressure heads in the case of a multi-input network system(Trifunović, 2006).

Stagnant or static water pressure, as well as pressure surges, can cause pipe collapse in a water distribution system. When valves open and close during network operation, pressure surges, causing pipe collapse in the water supply distribution system(Rostum, 2000).

### **2.6.2 Hydraulic Performance Indicators**

When we are talking about the water supply & distribution system, there are type of performance indicators which are more important than the Common performance indicators and they are the Hydraulic Performance Indicators. Hydraulic Performance Indicators are some type of indicators which concerns about the Hydraulic of a pipe system such as pipe diameter, soil corrosively, pipe material, sustainability of the system, etc. (WHO, 2000).

### **2.7 Water Distribution Simulation**

The process of imitating the behavior of one system through the functions of another is called simulation. In this situation, simulation refers to the process of applying a mathematical

representation or real system known as a model. Simulation may be used to simulate system responses under a variety of situations without disturbing the actual system, and solutions can be assessed before investing time, money, and resources in a real-world project (Bentley, 2014).

A model can perform one of two sorts of simulations, depending on what the modeler is trying to observe or predict.

There are two types of simulations:

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

#### **2.7.1 Steady State Simulation**

For a specific set of hydraulic demands and boundary conditions, a steady-state simulation offers information on the equilibrium flows, pressures, and other variables that define the network state. steady-state models are commonly utilized, in situations where the effects of time are not very significant, such as peak demand times, fire protection consumption, and system component failures,

It calculates the state of the system (flows, pressures, pump operating attributes, valve position, and so on) on the assumption that hydraulic demands and boundary conditions do not change over time.

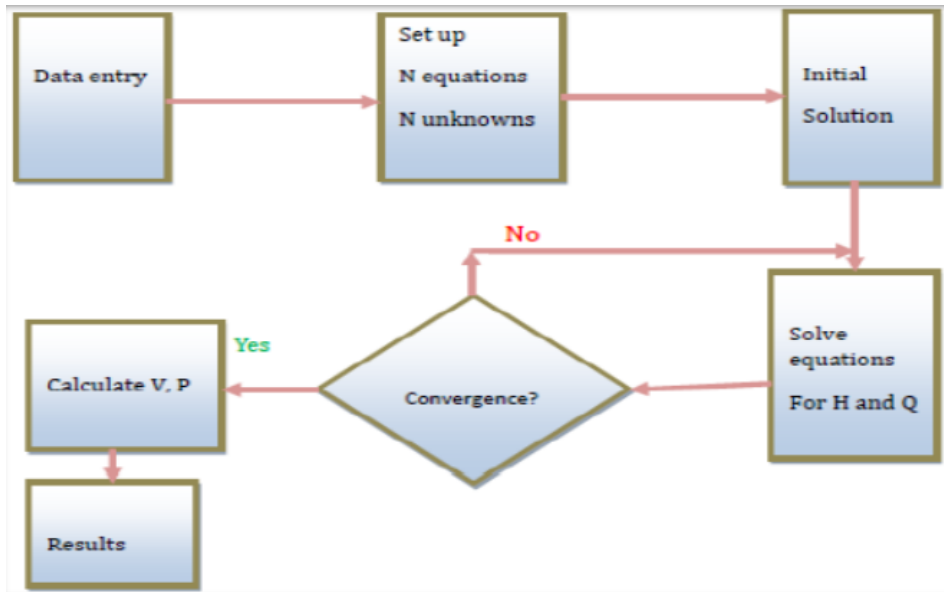


Figure 2-3: Flow chart for Steady state simulation(Bentley, 2014)

### 2.7.2 Extended Period Simulation (EPS)

Extended period simulation is a type of linked steady state run that tracks a system over time. The necessity to run Extended period simulation relates because the system activities vary with time.

- ❖ Demands fluctuate throughout the day.
- ❖ Pumps and wells are turned on and off,
- ❖ Pumps and wells are turned on and off,
- ❖ valves are opened and closed, and
- ❖ tanks are filled and drained.

**Simulation Time:** Depending on the aim of the analysis, an extended-period simulation can be run for any period of time. the most frequent simulation time is often a multiple of 24 hours Because the most recognizable pattern for demands and operations is a daily one.

### **3. MATERIALS AND METHODS**

#### **3.1 Methods**

The study was divided into three stages. The first phase consisted of a desk research that focused on a literature review and the development of data gathering methods. The second phase entails secondary data collecting from legal organizations, primary field data gathering from selected regions of the town, and conversations with the municipality's water supply office's stakeholders. Finally, the acquired data was examined and the thesis was written in the final phase. The actions in each of these phases are explained in the sub-sections that follow, as well as in the schematic representation of the entire study strategy illustrated in figure below.

The desk research included a review of relevant studies. The means of data collecting and data collection indicators were created during this phase of methodology. The features of municipal water delivery systems were investigated. The pressure and quality restrictions of the water supply systems at lower elevations areas of the water delivery services were investigated.

In addition, literature evaluations on water supply system evaluation techniques and processes were conducted. The hydraulic performance of current water supply systems was assessed and discussed based on the views of users in the study area by gathering diverse customer opinions at the household level and at the water supply office using the following water system indicators.

Water quantity given to consumers, water supply system dependability for continuous delivery, water point convenience, distribution system coverage, and pump operating schedule and efficiency.

## 3.2 Description of Study Area

### 3.2.1 Location

Jigjiga Town (which is the capital city of the Somali region) is found within fafan zone and is located at 675 km from Addis Ababa and at closer distance to Hargeysa.

It Covers a land area of about 9218 ha (Structure Plan 2012).

The municipality astronomically lies between 9° 16' 30" to 9° 24' 30" N latitude and 42° 44' 0" to 42° 51' 0" E longitude. The altitude of the city ranges between 1620 to 1720 meters.

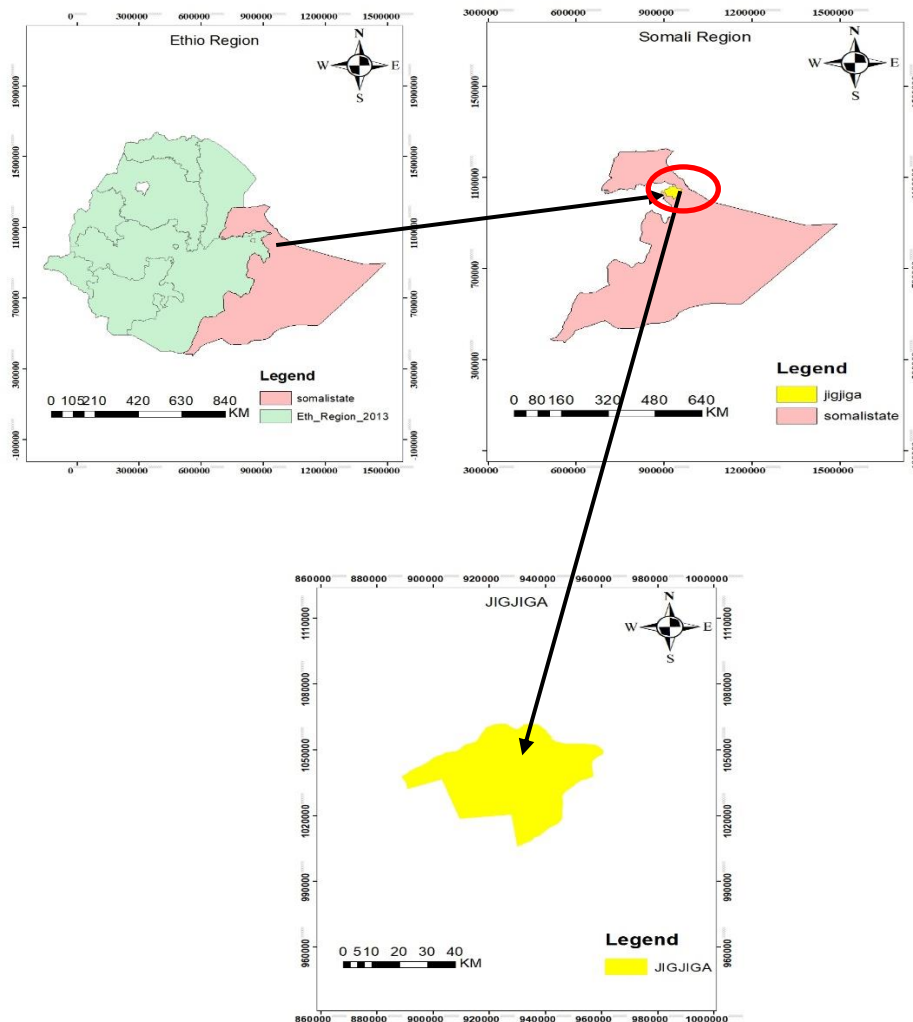


Figure 3-1 : Location of study area

### 3.2.2 Population

According to (CSA, 2012) the total number of Jigjiga Town population has been found 111,069 for the year 2010 out of this population were 52202 are males(47%) and the females were 58867 (53%)

### 3.2.3 Climate

The climate of Jigjiga Town is a subtropical highland climate (Köppen climate classification) extremely wet and lush during rainy season, as with the rest of the Ethiopian highlands, Seasonal differences relate only to rainfall, as temperatures year round are cool to mild in the mornings and uniformly very warm though not hot during the afternoons.

There are two rainy seasons: the main meher rains occur from July to September, and the short belg rains in April and June. The dry season, known as bega, is cooler by morning than the wet seasons due to lower cloud cover, but equally hot by afternoon though less humid

According to (Asfaw et al., 2016), Mean maximum annual temperature of the city is 19.54°C, while monthly average temperature ranged between 25.24 °C in November to 29.39 °C in March.

As they say the minimum and maximum rainfall lying between 400mm and 800mm with the annual mean of 712mm is attributable to Jigjiga Town and its vicinity.(Berisa & Birhanu, 2015)

### **3.3 Existing Water Supply in Jigjiga Town**

The system's water will come from underground sources. Two well fields will be available. The first well field is a pre-existing well field with 22 operational boreholes drilled across the city. The other well field is a new well field found about 23 km south of the city in Jerer Valley, with 8 wells drilled and linked to the system. The anticipated production rate of the existing well field, which will be kept in the new system and is now piped directly to the beneficiaries, is around 52 liters / sec from the 22 operational wells. According to the proposed design, water extracted from the existing 22 boreholes would be piped straight into the newly constructed 1000m<sup>3</sup> reservoirs and then redistributed to the beneficiaries via distribution network. The water produced from the new well field in Jerer valley, on the other hand, will be pumped to the new 3000m<sup>3</sup> reservoirs through two booster stations placed along the 23km pressure line, with a total discharge of around 75l/s projected from this freshly built pressure line. As a result, if the system is operating securely and without any faults, the present system can deliver a total of 127 l/s, which is 18.59 % less than the theoretical average day demand of the system of 156 l/s required in 2020 and 51.7% less than the necessary in 2030, which is 263 l/s. Because the yield and water quality of the other existing boreholes is decreasing, no further discharge is predicted from the ancient boreholes. As a result, these boreholes will be abandoned or limited to animal watering or other such uses.

The existing water supply system of the city was designed in 1975 by a German consultancy for an expected total population of 20,000. There is a higher demand of water supply due to the increased population and effects of climate change. The distribution of water is provided with piped system and on-site sources. Jigjiga Town water sources are classified in to two: the modern water supply system which is the ground water i.e. boreholes through pipes and the traditional system sources directly supplied from surface water sources and hand dug

wells in the residential areas, especially southern part of the city. In addition, considerable numbers of people obtain water from local water venders called ‘Beyollie’ who dispense water using plastic barrel carried on donkey carts.(Asfaw et al., 2016)

The former design of 2001 has two phases. Phase I covers the time from 2004 to 2014 and phase II covers from 2014 to 2024. It was scheduled the system to be constructed and give service in 2004. However, it was not implemented. Thus, in this design review, the phase year is adjusted and phase I covers the time from 2010 -2020 and Phase II from 2020-2030.(SRSWRDB, 2011)

### 3.3.1 The Major Components of the Existing System Are the Following;

Table 3-1: Components of existing system

Existing structure type	X-Coordinate	Y-Coordinate	Elevation(M)
25 (22 functional & 3 Non-functional) bore holes of different capacity around the city (1-6l/s)	259,235.74	1,033,369.08	1,651.90
	259,961.01	1,033,462.94	1,644.90
	263,250.58	1,019,431.90	1,444.90
	263,574.16	1,019,105.13	1,438.90
	264,159.87	1,018,054.34	1,446.90
	257,021.60	1,042,416.35	1,685.90
	259,774.67	1,035,772.67	1,652.40
	256,993.18	1,043,212.08	1,683.00
	259,589.15	1,035,778.61	1,652.00
8 Functional bore holes of different capacity at Jerer well field (5-20l/s)	262,052.11	1,021,224.12	1,467.90
	262,614.51	1,020,465.05	1,453.90
	262,758.12	1,018,979.64	1,444.90
	263,172.15	1,018,884.03	1,438.90
	264,018.79	1,018,626.85	1,438.90

	264,260.37	1,018,074.44	1,446.90
	264,951.85	1,017,480.20	1,444.90
	265,498.67	1,017,052.17	1,434.90
350m <sup>3</sup> servicerereservoir( not functional)	255750.85	1034893.8	1740.60
new reservoirs each having a capacity of 3000m <sup>3</sup>	262501.05	1033258.27	1788.25
new reservoirs each having a capacity of 1000m <sup>3</sup>	254660.2	1036967.6	1778.8
Public fountains 17 numbers (9 Functional & 7 Non-Functional.) and cattle troughs			
Newly constructed distribution system and auxiliary works			
Main pump house & two Booster station # 1 at Jerer	262998.97	1021399	
Main pump house & Booster station # 2 at Jerer	260813	1026926	
Collector pipes and two rising mains at Jerer valley			
Pipe distribution network comprising of PVC with sizes ranging DN 50-400 and length of 81,870m & DCI with a diameter of 500mm total length of 2,390 meters			
Rising main line from Jerer Well field to 3,000m <sup>3</sup> Reservoir DCI pipe having a length of 17000 meters			
Auxiliary Building, administration building and store and workshop.			

### 3.3.2 Distribution Network

The distribution pipes are constructed in accordance with the city's road master plan. Areas that might be used for future expansion have been identified. An arbitrary pipeline is intended for expanding regions where the present master plan does not cover, and it will be adjusted in the future as per the future master plan to be established. The distribution system

is planned and built for phase II's peak hour demand, and pressure and velocity are verified for phase I.

The pipes are sized in such a way that:

- the velocity should not be too high, causing high head loss, or too low, preventing free circulation of water, causing stagnation of water, which leads to bacterial growth;
- the pressure should not be too high, causing higher investment costs, or too low, causing inconvenience to the water consumers.
- The entire pipe should be looped, allowing for free multidirectional water circulation.
- the pipe diameter should not be less than 50 mm.

All of the old distribution pipes were assessed and were removed from the newly installed system because they were too old and had limited hydraulic capacity, but local plumbers continue to use them to deliver water to local residents as the new distribution system is being installed.

### 3.3.3 Reservoirs

The primary purpose of storage reservoirs is to deliver water to customers when facilities are shut down, or, in the case of urban supplies, to help the system meet peak demand if the source or pumping facilities are unable to offer the needed capacity. The existing service reservoir was built in 1968 E.C. and has a capacity of 350 m<sup>3</sup>. It's in the heart of town, at an average elevation of 1737 meters above sea level. It features a valve chamber and is built of reinforced concrete. The reservoir was designed with the expectation that water from boreholes would be immediately pumped to the distribution system, with any excess water being kept in the service reservoir and utilised during peak hour demand. However, because

to incompatibility between production and consumption, the reservoir has not yet performed as intended. Water is piped straight to the distribution network, bypassing this service reservoir. The reservoir is in poor structural condition, as noticed during the field inspection and according to information acquired from the water service bureau; excessive fractures are visible on the external surface of the wall. This reservoir will require specific maintenance in order to become a part of the city's future water delivery system. The external wall's plastering has already been removed. The images below indicate the present state of the reservoir. In addition, the region has constructed two concrete reservoirs, one with a capacity of 1000 m<sup>3</sup> and the other with a capacity of 3000 m<sup>3</sup> along the route to Kebribeyah.



Figure 3-2: Current Status of the existing 350m<sup>3</sup> reservoir

Table 3-2: Reservoirs in Jigjiga Town

No.	Volume	Year of Construction	Elevation	Remark
1	350m <sup>3</sup>	1996	1635m	Not Functional
2	1000m <sup>3</sup>	2009	1778.8m	Functional
3	3000m <sup>3</sup>	2009	1782.2m	Functional

#### 3.3.4 Water Production

Jigjiga Town receives its water from a variety of boreholes situated across the city. In this area, there is no perennial stream. Although there is a dam near the city, the amount of water available does not enable the construction of a treatment facility. As a result, it is only

utilized for animals and other purposes. People also use unprotected sources such as dug wells and ponds for diverse purposes in addition to boreholes.

The supply is insufficient, and there is a severe water scarcity in the city. The public water fountains and household faucets are frequently dry. In the city, water selling is common, and a 25-liter Jerrycan costs around 40 birr. The amount of water generated by existing boreholes (52 l/s) is less than a quarter of the estimated average daily requirement in 2030, which is around 263 l/s. Currently, borehole water is piped directly into the distribution system. The city relies on groundwater for its water supply.

### **3.4 Data Collection**

Prior to the fieldwork, the regional Water Resource Bureau prepared the essential information, which was used to choose the research area. The city administrative municipality office, the regional Water Mines & Energy Bureau, and other related offices of the city Water Service Office and others used to collect secondary data. Discussions with local experts from the regional water mining and energy bureau direct concerned various technical staff and departments provided useful qualitative data.

#### **Secondary Data Collection**

Secondary data were gathered from recognized or legal organizations, agencies, and literatures. The following secondary data was collected: town water supply network data, including node elevation, type of water sources and yield or discharge, depth of bore hole, static and dynamic water level, existing pump head and discharge capacity, and power, current and forecasted population, and growth rate The node's base demand, the layout and length of pipe links, as well as their diameter the amount of water consumed Time spent operating the pump Water consumption by mode of service on a monthly basis, Water production on a monthly basis.

## **Primary data**

The information was gathered by observation, collection, and measurement during a field survey.

- ❖ To accomplish calibration, pressure measurements were obtained at various times and locations.
- ❖ Using diverse technologies such as GPS and GIS to obtain a location of the research area.
- ❖ Forecasting the number of population in the next decade in order to estimate how much water the population will use in the coming years.

## **3.5 Method of Data Analysis**

### **3.5.1 Population Projection & Forecasting Methods**

There are different methods for population forecasting but the most important 3 methods are Arithmetic Increase Method, Geometrical Increase Method and Incremental Increase Method.

In Arithmetic increase method is based on the assumption that the population is increasing at a constant rate while the Geometric increase method is mostly applicable for growing cities having a vast scope of expansion.

So for that reason, it will be used Geometric Increase Method to forecast the future population.

$$P_n = P_o \left[ 1 + \frac{r}{100} \right]^n$$

### 3.5.2 Population Projection

The demand for water in a given city is proportionate to the population to be serviced. The population of Jigjiga Town was estimated to be 116,069 in an Ethiopian CSA study conducted in 2010, and this figure was used as the basis for the present estimate.

The total population of Jigjiga Town for the base year which is 2010 is estimated to be 111,069 with an average annual growth rate of 4.11% as per the CSA Final result of 2015.

This figure has been adopted for this research.

Table 3-3: Jigjiga Town projected population figure (2010-2030)

year	po	r%	$(1 + r)^n$	Estimated Jigjiga University population	Total Population
2010	111069		base year	5000	116069
2015		4.11	1.2	11000	146849
2020		4	1.5	20000	184409
2025		3.8	1.7	20000	214336
2030		3.6	2.0	25000	250314

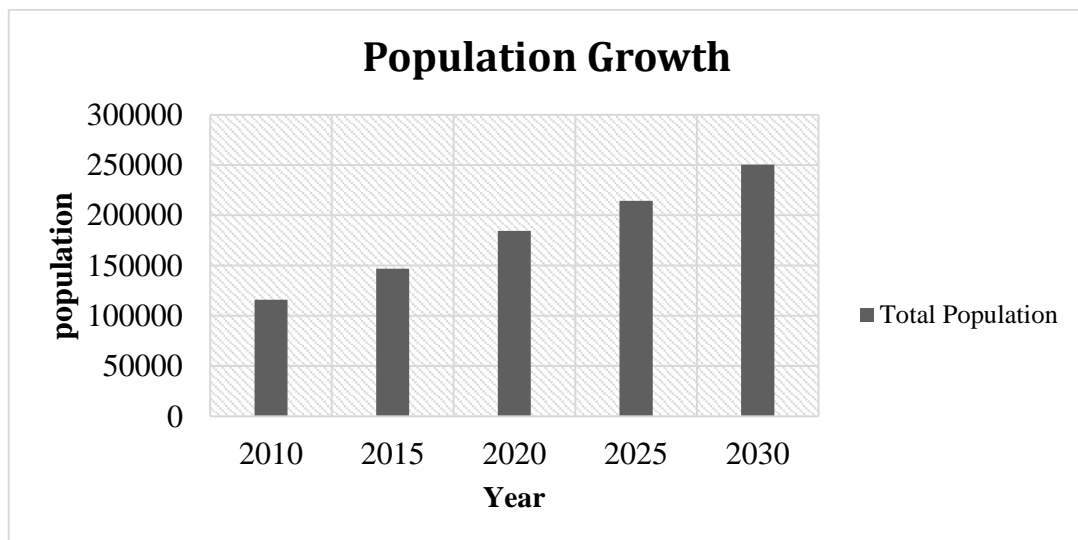


Figure 3-3: Population Growth

### 3.6 Current and Future Water Demand Analysis

In this study water demand is classified two major categories as domestic and non-domestic water demand

#### 3.6.1 Overall water Demand

The Total water demand for a particular year is obtained by multiplying the per capita demand in each category of the year under consideration with the corresponding population figure for the same year.

$$\textit{Total water Demand: Population number * Per Capita Demand(Pcd)}$$

#### 3.6.2 Domestic water demand

Water for drinking, food preparation, washing, cleaning, and other home functions are all part of the domestic water demand. The quantity of water used for domestic purpose varies according to the user's lifestyle, living standard, environment, mode of service, and, most importantly, their affordability. The theoretical domestic water demand for various population categories of domestic consumers is computed for various population categories of domestic consumers in any city. The population of most Ethiopian cities is serviced by five different types of water supply systems.

- a) House tap users
- b) Yard tap users
- c) Neighborhood Tap users
- d) Public tap users
- e) Traditional source users

However, there are individuals who use traditional sources and those who buy water from vendors. This method of service, however, is not included in the study since it is not their

only option, and they prefer to use it as a backup to provide for a shortfall in water demand when their primary mode of service is interrupted or insufficient.

For different categories of domestic users, the theoretical domestic water demand for varying populations of any city is estimated. The assumptions are based on Water Works Design and Supervision's previous study of the % service level for home connections, yard connections, and public fountain users.

The values in table below were used to establish domestic per capita demand by mode services of Jigjiga Town.

Table 3-4: Water consumption by mode services(MOWR, 2006)

Mode of service	Per capita water Demand(l/c/d)
House Tap user	70
Yard Tap user	30
Neighborhood Tap user	40
Public Tap user	25

### 3.6.3 Non Domestic Water Demand

Institutional, commercial (public), and industrial demand are the three types of non-domestic demand. Estimating non-domestic demand requires a detailed analysis of the town's past, present, and future, commercial, institutional, and industrial establishments. Furthermore, it is essential to define exactly the industry's scale since it directly regulates water use, having an impact on the town's overall water consumption pattern.

### 3.7 Climatic and socio-economic Factors

There are 2 main adjustment factors which are the Climate Adjustment factor and Socioeconomic adjustment factor.

The demand for water is also closely connected to the climatic and socioeconomic characteristics of a certain city. Cities with higher average temperatures require more water than cities with lower average temperatures, while those with more socioeconomic activity demand more water than cities with lower economic activities. The standard of living will be higher in cities with higher economic activity and growth, requiring more water for both domestic and non-domestic usage. Furthermore, religious background has a major impact on water consumption.

#### 3.7.1 Climatic Adjustment factor

Climate adjustment factor is concerned with the climate of the area which is directly related to the consumption of the water. Hence, to consider climatic conditions, climatic factors are adopted and applied to the average. From the hydro metrological data of the region, Jigjiga Town has a mean annual precipitation of higher than 900 mm. Therefore, a climatic adjustment factor of 1.0 is used to adjust the per capita average domestic demand.

Table 3-5: Demand adjustment factors due to climate effects (MOWR, 2006)

Group	Mean annual precipitation (mm)	Factor
A	900 or less	1.1
B	900-1200	1.0
C	1200 or more	0.9

### 3.7.2 Socio-economic adjustment factor

Socio-economic conditions also play a role in determining the water consumption in a town. factor which influences the socio-economic factor of a town is to look at its development in growing infrastructures. For the reason, Jigjiga Town has growing infrastructures, Jigjiga is one of the cities in the country with high social, economic, and religious values,, it is grouped in-group A, having a socio-economic adjustment factor of 1.1.

Table 3-6: demand adjustment factors for socia - economic situation(MOWR, 2006)

Group	Description	factor
A	Town enjoying high living standard and high potential for development	1.10
B	Town with high potential for development but lower living standard at present	1.05
C	Town under normal Ethiopian conditions	1.00
D	Advanced rural Towns	0.95

## 3.8 Water Loss Analysis

### 3.8.1 Unaccounted for Water(UFW)

The whole annual water produced and delivered to the distribution system, as well as the water billed from individual customer meter readings, were used to calculate the Jigjiga town total water loss. all water consumptions in the city were metered.

Water losses in the water supply system, illegal connections, firefighting, reservoir overflow, and inaccurate metering are all examples of unaccounted-for water. It's also known as "non-revenue-water," which relates to water for which the bills have not been paid. unaccounted for water (UFW) has been utilized in this research as a synonym for total water loss.

$$Total\ waterloss(\%) = \frac{(Total\ water\ produced - Total\ water\ billed)}{Total\ water\ produced} * 100$$

### 3.8.2 Water Loss Per Number of Connections

This equation was used to calculate the water loss per connection.

$$\text{Water loss} = \frac{\text{Annual loss} * 1000}{\text{Number of connection} * 365\text{days}}$$

### 3.8.3 Water Loss as Per Length of Pipes

One approach to express the loss is to express it in terms of water loss per kilometer of main pipe. Total water loss per pipe length stated as:

$$\text{water loss} = \frac{\text{Annual loss}}{\text{Length in KM} * 365\text{days}}$$

### 3.8.4 Real and Apparent Loss Calculation

According to IWA (International Water Association) , water loss have two main parts: Real Losses and Apparent Losses.

Apparent loss is The loss due to illegal consumption, customer metering errors, and data handling faults. The physical losses of the water distribution system, such as leakage and storage overflows, are referred to as real losses. Because these losses indicate water that is collected and processed but never reaches useful use, they raise the water utility's production costs and put a lot of stress on water supplies.

$$\text{Unavoidable annual real loss(UARL)} = [18 * L_m + 0.80 * N_c + 25L_p) * P$$

Where;

$L_m$  = Length of mains in km

$N_c$  = Number of service connections

$L_p$  = Total length in km of underground connection pipes (between the edge of the street and customer meters)

$P$  = Average operating pressure in m

The infrastructure leakage index (ILI); A more accurate indicator Represents the level of infrastructure management quality(S. Sharma, 2008).

$$ILI = \frac{CARL}{UARL}$$

Where;

CARL: current annual real loss; UARL= unavoidable annual real loss

### **3.9 Water Coverage Evaluation**

The water supply coverage of the Town was first evaluated before analyzing the water loss by using the percentage of mode of service with current customer to determine the level of connection or per - capita demand of the Town.

Water supply coverage is often assessed based on amount, quality, people's financial ability, distance, and other factors; however, the goal of this study is to assess the quantity of supply and degree of connection as they relate to the city's water supply and consumption imbalance. The number of domestic connections per household and the average daily per capita usage are utilized to assess the domestic water supply coverage for the whole research area in this section of the analysis. The volume of water utilized and the level of connection can be used to assess water supply access. The annual water consumption is converted to average daily per capita consumption using the city's population statistics to determine the quantity of water consumed. As shown below, the number of domestic connections per household was also utilized to analyze the level of connection.

#### **3.9.1 Average Daily Per Capita Consumption**

To examine the distribution of water coverage in the study area, the amount of water consumed for household purposes has been aggregated to all users of the system. It's possible

that evaluating household water supply coverage based on consumption volume won't allow for a distribution comparison among the study area(Desalegn, 2005).

In the previous study paper, per capita consumption was assumed to be 25 liters per capita per day, however we may estimate this using actual data.

$$\text{Per capita Consumption} \left( \frac{\text{L}}{\text{person}} \right) = \frac{\text{Annual consumption in}(M^3) * 1000L/M^3}{(\text{Number of Population in city} * 365\text{days})}$$

$$\% \text{of water Coverage} = \frac{\text{Annual water production}}{\text{Annual water consumption}} * 100$$

### 3.9.2 Level of connection per family

The amount of water connection is a crucial aspect for evaluating the level of water coverage that was the subject of this section, as well as it has a direct influence on the water losses that were dealt with separately. To investigate the distribution of water connections throughout the city's various sites, the total number of connections is converted to a connection per family using population statistics from the city.

The average number of connections per family is calculated using the average family size of 5.57. According to the 2007 census, the following phrase was used.

$$\text{Connection per family} = \frac{\text{total number of connection by the city}}{(\text{number of population by city/average family size})}$$

### 3.10 Modeling a system Using WaterGEMS

The water distribution system layout will prepare using the surveyed data of base demand, Elevation and directions of Northing and Easting of Junctions, Source and Tanks and pipe data at links using WaterGEMS software. The existing water supply design network will evaluate with respect to the existing operating situation of the network. Determination of

head loss, velocity of the flow and pressure in water distribution were done using WaterGEMS software.

WaterGEMS is a water distribution system hydraulic modeling program with sophisticated interoperability, geospatial model creation, optimization, and asset management features. WaterGEMS provides an easy-to-use environment for engineers to evaluate, design, and optimize water distribution systems, from fire flow and constituent concentration studies to energy usage and capital cost management(Bentley, 2014).

Working across CAD, GIS, and stand-alone systems while accessing a single, shared project data source gives WATERGEMS V8i customers the power and adaptability they need. Water GEMS allows utilities and consultants to model using one of four interoperable platforms: Windows for ease of use, accessibility, and performance, ArcGIS for GIS integration, thematic mapping, and publishing, Micro-Station for bridging geospatial planning and engineering design environments, and AutoCAD for CAD layout and drafting. Modeling teams may combine the talents of engineers from many departments, and engineers can shorten their learning curves by selecting an environment that they are already familiar with(Mehta et al., 2017).

Bentley Systems distributes WaterGEMS, a hydraulic simulation program. The parameters that need to be defined for each model component once the spatial model is created are as follows:

- ❖ Nodes: Elevations and the basic requirements;
- ❖ Pipes: Diameters, lengths, and friction coefficient factors for pipes. The pipe material and Hazen William friction coefficient factor of 130 by default in Water GEMS.
- ❖ Tanks: Base Elevation, Minimum and Maximum Levels, and Tank Diameter

- ❖ Pumps: The pump curve is the most essential characteristic determining pump operation. The elevation of the pump is also required.
- ❖ Elevation of the reservoir

After all of the parameters needed to perform the simulation have been entered into the model, a successful simulation run will provide answers to the following questions:

- ❖ Pressure at every single element in the system
- ❖ Velocities in the pipes
- ❖ Flows at every point in time in the system
- ❖ tanks levels at a certain point.
- ❖ Pumping cycles
- ❖ The age of the water and the concentration of constituents.

It also has the capacity of doing system analysis for steady state situations and for any extended period of any time.

After all of that, in the water distribution system it will be used WaterGEMS software in order to lay the water supply distribution system. To compute friction head losses Hazen-Williams equation will be used.

$$HF = \frac{10.68L * Q^{1.852}}{C^{1.852} * D^{4.87}} \dots Eqn 2$$

Where: HF=Head friction; Q=Discharge ( $M^3/sec$ ); L=length of pipe ( $M$ ); D=Diameter ( $mm$ ) and C=Roughness Coefficient which varies for different pipe of materials.

### 3.10.1 Model Calibration and Validation

Once a water distribution model has been created, it must be calibrated to appropriately simulate an actual water distribution network under a set of scenarios. Pressures are

monitored using a pressure gauge device throughout the water distribution system, and the data is used to calibrate the model.

There are a lot of ways to measure the performance of model calibration. So, in this study, the calibration statistics was used the squared relative difference between observed and simulated pressure for each test. The results and the observation data were entered to an excel sheet and the value of squared error was calculated for every test then the mean square error and standard deviation calculated from Excel sheet: the lower values of these parameters, the higher is the accuracy of the calibration process. the level of pressure measurement has been done at 10 random selected points by using pressure gauge instrument

$$R^2 = \frac{\sum(X - X_{avg})(Y - Y_{avg})}{\sum \sqrt{(X - X_{avg})^2 (Y - Y_{avg})^2}}$$

## 4. RESULTS AND DISCUSSION

### 4.1 Current status of water Supply system

#### 4.1.1 Population Projection

The demand for water in a given city is related to the population to be served. According to the CSA, the annual growth rate for urban population at the regional level in 2015 was 4.11 %, using the above CSA (2007) census data as a foundation and applying exponential population forecasting. The latest predicted population number for Jigjiga Town was provided in table below.

Table 4-1: Jigjiga projected population Figure(CSA, 2007) (2010-2030)

	Base	Projected Population			
Year	2010	2015	2020	2025	2030
Growth rate(%)		4.11	4	3.8	3.6
Estimated Jigjiga University	5,000	11,000	20,000	20,000	25,000
Population	111,069	135,849	164,409	194,336.0	225,314
Total Population	116,069	146,849	184,409	214,336	250,314

#### 4.1.2 Population Projection by Mode service

There are four primary types of services for domestic water users in Jigjiga Town , according to information from the town water service office. These are the ones.

- a) House tap users
- b) Yard tap users
- c) Public tab users
- d) Neighborhood Tap users

Table 4-2: Population number per % of connections

Mode of Service	Year				
	2010	2015	2020	2025	2030
%					
HTU	5	6	6	7	8
YTU	22	25	28	31	34
PTU	28	31	34	37	40
NTU	45	39	32	25	18
Total	100	100	100	100	100

6%, 28, 34%, 32% are for a year of 2020, 6% of total populations is expected to be served through house tap users, 28% of the total population through yard tap users, 34% through public tap users and the rest 32% through neighbor tap users.

The MOWIE guidelines were adjusted one more when forecasting the above service levels.

The projection pattern used is shown in the table below.

House tap users (19,650) and Yard tap users (85,032 YTU and 100,176 PTU) are estimated to rise in 2030, whereas neighbor tap users are expected to decline from 25.0% to 18% with a population of 45,457.

#### 4.1.3 Per capita water demands

The MoWIE design standards were used to determine the initial per capita demand figures.

The demand prediction table developed by MoWIE in 2006 is also used to calculate the growth rate. In this regard, stage II demands are taken in consideration of the city's fast economic and population expansion. The initial per capita figure and its growth pattern considered in the system's design are shown in the table below.

Table 4-3: Projected Per capita demand in L/c/day

YEAR	2010(base year	2015	2020	2025	2030
HTU	50	55	61	67	74
YTU	30	33	37	40	45

PTU	20	22	24	27	30
NTU	40	42	45	47	50

## 4.2 Overall Water Demand Analysis

### 4.2.1 Domestic Demand (DD)

Table 4-4: Total domestic demand

Description	Unit	Year				
		2010	2015	2020	2025	2030
Population	No.	116,069	146,849	184,409	214,336	250,314
HTU	m3/d	290	458	723	1,024	1,454
YTU	m3/d	757	1,194	1,903	2,649	3,826
PTU	m3/d	645	990	1,503	2,138	3,005
NTU	m3/d	2,110	2,408	2,633	2,520	2,273
Total Domestic Demand	m3/d	3,803	5,050	6,762	8,332	10,559
Domestic Per Capita Demand	l/c/d	33	34	37	39	42

Domestic Per Capita demand in 2020 is 37 l/c/d, demand is low compared to country standard used for design purpose (30-50 l/c/d)(MoWR, 2002)

### 4.2.2 Summary of the Adjusted Domestic Water Demand

The average domestic water demand is estimated using both climatic and socioeconomic adjustment variables as I mentioned in chapter 3. Table below shows a summary of Projected Populations, Population by Mode of Service, Averages Domestic Demand (m3/d), adjustment factors and lastly, the estimated adjusted average domestic water demand.

The total domestic water demand of the town shows increases from time to time, such as in 2010 total domestic water demand 3,803m3/day and in 2030 this value increasing to 10,559m3/day.

Table 4-5: Summary of adjusted domestic daily demand

Descriptions	Year				
	2010	2015	2020	2025	2030
Projected Populations	116,069	146,849	184,409	214,336	250,314

Total domestic demand (m3/d)	3,803	5,050	6,762	8,332	10,559
(l/s)	44	58	78	96	122
Domestic per capita Demand (l/c/d)	33	34	37	39	42
Adjustment Factors					
Climatic	1.0	1.0	1.0	1.0	1.0
Socio-economic	1.1	1.1	1.1	1.1	1.1
Adjusted Domestic Water Demand (m3/d)	4183	5555	7438	9165	11614
(l/s)	48	64	86	106	134

#### 4.2.3 Non-Domestic Water Demand (NDD)

##### *Commercial and Institutional Water Demand*

The water requirements of health posts, schools, markets, and government offices fall under this group. This demand is computed as 10% of total domestic water demands (MoWR, 2002) based on socio-economic statistics from Jigjiga Town, as shown in Table below.

Table 4-6: Commercial and institutional water demand

	Year				
	2010	2015	2020	2025	2030
Adjusted Domestic Water Demand (m3/d)	4183	5555	7438	9165	11614
Commercial and institutional water demand (10% of Domestic Demand)(m3/d)	418	556	744	917	1161
(l/s)	5	6	9	11	13

##### *Industrial Water Demand*

For planning considerations, the following percentages of DWD were regarded to be a reliable IWD indicator: 30% of DWD in medium and large towns; and 10% of DWD in

small towns (MoWR, 2002). Thus Jigjiga Town industrial water demand is considered 30% of DWD.

Table 4-7: industrial water demand

	Year				
	2010	2015	2020	2025	2030
Adjusted Domestic Water Demand (m <sup>3</sup> /d)	4183	5555	7438	9165	11614
Industrial Water demand (30% of Domestic Demand)(m <sup>3</sup> /d)	1255	1667	2231	2750	3484
(l/s)	15	19	26	32	40

### ***Livestock Water Demand***

Livestock keeping is an important aspect of rural community life, and water is just as important for animals as it is for humans. The majority of the animals are expected to consume from surrounding natural sources such as rivers, streams, lakes, ponds, and springs. If there are no such sources nearby, the animals should be watered from cattle troughs located below water sources intended for human use. according to (MoWR, 2002) 2% of DWD is taken in design consideration .

Table 4-8: Livestock Water Demand

	Year				
	2010	2015	2020	2025	2030
Adjusted Domestic Water Demand (m <sup>3</sup> /d)	4183	5555	7438	9165	11614
Livestock water Demand (2% of Domestic Demand)(m <sup>3</sup> /d)	84	111	149	183	232
(l/s)	1	1	2	2	3

#### 4.2.4 Average Daily Demand (ADD)

The total of adjusted domestic water demand, public demand, industrial demand, animal demand, and system water losses is the average daily demand. As indicated in Table below, the numbers calculated in the previous sections are combined and added to estimate total average daily demand.

$$ADD: DD + NDD + Loss$$

Where; ADD-Total Average Daily Demand, DD-Domestic Demand, NDD- Non-Domestic Demand and (Loss)

Table 4-9: Average daily demand

Descriptions	Unit	Year				
		2010	2015	2020	2025	2030
Domestic water demand	m3/d	4183	5555	7438	9165	11614
Commercial and institutional water demand	m3/d	418	556	744	917	1161
Livestock water demand	m3/d	627	833	1116	1375	1742
Industrial Water demand	m3/d	1255	1667	2231	2750	3484
Average daily demand	m3/d	6483	8611	11529	14207	18001
The estimated water loss	%	11.0%	14.0%	17.0%	21.0%	26.0%
	m3/d	713	1205	1960	2983	4680
Total average day water demand	m3/d	7196	9816	13489	17190	22681

the total water demand of the town was calculated by combining the adjusted domestic and non-domestic water demands, . 11 %, 14 %, 17 %, 21 percent, and 26 % (SRSWRDB, 2011) of total water demand for Jigjiga town were provided for losses while calculating overall water demand. The water production capacity of Jigjiga town sources is 10972.8 m3/day, while the average daily demand in 2025 is 17190 (m3/day), which is very low due to less working hours, fewer borehole yield, pump failure, and lack of maintenance.

#### 4.2.5 Variation in Demand

Water consumption varies greatly depending on the month, day of the month, and hour of the day. Demand is lowest in the winter (cold) seasons and highest in the summer (hot) seasons. Water demand is high during the summer season due to high water usage for various purposes. The fluctuation in daily activities and holidays is associated to the variation in daily activities and holidays. During holidays and festivities, people consume a lot of water. Furthermore, daily demand variations may arise as a result of climatic circumstances and economic activity carried out in the region.

Table 4-10: Maximum daily and Peak hour factor Source: (CSA, 2007)

Population	Maximum Day Factor	Peak Hour Factor
0-20,000	1.3	2.00
20,001-50,000	1.25	1.90
50,001 and above	1.20	1.70

As a result, for economical design of this water supply system, a maximum day factor of 1.20 and a peak hour factor of 1.70 are selected. Due to the adjustment factor, the final of the estimated summery water demand are presented below.

#### *Maximum Daily Demand*

The maximum day demand (MDD) is the amount consumed on any given day of the year. The maximum day factor is the ratio of maximum daily intake to mean yearly daily consumption. This demand is used to calculate source capacity, riser mains, and service reservoir capacity.

Table 4-11 Maximum daily demand

Year	Population size	T. Average daily Demand	Maximum Coefficient (Cd max.)	Maximum Daily Demand
		(m3/d)		(m3/d)
2010	116,069	7196	1.20	8635
2015	146,849	9816	1.20	11779
2020	184,409	13489	1.20	16187
2025	214,336	17190	1.20	20628
2030	250,314	22681	1.20	27218

*Peak Hour Demand*

The peak hour demand is one of the maximum demands in any one hour during the period of the year, and it is calculated by taking into consideration the available water collection hours and amounts collected by each demand category.

The peak hour factor is clearly greater for a smaller population, according to previous research. The recommended maximum day and peak hour factor are presented below, according to water supply design standards published by the ministry of water resource.

Table 4-12 Peak hour demand

Year	Population size	T. Average daily Demand	Peak Hour Coefficient	Peak Hour Demand
		(m3/d)		(m3/d)
2010	116,069	7196	1.70	12233
2015	146,849	9816	1.70	16687
2020	184,409	13489	1.70	22932
2025	214,336	17190	1.70	29223
2030	250,314	22681	1.70	38558

Table 4-13 Summary of water demand projection

Descriptions	Unit	Year				
		2010	2015	2020	2025	2030
Population size	No.	116,069	146,849	184,409	214,336	250,314
Average daily demand	m <sup>3</sup> /d	7196	9816	13489	17190	22681
	l/s	83	114	156	199	263
Maximum daily demand	m <sup>3</sup> /d	8635	11779	16187	20628	27218
	l/s	100	136	187	239	315
Peak hour demand	m <sup>3</sup> /d	12233	16687	22932	29223	38558
	l/s	142	193	265	338	446

Average daily demand of Jigjiga town in 2025 is 199 l/s and the end of design period (2030) is 263 l/s

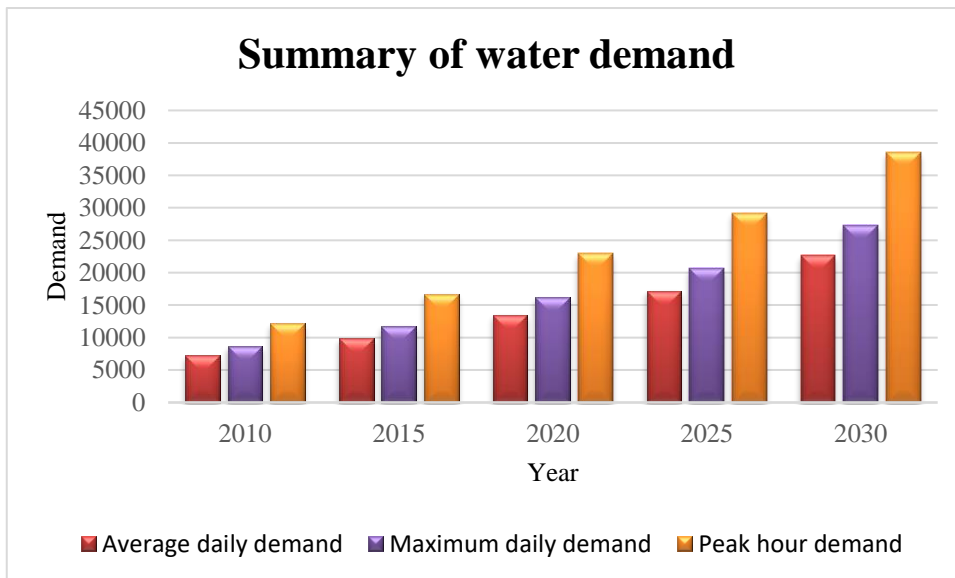


Figure 4-1: Summary of water demand

### 4.3 Water Loss Analysis

#### 4.3.1 Non-Revenue Water (NRW) loss analysis

The overall loss was calculated using three years of production and consumption data from the study area, as indicated in the table below.

Table 4-14: Computed Total water loss

Year	Water Production (m <sup>3</sup> /year)	Water Consumption(m <sup>3</sup> /year)	loss (m <sup>3</sup> /year)	Loss(%)
2013	2,268,708	1,497,347	771361.0	34.0
2014	2,368,771	1,539,701	829070.0	35.0
2015	2,471,959	1,529,759	942200.0	38.1
		Average	847543.7	36

According to the analytical results, the average water loss from the system is 847543.7 m<sup>3</sup>/year, or about 36% of the system intake volume. On the other hand, the average annual water loss in this existing system is 36% which is in the unacceptable limits of <10% according to NRW levels. The major causes of this significant water loss are the current method of water network management with inadequate maintenance, in which problems are addressed only when there is apparent proof of failure, and the utility's low financial resources.

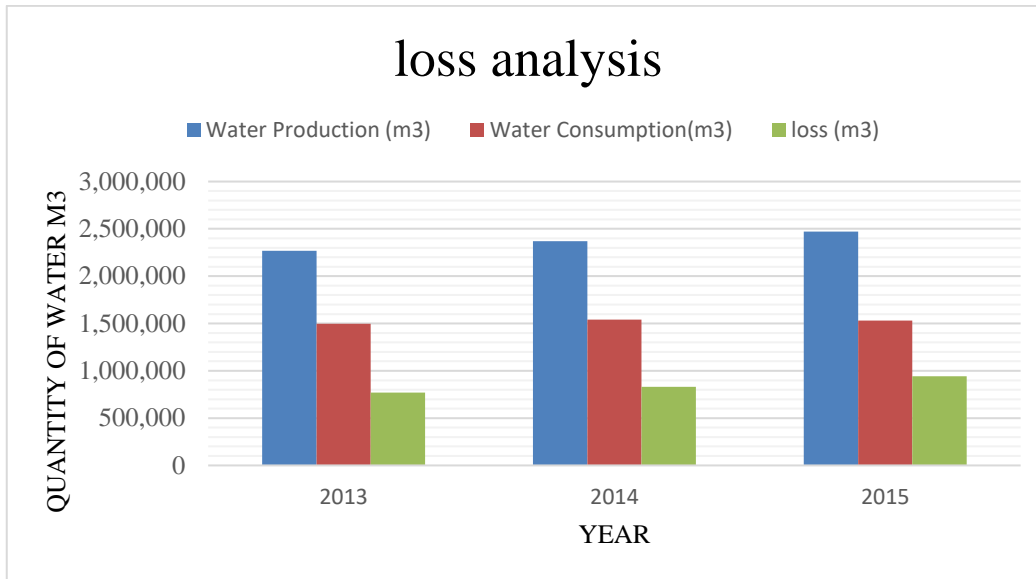


Figure 4-2: Water loss analysis

When the loss is less than 10%, UFW is regarded as acceptable, which can be monitored and managed, intermediate, which can be controlled when the loss is 10-25 %, and a matter of concern, which reduces the water supply when the loss is more than 25%. As a result, the average water of Jigjiga town loss was 36%, indicating that it is a cause for worry (S. Sharma, 2008).

#### 4.3.2 Water Loss per Number of Connection

The total number of connections in the study area is 10,153, and the yearly total water loss estimated using the above table for the three years is 942,200.0m<sup>3</sup>/year, with the most recent and maximum annual total water loss values used.

$$\begin{aligned}
 \text{Water loss} &= \frac{\text{Annual loss} * 1000}{\text{Number of connection} * 365 \text{days}} \\
 &= \frac{942200 * 1000}{10153 * 365} = 254.25 \text{ litre/day/connection} \\
 &= 92 \text{m}^3/\text{year/connection}
 \end{aligned}$$

### 4.3.3 Water Loss as Per Length of Pipes

One approach to express the loss is to express it in terms of water loss per kilo meter(KM) of the main pipe. Total pipe length of Jigjiga town is 76 km

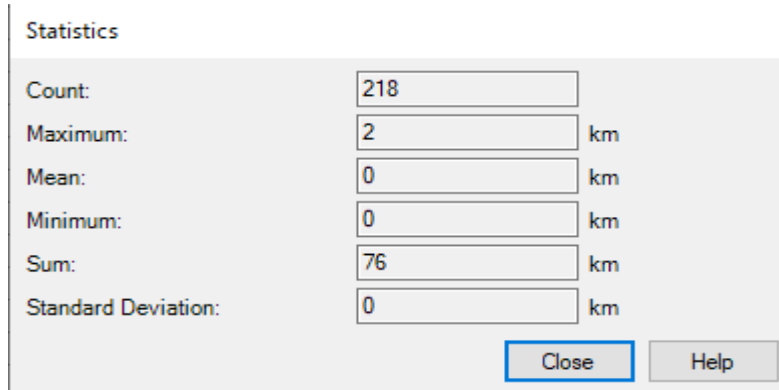


Figure 4-3: Jigjiga town pipe length

$$\begin{aligned}
 \text{water loss} &= \frac{\text{Annual loss}}{\text{Length in KM} * 365\text{days}} = \frac{942200}{76 * 365} \\
 &= 33.97 \text{ M}^3/\text{km}/\text{day}
 \end{aligned}$$

### 4.3.4 Real and Apparent Loss Analysis

The sum of real and apparent water loss is the total water loss. The following equation for calculating Unavoidable Annual Real Losses(UARL) was provided by the IWA Water Loss Task Force, which is widely recognized by water utilities.

$$\begin{aligned}
 \text{Unavoidable annual real loss(UARL)} &= [18 * L_m + 0.80 * N_c + 25L_p] * P \\
 &= [18 * 76 + 0.80 * 10153 + 25 * 5.25] * 57 \\
 &= 548434.05\text{m}^3/\text{year}
 \end{aligned}$$

Infrastructure Leakage Index (ILI) is the most critical benchmarking tool for water losses.

$$ILI = \frac{CARL}{UARL}$$

CARL of 2015 is  $942,200 \text{ m}^3$   $CARL = 942200 - 548434.05 = 393765.95 \text{ m}^3/\text{year}$

$$ILI = \frac{CARL}{UARL} = \frac{393765.95}{548434.05} = 0.72$$

According to the World Bank Institute's guiding lines (2005), the result is defined as Band A. further loss reduction may be uneconomical unless there are shortages.

The real loss of the system is ;

$$rea\ loss = \frac{393765.95}{1686566.02} * 100 = 23.35\%$$

Understanding Real Losses requires priority and selections on whether to repair, replace, rehab, or keep assets in their current state, all while applying pressure management and enhancing the operation and maintenance program.

#### **4.4 Existing Water Supply Coverage in The Town**

##### **4.4.1 Average Daily Per capita Consumption**

According to (Desalegn, 2005), per capita consumption was assumed to be 25 liters per capita per day, the average domestic water supply coverage is 29 liters per capita per day. When compared to the country standard used for design (30 to 50 l/capita/day), this average per capita usage is low.

##### **4.4.2 Level of Connection Per Family**

The level of water connection is a crucial factor in determining the amount of water coverage, and it also has a direct influence on water loss, which will be discussed separately. According to billed data from Jigjiga Town Water Service Office, there are about 14,466 connections or water meters in the study area, 13,117 are private residential customers, 853 commercial customers, 445 government customers, and 51 standing pipe or public tap users. The total number of connections or water meters in the city is about 10,153 households that

get drinking water for domestic use from a tap inside the compound. To examine the distribution of water connections throughout the city's different sites, the total number of connections is converted to a connection per family using the city's population data.

the average family size of 5.57 is used for calculating the average number of connection per family According to the census of the 2007, the average connection per household for the entire town is found to be 0.385, similar to the per capita consumption after analyzing for outliers. This means that on average, more than 3.0 families or fifteen people share a single water tap or connection. In other words, the average household or yard connection in the town is approximately 38.5%.

#### 4.4.3 Water Supply Coverage

The level of water production and water consumption for domestic purpose of the entire town used analysis the distribution of the water coverage in town.

Table 4-15: Water production and consumption of Jigjiga Town (2010,2015 and 2020)

Year	Water Production (m3)	Water Consumption(m3)	Coverage
2013	2,268,708	1,497,347	66
2014	2,368,771	1,539,701	65
2015	2,471,959	1,529,759	62
		Average	64

The town's water supply coverage was gradually decreasing from year to year due to a floating population that shares in the daily water flow, as well as an increase in the number of university and college students, hospitals and health centers, gusts and visitors as a result of conferences, hotels, and industries, all of which contributed to the town's water shortage.

## **4.5 Hydraulic Performance of the Distribution System**

The goal of the hydraulic performance evaluation model is to judge and quantify the outcomes of water distribution system. The hydraulic component of the performance assessment using the model created during this thesis is the most important aspect.

Mathematical models were used to properly comprehend the state of the level of service when it came to component failure and performance measurement. It will also be easier to maintain and operate the system if you can clearly see where the actual water supply components are located within the system.

WaterGEMS software was used to perform hydraulic modeling in this theses since it is free and user-friendly, which is important for water supply systems like the one under study.

WaterGEMS simulates hydraulic and water amount in pipe networks over a extended period of time. To comprehend the reality situation on the ground, the software analyzes the flow in the distribution system, pressure on the node, and head of water within the reservoir.

### **4.5.1 Hydraulic Modeling Calibration and validation**

The modeler cannot assume that the hydraulic model is an accurate mathematical description of the system because the relevant data has been obtained and loaded into a simulation software program.

Using the data provided, the hydraulic simulation program simply performs the equations of continuity and energy. As a result, some quantitative information is necessary to quantify model performance in order to calibrate and validate the models, as well as for comparison purpose. The pressure data recorded 10 random points at the system, near-node dwelling faucets was utilized to evaluate the performance of the model in this research.

According to Pearson the measured and simulated data was correlation below

$$R^2 = \frac{\sum(X - X_{avg})(Y - Y_{avg})}{\sum\sqrt{(X - X_{avg})^2(Y - Y_{avg})^2}} = \frac{24.89}{\sum\sqrt{26.51 * 24.20}} = 0.982$$

Table 4-16: Comparison between Measured and Calculated pressure value during EPS

Time	Junction	M. Pressure (X)	C. Pressure (Y)	X- Xavg	Y- Yavg	Sqr(X- Xavg)	Sqr(Y- Yavg)	(X-Xavg)*(Y- Yavg)
7:00 AM	J-52	3.31	3.04	-0.95	-1.28	0.91	1.65	1.22
7:30 AM	J-154	0.71	0.89	-3.55	-3.43	12.63	11.79	12.20
8:30 AM	J-53	5.2	4.9	0.94	0.58	0.88	0.33	0.54
9:00 AM	J-29	2.91	3.41	-1.35	-0.91	1.83	0.83	1.24
10:00 AM	J-60	5.65	5.61	1.39	1.29	1.92	1.66	1.78
11:30 AM	J-6	3.2	3.57	-1.06	-0.75	1.13	0.57	0.80
12:00 AM	J-145	5.28	5.23	1.02	0.91	1.03	0.82	0.92
1:30 PM	J-36	4.58	4.35	0.32	0.03	0.10	0.00	0.01
2:30 PM	J-32	6.5	6.37	2.24	2.05	5.00	4.19	4.58
4:00 PM	J-59	5.3	5.86	1.04	1.54	1.07	2.36	1.59
Sum		42.64	43.23			26.51	24.20	24.89
Average		4.264	4.323					

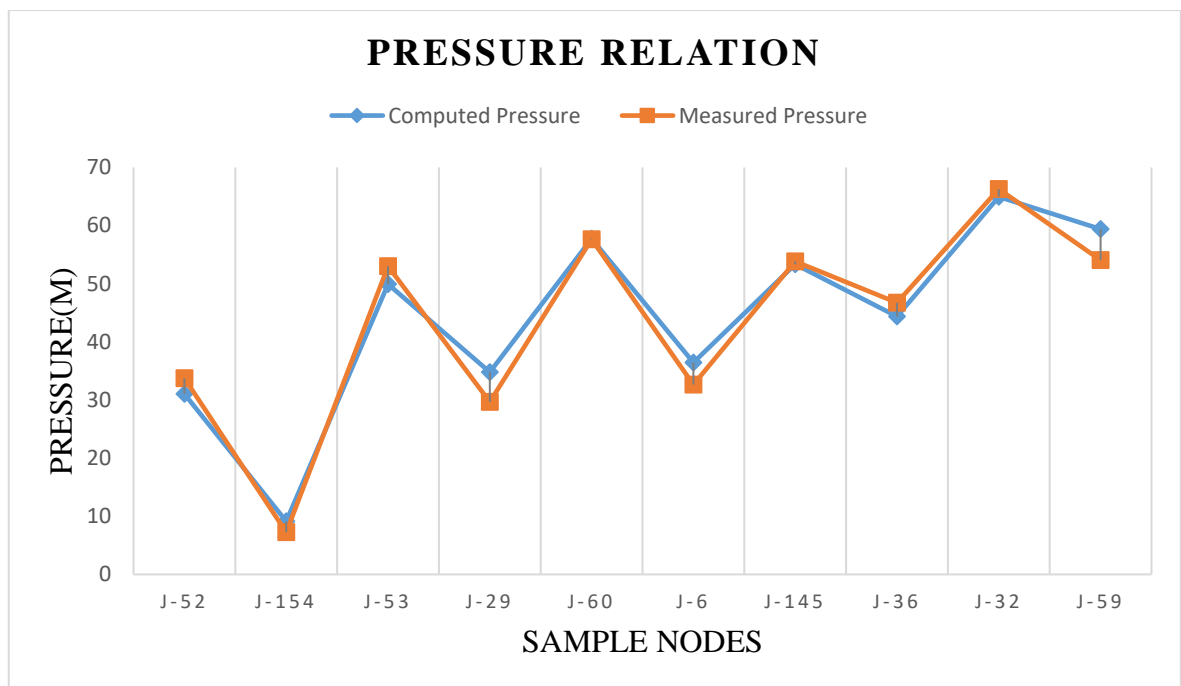


Figure 4-4: Graphical representation of measured and calculated pressure Value

The Pearson Correlation value of ( $R^2$ ) during model calibration is 0.982 or 98.2%, indicating that the model is very strong and the computed pressure is within acceptable limits, indicating that the model is ready to simulate.

#### 4.5.2 Distribution System Map

In the construction of a system model, it is common to use full to design a system map for the water distribution system since it shows a good form of useful features. Information such as pipe alignment, property, material, and diameter might be included in system maps, as well as the position of other system parts like as tanks and reservoirs and node positions like elevations.

Table4-17:Modelsummery

Number of Junctions	155
Number of Pipes	218
Number of Reservoir	2
Flow Units	Liter per second (l/s)



Figure 4-5: Layout of Jigjiga Town water supply system

### 4.5.3 Distribution System Pressure

The pressure at nodes is determined by the network's adopted minimum and maximum pressures, topographic conditions, and network size. The minimum pressure should be maintained at all times to guarantee that customers' demands are met. The maximum pressure also serves as a leakage limit, resulting in water losses in the distribution system.

Table below shows the operating pressure in the distribution network.

Table 4-18: Operating pressure in the distribution network (MOWR, 2006)

Pressure	Normal condition	Exceptional conditions
Minimum	15 m	10 m
Maximum	60 m	70

### 4.6 Steady State Simulation

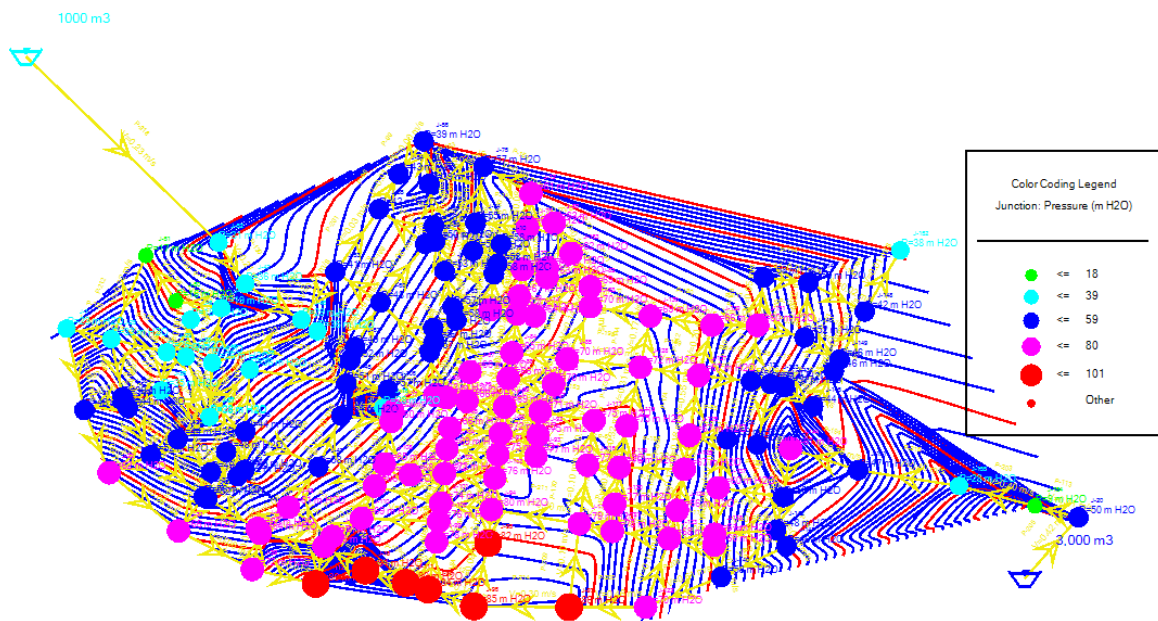


Figure 4-6: Pressure contour map of water distribution system at steady state condition

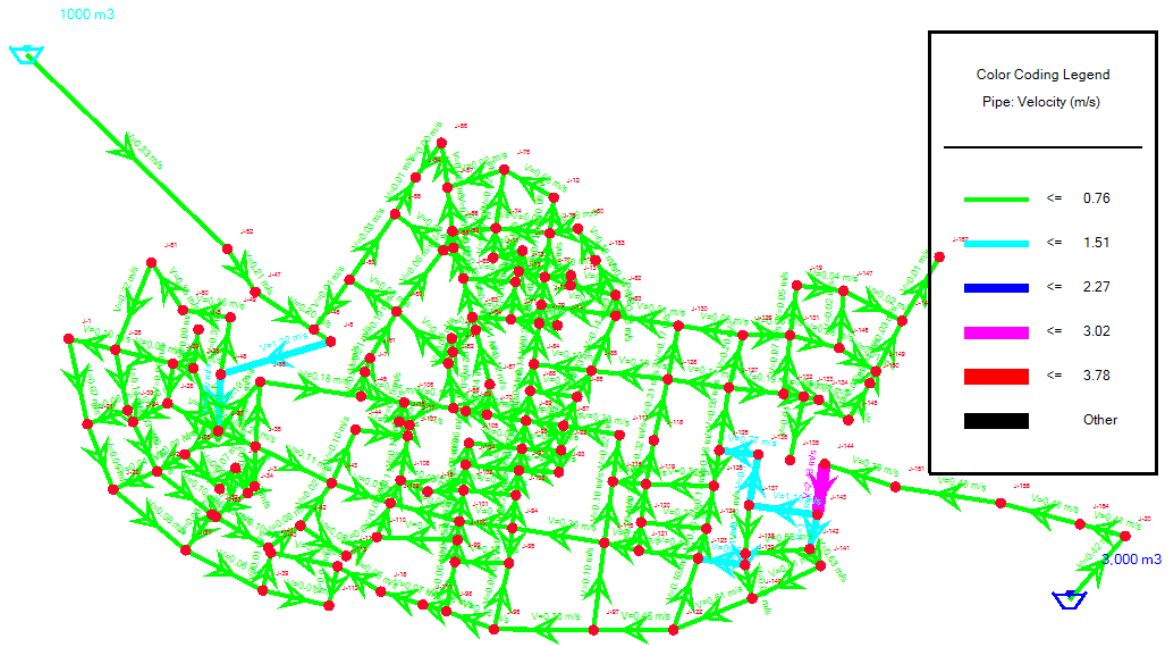


Figure 4-7: Velocity at steady state

Table 4-19: Pressure and Velocity at Steady state

Pressure	Nodes (Number)	Percentage (%)	Velocity	Links (Number)	Percentage (%)
>70	28	18.1	> 2m/s	1	0.5
60-70	41	26.5	1.5-2m/s	0	0.0
50-60	37	23.9	1-1.5m/s	3	1.4
40-50	25	16	0.5-1m/s	11	5.0
30-40	11	7.1	< 0.5m/s	203	93.1
20-30	8	5.2	total =	218	100
15-20	4	2.6			
<15	1	0.6			
Total =	155	100.00			

During the steady state, one node (0.6%) drops below the minimum pressure requirement of 15m, while 18.1 % of nodes exceed the maximum allowable pressure of 70m. Finally, 81.3 % of nodes are within the acceptable pressure range of 15 to 70 meters. As a result, it emphasizes that the 28 nodes are located in low-demand regions, such as the outskirts of town.

During the steady state, however, 93.1% of the pipes are less than the minimum velocity requirement of 0.5m/s, with only one (0.5%) pipe exceeding the highest permitted velocity of 2m/s, percentage of pipes in the permissible velocity range of 6.4 %.

## 4.7 Extended Period Simulation

### 4.7.1 Pressure and Velocity distribution during Minimum Hour Demand

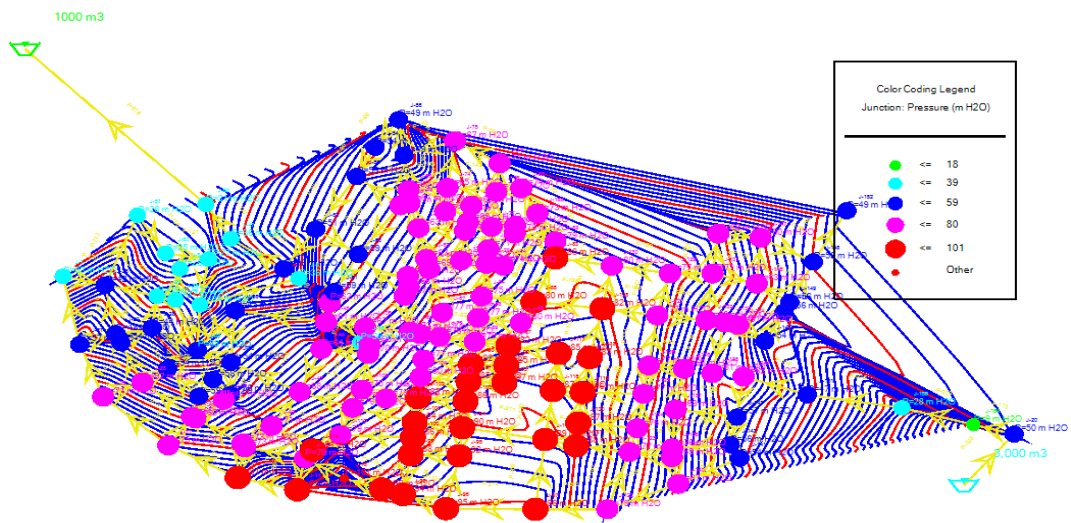


Figure 4-8: Pressure contour map of water distribution systems at extended period simulation at minimum hour demand

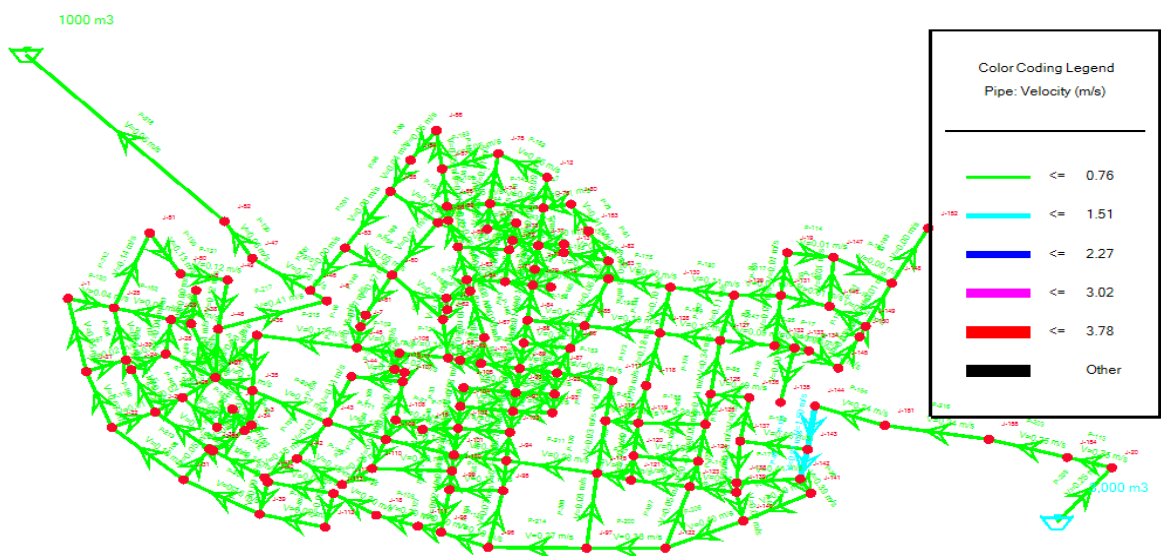


Figure 4-9: Velocity at Extend Period Simulation at minimum hour demand

Table 4-20: Pressure and Velocity at EPS at minimum hour demand

Pressure	Junction (Number)	Percentage (%)	Velocity	Pipe (Number)	Percentage (%)
>70	69	44.5	> 2m/s	0	0
60-70	38	24.5	1.5-2m/s	1	0.5
50-60	22	14.2	1-1.5m/s	0	0.0
40-50	10	6.5	0.5-1m/s	5	2.3
30-40	10	6.5	< 0.5m/s	212	97.2
20-30	5	3.2	total =	218	100
15-20	0	0.0			
<15	1	0.6			
Total =	155	100.00			

Only one node (0.6%) failed to meet the minimum pressure requirement of 15m, while 44.5% of nodes in the EPS exceed the maximum allowable pressure of 70m. The remaining 54.9% of nodes are within the allowable pressure range of 15 to 70 meters.

Furthermore, during EPS at minimum hour consumption, 97.2% of the pipes are less than the minimum velocity requirement of 0.5m/s, indicating two scenarios: the first is that there is no demand at all, and the second is that the supplied water in the system is much less than the town's demand, preventing the system from running in the pipes. Only 6 pipes (2.8%) meets the allowable velocity criteria which is greater than 0.5m/s

Water consumers at higher elevations receive less water than those at lower elevations, and they collect after those at lower elevations have been satisfied or have turned off their water taps (Anore, 2020).

### 4.7.2 Pressure and Velocity distribution during Peak Hour Demand

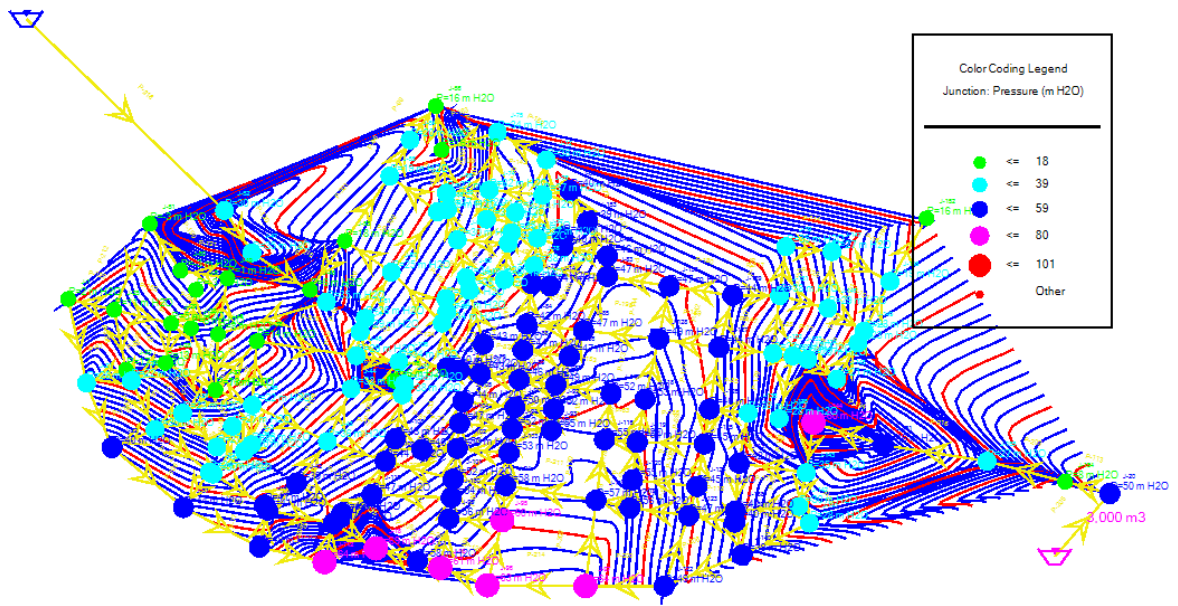


Figure 4-10: Pressure distribution during peak hour demand

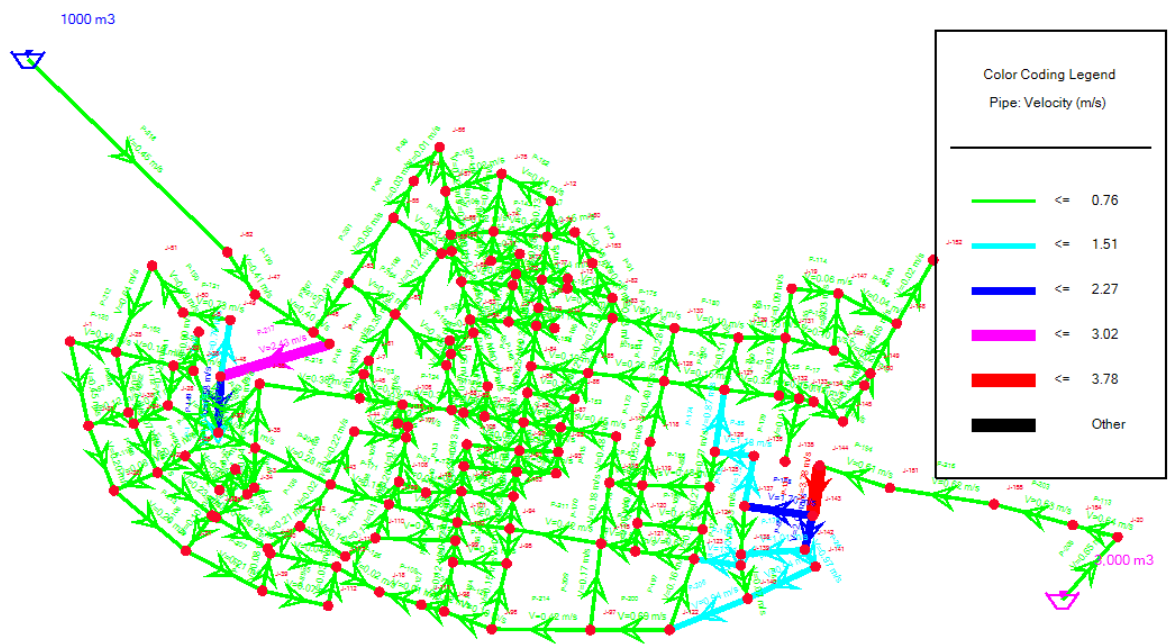


Figure 4-11: Velocity distribution during peak hour demand

Table 4-21: Pressure and Velocity at peak hour demand

Pressure	Nodes (Number)	Percentage (%)	Velocity	Links (Number)	Percentage (%)
>70	0	0.0	> 2m/s	3	1.4
60-70	5	3.2	1.5-2m/s	2	0.9
50-60	18	11.6	1-1.5m/s	7	3.2
40-50	39	25.2	0.5-1m/s	24	11.0
30-40	40	25.8	< 0.5m/s	182	83.5
20-30	29	18.7	total =	218	100.0
15-20	9	5.8			
<15	15	9.7			
Total	155	100			

9.7 % of nodes failed to meet the desired minimum pressure during the PHD at extended period simulation. However, there is any node above the maximum permissible pressure of 70m. While 90.3 % of nodes are within the acceptable pressure limits of minimum 15m and maximum 70m. According to the above data, 9.7% of the results need be improved in order to meet the minimum pressure requirement in the water supply system.

15.1 % of the velocity in the water distribution network is within the recommended limits during peak hour demand, and 83.5 % of the velocity is less than 0.5m/s, and there is three nodes (1.4%) velocity higher than maximum velocity.

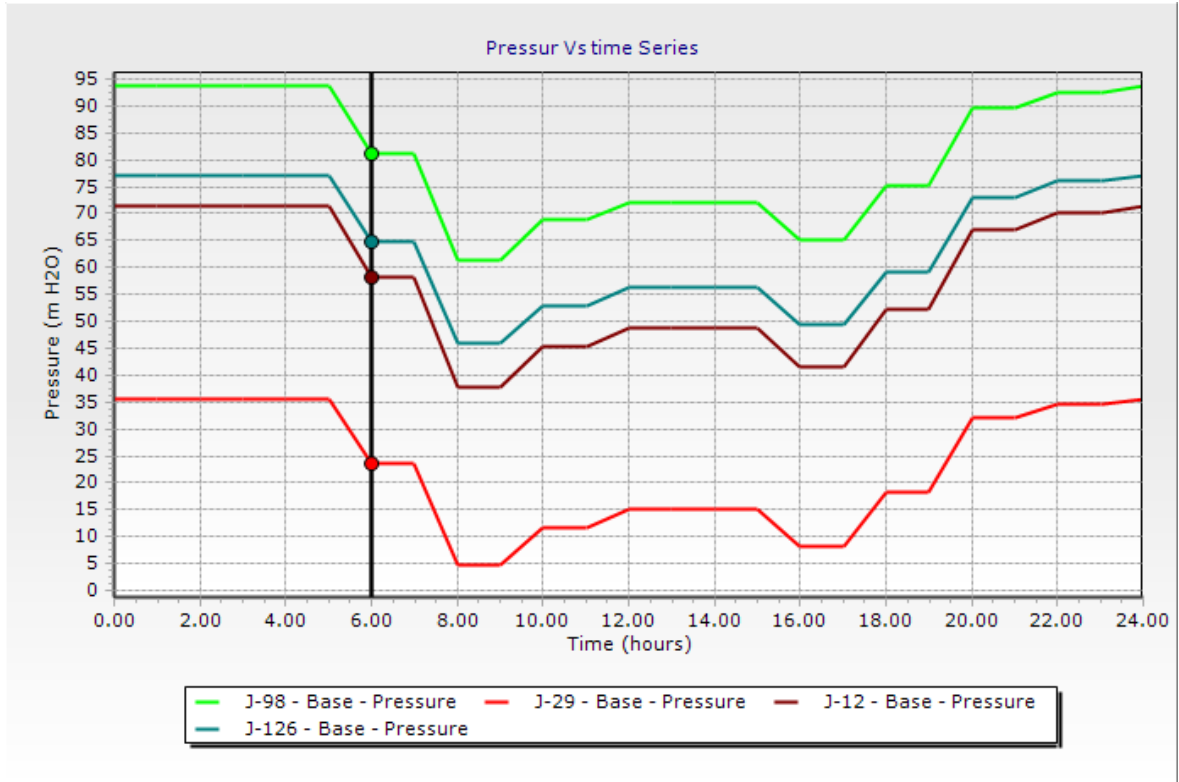


Figure 4-12: Pressure Vs time series

This pressure vs time figure shows how the pressure of four junctions changes over time. For example, at midnight (12AM to 5AM), the pressure is high (about 94m, 77m, 71m, and 36m at junctions 98, 126, 12, and 29 respectively) because there are no users, and then it drops significantly to 61m, 5m, 38m, and 46m at the respective nodes during the sunrise (8AM to 9AM) because demand will be high, and then it rises again and as a result, when demand decreases, pressure increases, and vice versa.

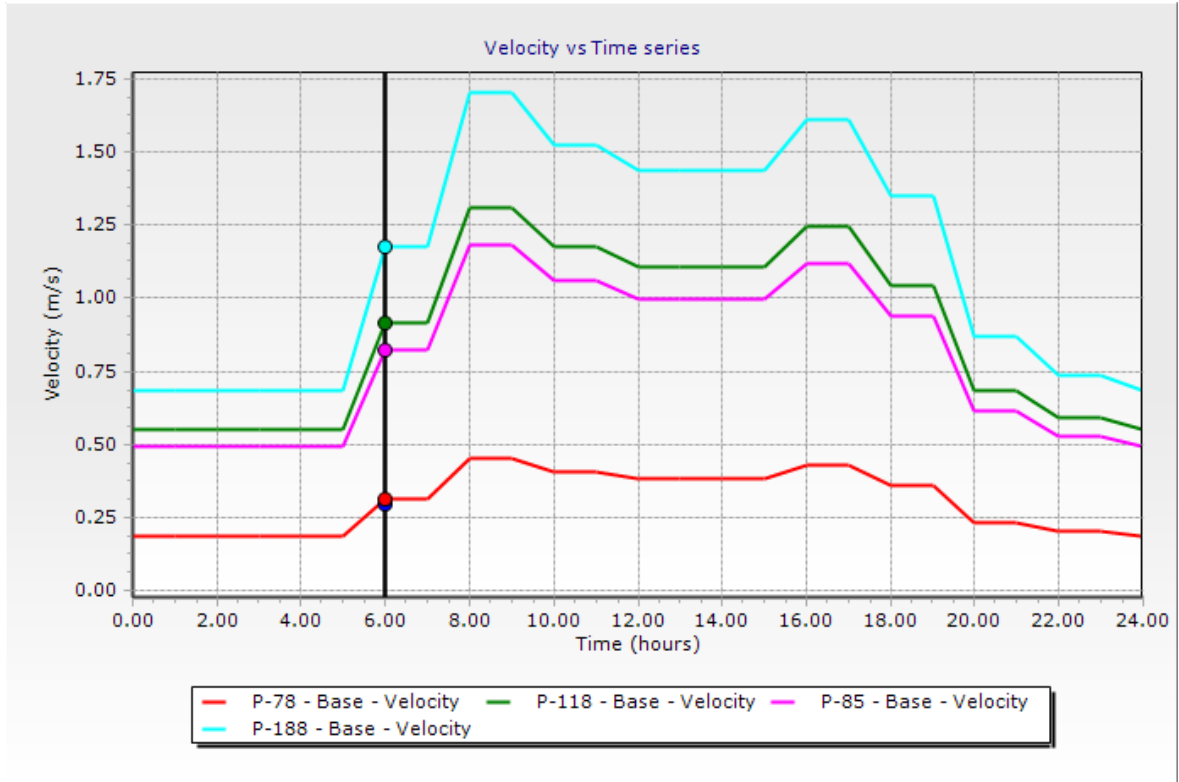


Figure 4-13: Velocity Vs Time series

This velocity vs time figure illustrates the velocity of 4 pipes which changes from time to time, for example at midnight (12:00Am --- 5:00Am) the velocity is 0.68m/s, 0.55m/s, 0.30m/s and 0.49m/s at pipe 188,118,164,85 respectively and then it significantly rises to 0.70m/s, 1.31m/s, 0.67m/s & 1.18m/s at link 188, 118, 164& 85 respectively at morning (8Am --- 9Am) and then it drops again and finally stays constant during the day (12Pm - 3Pm). So, this clarifies when the demand increases the velocity increases or vice versa.

Moreover, the velocity is low at midnight because the demand is low and increases when the demand increases at sunrise. For example, if we look at pipe-188 in the model, the pressure at midnight is 0.68m/s and then it gradually increases until it reaches its maximum capacity of 1.01m/s at the 8:00Am. So, that clarifies that the velocity in the pipe increases as the demand of the water increases.

## 5. Summary and Conclusion

### 5.1 Summary

Water supply in sufficient amount is one of human beings' basic necessities, however Jigjiga Town provision of potable water is inadequate. The situation is deteriorating due to population increase, a shortage of suitable water sources, the town's spatial extension, and a technical and managerial issues that have outstripped its ability to provide adequate water to its residents. As a result, the evaluation of the current urban water supply system was conducted in this study, assessing the hydraulic performance of the WSS and identifying the major problems and propose a solution.

The total water loss has also been calculated using production and consumption volume in water in three years. In general, the overall water loss from the system is 942200.0m<sup>3</sup>/year, or around 36% of the system input volume, according to the analytical results.

The main causes of this substantial water loss are the current method of water network management with poor maintenance, in which problems are addressed only when there is clear evidence of failure, and the utility's insufficient financial resources

62% coverage of the town's water supply distribution system was also assessed using water demand and production, with 942,200m<sup>3</sup> No-Revenue Water, 2,471,959 m<sup>3</sup> production, and 1,529,759 m<sup>3</sup> Authorized Billed consumption for the year 2015.

In order to develop a hydraulic model in this study, WaterGEMS software was utilized, which is capable of modifying high and low pressures at different zones, as well as allowing us to determine whether the velocity in a pipe is above or below the required value. In other words, by doing Extended period simulation and steady state scenarios, it makes model simulation easier and identifies the problem.

## 5.2 Conclusion

After the analysis, it was discovered that there is a gap between the town's demand and supply, with the supplied water only covering 64% of the demand. In addition, the system's annual water loss increased to 36%. This is the major problem that the Jigjiga water supply system is now facing.

As a result, the majority of consumers are unsatisfied with the system's quality of service. The analysis indicated that the acceptable minimum and maximum pressures & velocity have not been met. parts of the distribution receive water with low pressure.

The utmost pressure in the extended period simulation in low hour demand and peak hour demand is 101mH<sub>2</sub>O and 69mH<sub>2</sub>O respectively. 83.5% of the velocity is less than 0.5m/s at PHD.

Because of the variable demand, there is a small problem in the hydraulic system, which is the difficulty to obtain the adequate water pressure and velocity in the system. As a result, pressure reduction valves must be put at high pressure nodes such as J-18, J-97 &etc. and low pressure zones such as J-50 must have booster pumps to raise the pressure.

Because of the low elevation, 18.1 % of the junctions generated pressures greater than 70 m during the steady state simulation.

During EPS at peak hour demand the pressure junctions were within the optimum range in 90.3 %. Because of the high elevation, 9.7% of the pressure junctions had the lowest pressure, which was recorded at J-50

In this water supply system, inefficient hydraulic performance is primarily caused by insufficient performance of water distribution components, a weak management system, and a lack of inspection, all of which lead to a poor level of service to the satisfaction of the user community. Some of the key performance problems discovered and taken into account on the system in this study are:

- ❖ Insufficient water supply at some water stations, unequal distribution
- ❖ Taps and valves are not working properly, and joints are frequently disconnected.
- ❖ On several sections of the system, poor workmanship and a lack of construction oversight resulted in pipe types and dimensions being placed that differed from the approved type and size.
- ❖ Poor management, inspection, and maintenance (O&M) are all issues that need to be addressed.
- ❖ Control demand through reducing waste or loss due to pipe leakage, as well as consumption, through the use of meters and tariffs based on the volume of water consumed.

Finally, involved government agencies such as the Jigjiga Town Water Supply Agency and the WWDSE should monitor the system on a regular basis and pay close attention to the size of the water system in the town.

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## APPENDICES

Appendix 1 : Steady state analysis table for nodes (junctions)

Label	X (m)	Y (m)	Elevation (m)	Pressure (m H <sub>2</sub> O)	Demand (L/s)
J-1	255,235.10	1,035,295.70	1,741.00	23	0.8
J-2	256,450.80	1,034,354.70	1,715.80	48	0.2
J-3	256,591.20	1,034,218.20	1,716.00	48	0.1
J-4	256,335.50	1,034,200.70	1,715.20	49	0.4
J-5	256,181.50	1,035,363.50	1,746.00	18	0.1
J-6	257,146.60	1,035,275.30	1,736.30	36	1.4
J-7	257,396.40	1,035,053.40	1,712.00	52	0.1
J-8	258,029.60	1,035,299.90	1,707.80	56	0.1
J-9	258,037.10	1,035,200.20	1,706.50	57	0.0
J-10	258,545.80	1,035,938.60	1,705.70	58	0.2
J-11	258,332.50	1,035,886.80	1,708.20	56	0.2
J-12	258,774.40	1,036,325.40	1,703.00	61	0.5
J-13	258,896.80	1,035,685.60	1,701.10	63	0.2
J-14	258,802.20	1,035,392.60	1,700.20	64	-0.1
J-15	257,853.70	1,034,181.30	1,696.00	68	0.3
J-16	257,647.30	1,034,691.30	1,736.00	28	0.0
J-17	257,721.50	1,034,666.80	1,704.60	59	-0.1
J-18	257,512.50	1,033,451.20	1,672.90	91	0.5
J-19	260,548.10	1,035,684.30	1,706.60	58	0.5
J-20	262,946.70	1,033,856.10	1,732.00	50	1.5

Appendix 2: Steady state analysis table for pipes

Label	Length (m)	Diameter (mm)	Material	Flow (L/s)	Velocity (m/s)	Headloss Gradient (m/km)
P-1	1	200.0	PVC	16.0	0.51	1.488
P-2	31	200.0	PVC	1.5	0.05	0.019
P-3	70	200.0	PVC	-0.4	0.01	0.002
P-4	72	150.0	PVC	1.8	0.10	0.108
P-5	77	150.0	PVC	-0.7	0.04	0.016
P-6	78	150.0	PVC	2.6	0.15	0.213
P-7	81	150.0	PVC	2.5	0.14	0.199
P-8	82	200.0	PVC	28.6	0.91	4.547
P-9	82	150.0	PVC	-0.2	0.01	0.000
P-10	89	150.0	PVC	0.4	0.02	0.007
P-11	91	150.0	PVC	-0.8	0.05	0.024
P-12	92	200.0	PVC	0.8	0.03	0.006
P-13	98	200.0	PVC	-1.4	0.04	0.017

P-14	100	150.0	PVC	1.9	0.11	0.121
P-15	100	150.0	PVC	0.4	0.02	0.006
P-16	107	150.0	PVC	-3.7	0.21	0.410
P-17	112	200.0	PVC	-2.1	0.07	0.036
P-18	122	200.0	PVC	0.5	0.02	0.002
P-19	122	200.0	PVC	0.5	0.02	0.002
P-20	135	150.0	PVC	0.1	0.01	0.000

Appendix 3: Extended period state analysis table for nodes (junctions) at low hour demand

Label	X (m)	Y (m)	Elevation (m)	Pressure (m H <sub>2</sub> O)	Demand (L/s)
J-1	255,235.10	1,035,295.70	1,741.00	33	0.2
J-2	256,450.80	1,034,354.70	1,715.80	58	0.1
J-3	256,591.20	1,034,218.20	1,716.00	58	0.0
J-4	256,335.50	1,034,200.70	1,715.20	59	0.1
J-5	256,181.50	1,035,363.50	1,746.00	28	0.0
J-6	257,146.60	1,035,275.30	1,736.30	36	0.4
J-7	257,396.40	1,035,053.40	1,712.00	62	0.0
J-8	258,029.60	1,035,299.90	1,707.80	66	0.0
J-9	258,037.10	1,035,200.20	1,706.50	68	0.0
J-10	258,545.80	1,035,938.60	1,705.70	69	0.0
J-11	258,332.50	1,035,886.80	1,708.20	66	0.1
J-12	258,774.40	1,036,325.40	1,703.00	71	0.1
J-13	258,896.80	1,035,685.60	1,701.10	73	0.1
J-14	258,802.20	1,035,392.60	1,700.20	74	0.0
J-15	257,853.70	1,034,181.30	1,696.00	78	0.1
J-16	257,647.30	1,034,691.30	1,736.00	38	0.0
J-17	257,721.50	1,034,666.80	1,704.60	69	0.0
J-18	257,512.50	1,033,451.20	1,672.90	101	0.2
J-19	260,548.10	1,035,684.30	1,706.60	68	0.2
J-20	262,946.70	1,033,856.10	1,732.00	50	0.4

Appendix 4: Extended Period State Analysis Table for Pipe at low Hour demand

Label	Length (m)	Diameter (mm)	Material	Flow (L/s)	Velocity (m/s)	Head loss Gradient (m/km)
P-1	1	200.0	PVC	-6.9	0.22	0.343
P-2	31	200.0	PVC	-2.0	0.07	0.034
P-3	70	200.0	PVC	-0.4	0.01	0.000
P-4	72	150.0	PVC	1.9	0.10	0.116
P-5	77	150.0	PVC	-2.5	0.14	0.198
P-6	78	150.0	PVC	-0.3	0.02	0.004
P-7	81	150.0	PVC	-0.3	0.02	0.006
P-8	82	200.0	PVC	18.3	0.58	1.986
P-9	82	150.0	PVC	0.7	0.04	0.020
P-10	89	150.0	PVC	-1.8	0.10	0.110
P-11	91	150.0	PVC	-2.7	0.15	0.230
P-12	92	200.0	PVC	-1.7	0.05	0.023
P-13	98	200.0	PVC	-0.8	0.03	0.006
P-14	100	150.0	PVC	-1.4	0.08	0.069
P-15	100	150.0	PVC	-1.8	0.10	0.107
P-16	107	150.0	PVC	2.9	0.17	0.270
P-17	112	200.0	PVC	-1.0	0.03	0.009
P-18	122	200.0	PVC	-0.6	0.02	0.004
P-19	122	200.0	PVC	-0.6	0.02	0.004
P-20	135	150.0	PVC	0.0	0.00	0.000

Appendix 5: Extended period state analysis table for nodes (junctions) at Peak hour demand

Label	X (m)	Y (m)	Elevation (m)	Pressure (m H2O)	Demand (L/s)
J-1	255,235.10	1,035,295.70	1,741.00	2	1.4
J-2	256,450.80	1,034,354.70	1,715.80	27	0.3
J-3	256,591.20	1,034,218.20	1,716.00	26	0.2
J-4	256,335.50	1,034,200.70	1,715.20	27	0.6
J-5	256,181.50	1,035,363.50	1,746.00	-3	0.1
J-6	257,146.60	1,035,275.30	1,736.30	35	2.4
J-7	257,396.40	1,035,053.40	1,712.00	29	0.1
J-8	258,029.60	1,035,299.90	1,707.80	33	0.1
J-9	258,037.10	1,035,200.20	1,706.50	34	-0.1
J-10	258,545.80	1,035,938.60	1,705.70	35	0.3
J-11	258,332.50	1,035,886.80	1,708.20	33	0.4
J-12	258,774.40	1,036,325.40	1,703.00	38	0.8
J-13	258,896.80	1,035,685.60	1,701.10	40	0.3
J-14	258,802.20	1,035,392.60	1,700.20	41	-0.2
J-15	257,853.70	1,034,181.30	1,696.00	46	0.5

J-16	257,647.30	1,034,691.30	1,736.00	6	0.0
J-17	257,721.50	1,034,666.80	1,704.60	37	-0.1
J-18	257,512.50	1,033,451.20	1,672.90	69	0.9
J-19	260,548.10	1,035,684.30	1,706.60	35	0.9
J-20	262,946.70	1,033,856.10	1,732.00	50	2.5

Appendix 6: Extended Period State Analysis Table for Pipe at peak Hour demand

Label	Length (m)	Diameter (mm)	Material	Flow (L/s)	Velocity (m/s)	Headloss Gradient (m/km)
P-1	1	200.0	PVC	32.6	1.04	5.839
P-2	31	200.0	PVC	3.1	0.10	0.077
P-3	70	200.0	PVC	-1.0	0.03	0.008
P-4	72	150.0	PVC	2.6	0.15	0.217
P-5	77	150.0	PVC	-0.6	0.03	0.014
P-6	78	150.0	PVC	4.4	0.25	0.571
P-7	81	150.0	PVC	4.2	0.24	0.540
P-8	82	200.0	PVC	44.1	1.40	10.172
P-9	82	150.0	PVC	-0.6	0.03	0.013
P-10	89	150.0	PVC	1.1	0.06	0.042
P-11	91	150.0	PVC	-0.5	0.03	0.010
P-12	92	200.0	PVC	2.1	0.07	0.037
P-13	98	200.0	PVC	-2.2	0.07	0.040
P-14	100	150.0	PVC	3.9	0.22	0.465
P-15	100	150.0	PVC	1.1	0.06	0.048
P-16	107	150.0	PVC	-7.2	0.41	1.436
P-17	112	200.0	PVC	-3.5	0.11	0.092
P-18	122	200.0	PVC	1.1	0.03	0.010
P-19	122	200.0	PVC	1.1	0.03	0.010
P-20	135	150.0	PVC	0.2	0.01	0.001