**HAWASSA UNIVERSITY**

**SCHOOL OF GRADUATE STUDIES**

# ASSESSMENT WATER DISTRIBUTION NETWORK OF WERABE TOWN WATER SUPPLY SYSTEM, SNNP, ETHIOPIA

**M.Sc. THESIS**

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**JUNE, 2023**

**HAWASSA, ETHIOPIA**

# ASSESSMENT WATER DISTRIBUTION NETWORK OF WERABE TOWN WATER SUPPLY SYSTEM, SNNP, ETHIOPIA

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**A THESIS SUBMITTED TO HAWASSA UNIVERSITY DEPARTMENT OF WATER RESOURCE AND IRRIGATION ENGINEERING, INSTITUTE OF TECHNOLOGY, SCHOOL OF GRADUATE STUDIES, HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA**

**IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE PROGRAM OF MASTER OF SCIENCE**

**(IN WATER RESOURCE ENGINEERING AND MANAGEMENT)**

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**HAWASSA, ETHIOPIA**

## APPROVAL SHEET

Hawassa University Institute of Technology School of Bio system and Environmental Engineering, The Research Entitled, has been approved by the school of Bio system and Environmental Engineering for partial fulfillment of the requirements for the degree of Master's with specialization in Water Resource Engineering and Management.

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We the undersigned, members of the Board of Examiners the Final open defense by Mifta Seid Hussen have read and evaluated his/her thesis entitled "Assessment Water Distribution Network of Werabe Town Water Supply System, SNNP, Ethiopia" and examined the candidate. This is, therefore to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree.

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## DEDICATION AND STATEMENT OF OUTHOR

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 thesis have been duly acknowledged.

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## LIST OF ACRONYMS & ABBREVIATIONS

| | |
|---|---|
| A.M.S.L | Above Mean Sea Level |
| AWWA | American Water Works Association |
| CSA | Central Statistical Agency |
| CBA | Customer Billing Aggregation |
| DCI | Ductile Cast Iron |
| DEM | Digital Elevation Model |
| DWD | Domestic Water Demand |
| EPS | Extended Period Simulation |
| FIG | Figure |
| GIS | Geographic Information System |
| GUI | Graphical User Interface |
| GPS | Global Positioning System |
| UFW | Unaccounted For Water |
| NGO | Non-Governmental Organization |
| NRC | National Research Council |
| NRW | Non-Revenue Water |
| NSE | Nash-Sutcliffe Efficiency |
| PCD | Per Capita Demand |
| SCADA | Supervisory control and data acquisition |
| SNNPR | Southern Nations Nationalities People Region |
| UTM | Universal Transverse Mercator |
| WaterGEMS | Water Geospatial Environmental Monitoring Software |
| WDN | Water Distribution Network |
| WDS | Water Distribution System |
| WDM | Water Distribution Model |
| WHO | World Health Organization |
| WSS | Water Supply System |
| WTWSSSO | Werabe Town Water Supply and Sewerage Service Office |
| WTWSSDR | Werabe Town Water Supply System Design Report |

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# ABSTRACT

It's mandatory to assess the hydraulic performance of water supply distribution systems to address water distribution issues in an urban water supply system. This can be accomplished by analyzing the current status of the water distribution system. This study was aimed to analyze the existing water distribution system in Werabe town using WaterGEMS software. WaterGEMS model was used for automated calibration and analyzing the hydraulic parameters of water distribution system. To reduce the difference between measured and predicted pressure, the model was calibrated at the selected nodes within good performance. The result showed that the water supply coverage was low which covers only 69.5%. besides water demand and supply of Werabe town were not balanced. The people used daily water of 41.7 l/day with the billed water amount is 70% of production and 30% water is considered to be non-revenue (NRW). The simulation result of the existing water distribution system showed that, during peak hour demand 27.68% of junction have within the recommended pressure ranges of minimum 15 m and maximum 70 m H2O. The hydraulic performance analysis also revealed that 82.11% and 44.6 % of total pipes have velocity below 0.6m/s at minimum and peak demand respectively. The study concluded that the hydraulic performance of Werabe town water supply distribution system is running below the expected level. Thus, the high pressures in the distribution should be managed by using pressure reducing valves and a low pressure and velocity should be improved by making rehabilitation of existing boreholes, which satisfy the existing peak water demand.

**Key Words**: water distribution network, water loss, Water GEMS V8i, Werabe Town, SNPPR, Ethiopia.

# CHAPTER ONE

# 1. INTRODUCTION

## 1.1. Background

Water is the primary need to sustain life; every citizen in the country has the right to have access to potable water. Provision of safe and adequate water supply services is necessary components for sustainable development. The provision of adequate supplies potable water for use in urban areas in developing countries is crucial for the well-being of the people. The demand for such supplies in the developing countries has been on the increase over time as a result of rising standards of living that occur with economic progress and population increase resulting from natural growth, and rural urban migration and rising per capital income. According to global water supply and sanitation assessment report in 2000, 1.1 billion people of the world population were without access improved water supply. The majority of these people live in Asia and Africa, where two out of five African lacks improved water supply. In Sub- Saharan Africa, 748 million people were relying on unsafe drinking water sources in 2012 of which 173 million obtained their drinking water straight from rivers, streams and ponds. In Ethiopia, urbanization growth rate highly increasing time to time, 18% of the population is urbanizing according to data published by the country's Central Statistical Agency(CSA, 2007). According to UNICEF joint monitoring programmer 2014 report, Ethiopia has improved water supply by 57% (97% in urban areas and 42% in rural areas). Despite the progress seen in Ethiopia, 43% of the population does not have access to an improved water sources(Asmare, 2019).

Water distribution system (WDS) is responsible for delivering water from the source to its consumers at serviceable pressures and velocity (Walski et al., 2003). It consists of pipes, pumps, junctions, valves, fittings, and storage tanks. An effective WDS requires an adequate supply of water into the system, functional pumping facilities as well as efficient distribution network. Poorly installed water distribution network coupled with lack of proper operations, day-to-day inefficient performance and maintenance always results in distribution network failure. The most common challenges in water distribution networks include water quality degradation, capacity shortages, infrastructure aging and deterioration, demand increases, and their ever- increasing energy consumption coupled with the global energy crisis (CSA, 2007). The other major factor which affecting the water distribution system is Non-Revenue Water (NRW). Current statistical surveys indicated that NRW in developing countries is around 45 to 50% of the total system input volume. This is largely because most of the water utilities do not have enough attention and monitoring systems within water losses and its management, further, water theft, metering error and lack of effective data recording and handling system is the other problem of the water utilities in developing countries (EPA, 2010). Generally, because of rapid growth and high water losses from the distribution network, the total water demand of the system in many developing countries exceeds available production capacity.

According to Werabe town water supply service office, the most common problems in the town water supply system were shortage of water, interruption of water supply, break and burst of pipe, low coverage of water. Therefore, this research work was prepared to assess the hydraulic performance of existing water supply distribution system in Werabe town using a hydraulic model WaterGEMSv8i. Water GEMS is optimization software that can be used to imitate or partially utilize existing gravity fed water distribution systems. It is a productive technique for creating new pipe layouts and undertaking pipe restoration work (Dessalegn, 2021).

## 1.2. Statement of the problem

Ethiopia's water distribution systems have been facing several challenges due to the potential effects of climate change and rapid population growth (Tiwari, 2016). Currently, Werabe town is facing a continuous and repeated deficiency in adequate water demand services. According to the Werabe water supply service office, the common problems in the town's water supply system is experiencing frequent and regular disruptions of water supplies, high rates of water losses from the distribution systems, frequent pipe bursting in the water distribution network, water pressure and velocity variation. These problems affected the performance of existing water distribution networks. Thereby, there are inadequate amount of water supply and low coverage in the town. Therefore, this research work was prepared to assess Werabe town water distribution network in terms of the hydraulic performance and water loss in water distribution system.

## 1.3. Objective of the study

### 1.3.1. General Objective

The General objective of the study is to assess the performance of Werabe town water distribution network and to address any improvements required in existing network.

### 1.3.2. Specific Objective

- To assess the existing water supply and demand of the town,
- To evaluate the water losses in distribution system and the existing water supply coverage of the town.
- To evaluate the hydraulic performance of water supply distribution system.

## 1.4. Research Questions

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

- ✓ How much is the current status of water supply and demand of the town?
- ✓ How much water is lost while comparing with the water produced?
- ✓ What is the present water supply coverage of Werabe Town?
- ✓ What are the key hydraulic parameters affecting the performance efficiency of the Werabe WDN?

## 1.5. Significance of the Study

From the study, it is expected that the deficiencies of the water supply system which encompass the estimate of unaccounted water, causes for the water loss and water supply coverage is determined. The main significance of this study is to analyze the water distribution networks, control its operation, management, maintenance, and leak detection for minimizing non-revenue water and analysis the WDS for planners, decision makers concerned to water distribution system of Werabe Town. The current study aims to assess the hydraulic performance of existing water distribution system in Werabe town. The research findings can strongly help, decision or policy makers in planning, urban water and other development activities to achieve good hydraulic performance of water distribution system. In general, the research will be significant for Werabe Town water supply office to improve the performance of the existing subsystem and to reduce the deficit of supply.

## 1.6. Limitation of the Study

For the whole distribution network to be covered by field data collecting for calibration and validation, the study's available funds was insufficient. Due to the high cost and restricted funding associated with water meter testing, this research acquired the necessary data by reviewing the documents. Due to resource limitations in terms of the research experiment materials and the expense associated with the research to study water quality, there was a dearth of acceptable data sources and well-documented data sources, particularly in the study area Werabe town water utility.

### 1.7. Scope of the study

This study is limited to assess the water distribution network (from clear water well to distribution end point) of Werabe town water supply system, it mainly focus and assess to identify the hydraulic performance and the factors for intermittent supply, water loss, and leakage of the town water distribution system. However, these studies do not examine the water quality in the research area's distribution system due to a lack of finance, time, chemical reagents, resources, logistics, and logistical considerations.

### 1.8. Structure of the thesis

In order to make the complete thesis work understandable and to be able to synthesize and convey the results in the most practical manner, it has been documented in this report in a thorough and organized manner. The five chapters that make up this thesis.

Chapter one: The introduction part contain about the background of the study, statement of problem, general objective, specific objectives, and research question that guided the study. It also covers the significance of the study, limitation of the study and scope of the study.

Chapter two: was review of relevant studies and theories done by scholars related to factors influencing the hydraulic performance of the existing water distribution system. Under this section, a literature review was discussed under urban water supply, performance evaluation of urban water distribution system, water supply modes, water losses and its component.

Chapter three: was described of the research methodology used to conduct the study. Description of the study area and method of data collection, data analysis, and model calibration and validation material used for data collection, processing and evaluation are explained.

Chapter four: data analysis, presentation, interpretation and discussion of the findings of the research study. The findings of the study as per the study objective are presented in the form of tables and graphs.

Chapter five: was conclusion and gives recommendations based on the study findings.

# CHAPTER TWO

# 2. LITERATURE REVIEW

## 2.1. Overview of Water Distribution System

Urban area development requires a carefully thought-out water distribution system. A WDN is an important hydraulic infrastructure that is a component of the water delivery system made up of a variety of pipelines, hydraulic devices, and storage reservoirs, according to (Shinde et al., 2018). Hydraulic components are used by WDN to link customers to water sources. As a result, the design characteristics, such as pipe diameters, reservoir capacities, and elevation, make up the choice variables. Three main parts make up a water distribution system: a piping system for the water, pumps, and storage for the water. Table 2.1 provides a breakdown of the water distribution system's parts and their role in modeling.

Table 2

Table 2. 1: Components of Water Distribution System and Modeling purposes

| Component | Type of Network Modeling Element | Primary Modeling Purpose |
|---|---|---|
| Reservoir | Node | Provide water to the system |
| Pipe | Link | Conveys water from one node to another |
| Pump | Node | Raises the hydraulic grade to overcome elevation difference and friction losses. |
| Storage Tank | Node | Store excess water within in the system and release that the water at times of high usage |
| Junction | Node | Removes (demand) or add ( inflow) water from to the system |
| Valve | Node and Link | Controls from or pressure in the system based on specified criteria |

## 2.2. Urban Water Supply Demand

Water demand is defined as the volume of water quested by users to satisfy their needs. In other way it is often considered equal to water consumption, although conceptually the two terms do not have the same meaning in most developing countries, the theoretical water demand considerably exceeds the actual consumptive water use. Urban water demand is classified in to different categories: the domestic water demand that includes in house use and out of house use is among the others. Urban water demand is usually quoted in terms of liter per capita per day (l/cap/day) (Wallingford, H, and Mebet, 2007)

### 2.3. Urban Water Supply coverage

All sources confirm that water supply coverage in Ethiopia is on a strong upward trajectory. According to official government data, water supply coverage has risen from 19 percent in 1990 (11 percent rural, 70 percent urban) to 66 percent in 2009 (62 percent rural, 89 percent urban). As Figure 2.1 shows, based on the official government data, Ethiopia has already met the MDG target of 60.4 percent. Estimates of current coverage from the international Joint Monitoring Programme (JMP) are significantly more cautious, due to a range of factors. Nevertheless, the JMP data still portray a remarkable increase in coverage of over 1 million people per year (1990–2008) (AMCoW, 2015).

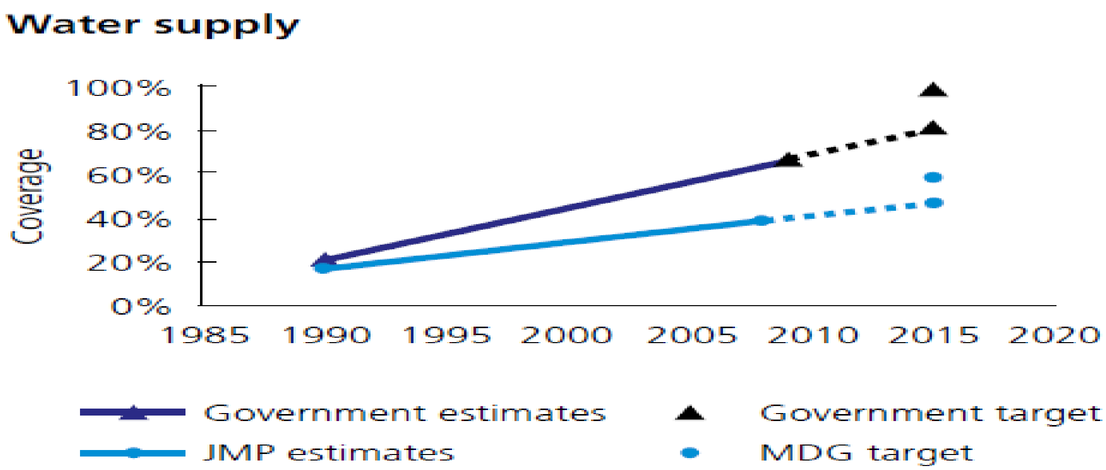


Figure 2. 1: Ethiopia Water supply coverage by Gov & JMP Report (1990-2008)

### 2.4. Water Demand Estimation

Demand estimation in a WDN gives essential information for system monitoring and control. Due to the stochastic behavior of water consumptions, estimation of the demand parameters is typically challenging. According to the input parameters are time-invariant or vary slowly, nodal demands are the only parameter that can cause immediate changes in the model output. In a WDS, nodal demands are often considered as the state variable and can be estimated using nodal pressures and pipe flow rates measured at sensors installed throughout the system(Letting et al., 2017).

Water demands, or consumption rates for distribution systems, are equivalents for determining the quantity of water demand and are expressed as the amount of water utilized per capita per day (l/c/d), as stated by (Mays, 2004). Projected population, per-capita demand, and the percentage share of various service modes are crucial factors in estimating water demand. The domestic water demand of the area is estimated based on the past and current water consumption pattern, which is expressed as a per-capita demand and percentage share of mode of services. In the same way, the non-domestic and industrial water demands are estimated based on the historical water consumption pattern of the area. Usually water demand estimation is made based on statistical analysis of previous and present water consumption pattern as well as the development trend of the study area. There are different methods used to estimate water demands and some of them are presented in the following table 2.2 below.

From the methods presented in the following table 2.2, the second method, the Per-capita Demand Method, is relatively realistic and can be approached by estimating the per-capita water demand from registered water consumption rates by different customer categories and from water demand standards set by (MoWIE, 2006)the water demand calculation for towns.

Table 2

Table 2. 2: Methods of Demand Estimation

| Methods | Description |
| --- | --- |
| Time Extrapolation Method | Mostly used in places where metered water is supplied; Needs sufficient database to bring the statistical error within the limit; Used for aggregated per capita daily demand by evaluating parameters as recorded for various kinds of customers; The method assumes that there is no direct correlation b/n water supply and factors as population, price, economic factors, etc, i.e. the water supply is only correlated with time. |
| Per Capita Demand Method | Most widely used method but does not relate the water use with disaggregated uses;<br>It assumes that only one variable, population, provides adequate information on |

| | |
|---|---|
| | the water use. |
| Coefficient Method | Forecasts by smaller aggregates separately as a small aggregate consumption could be better metered by adequate coefficient. |

(Source: (MoWIE, 2006)

### 2.4.1. Specific Water Demand Classification

(Piasecki et al., 2018) said that the amount of water demand is caused by a variety of elements in water consumption, which vary depending on the type of services, climatic circumstances, socio-economic status, and other associated aspects. Water demand of a town is generally categorized as domestic, non-domestic, industrial, fire fighting and unaccounted for water (MoWR, 2006).

- **Mode of Service**

According to the design criteria for urban water supply projects prepared by the Ministry of Water Resources published in January 2006, there are four types of connection profiles namely House Connections, Yard Connections (own), Yard Connections (Shared) and Public tap connections. As it is stated above, domestic water demand depends on the distribution of connection profiles that is dependent on the socio-economic level of the community. Moreover, according to the design criteria prepared by (MoWIE, 2006). The water demand for each categories of customers is also as indicated here below.

Table 2. 3: Per-Capita Demand With mode of Services

| Connection Type | Phase I | Phase II |
|---|---|---|
| House Connection (HC) | 50l/c/d | 70l/c/d |
| Yard Connections, own (YCO) | 25l/c/d | 30l/c/d |
| Yard Connection, shared (YCS) | 30l/c/d | 40l/c/d |
| Public tap supplies (PT). | 20l/c/d | 25l/c/d |

Source: Design Criteria, (MoWIE, 2006).

We examined the residential per-capita water demand based on the living standard and other economic factors, which are established for each mode of connection described above, using the facts provided above and from experience for similar towns in the area and across the country.

**A. Domestic Water Demand: -** water needed for drinking, food preparation, washing, cleaning, bathing and other miscellaneous domestic purposes. The amount of water used for domestic purposes greatly depends on the lifestyle, living standard, climate condition, mode of service and affordability of the service(Grassl & Hupfer, 2007).

**B. Non-Domestic Water Demand**: **-** is water required by commercial activities, administrative works, schools, public centers, hospitals, health centers, gardening, small scale industries and other similar activities, which are stated and estimated as presented in the following sections (ICID), 2006).

- **Public Water Demand**

This demand includes water required for other purposes than residential, industrial, commercial and institutional. Besides, this category usually includes water required at the head works (sanitary facilities, backwashing, flushing distribution systems, etc) when the system includes source considerations. The public gardens and parks, washing the streets, etc are also included in this category. Thus, as generally in Ethiopia public water demand is estimated as a percentage of the domestic demand. It is considered usually to be in the range of 5% to 10% of the domestic demand(Cleys & Hargiss, 2021)..

- **Commercial and Institutional Water Demand;**

In addition those of household consumers, the water requirement of towns include the need of such commercial and institutional consumers as public schools, clinics, hospitals, offices shops hotels and others similar facilities. Generally, in Ethiopia such water demands are estimated as a percentage of the domestic demand. It is considered usually to be in the range of 10% to 15% of domestic water demand based on the degree of development of the town(MoWIE, 2006).

- **Industrial Water Demand**

The industrial demand represents the amount of water demand required by industries and factories in the cities. industrial water use refers to the use of water in or during industrial production process, including water for manufacturing, processing, cooling, air conditioning, cleaning, boilers, and plant workers (Shang et al., 2016).

- **Fire Fighting Demand: -**

MoWR has recommended increasing volume of storage tanks by 10% to meet firefighting requirement directly from the distribution network, with a limitation of minimum allowable pressure in the system to be 15m.

- Unaccounted for (Non-Revenue):-

Unaccounted for (non-revenue) water includes water losses in the water supply system, consumption at illegal connections, overflow from reservoirs, improper metering and others. It is very crucial to estimate this quantity as it usually varies from 15 % to 50% depending on the age of the pipelines in the system and the size and complexity of the distribution system. (MoWIE, 2006).

### 2.4.2. Estimation of Per-Capita Water Demand

The per capita water demand for various demand categories varies depending on the size of the town and the level of development, the type of the water supply scheme, the socio-economic conditions of the town and the climatic condition of the project areas. The per-capita water demand is the sum of the water requirement for different uses, which are related to specific conditions of each area, living standard of the people and availability of water supply facilities of the specific town, etc. The water requirement for different domestic use could also vary based on the mode of service to be used and the closeness to water supply facilities(Agency & Lahore, 2022).

### 2. 4.3. Demand Variations

Towns in Ethiopia are characterized by widely varying climatic conditions and so the variations in consumption during the year, reflected by a peak seasonal factor, will similarly vary. It is expected that seasonal peak factors will vary between 1.0 and 1.2, representing the relative increase in the average daily demand during the dry and/or hot season months compared with the average annual demand. In line with the variations of demand with season and time, three demands have been identified: Average Day Demand, Maximum Day Demand and Peak Hour Demand, (MoWIE, 2006).

## 2.5. Water Losses in Distribution System

Water losses occur on all the systems. It is only the volume that varies; and it reflects the ability of a utility to manage its network (Environmental & Agency, 2010). The actual quantity of water lost from the water distribution system was varied from utility to utility depending upon local factors such as topography, length of mains, number of connection and standard of service and upon how well the system is being operated and maintained. In developing countries more than 40% of treated water was lost as non-revenue water (Harrison.E.Mutikanga, 2012).

There are many factors contributing to water losses in water distribution system ,such as ageing infrastructure, high pressure, external and internal pipeline corrosion, service tank overflows, poorly designed and constructed WDSs metering errors illegal use and poor operation and maintenance practices(Brhane,2019).

According to (Lambert, 2000) the actual quantity of water lost from the water distribution system was varied from utility to utility depending upon local factors such as topography, length of mains, number of connection and standard of service and upon how well the system is being operated and maintained. In developing countries more than 40% of treated water was lost as non-revenue water(Bogale, 2016). AWWA Leak Detection and Accountability Committee recommended 10% as a benchmark for Water loss. i.e.

- < 10% Acceptable, monitoring and control,
- 10-25% Intermediate, could be reduced
- 25% Matter of concern, reduction needed(Liemberger, R., & Farley, 2010).

### 2.5.1. Causes of Water Loss

- **Leakage in Water Distribution Systems:**

Leakage is often a large source of unaccounted for water (UFW). Leakage may be caused for poor management of pressure zones, which result in pipe or pipe-joint failure. Although some leakage may go unnoticed for a long time, detection of visible leakage also required good reporting which also needs a strong public participation (Farley, Malcolm, Wyeth, G., Ghazali, Z. B., Istandar, A., & Singh, 2010). From one municipality to another and even from one location to another, the causes of leaks will vary depending on the nature of the soil, the quality of construction, the materials used the pressure level and the utilities operating and maintenance practice (Vermersch et al., 2016)

- **Pressure in The Distribution System:**

It has proved that pressure is directly proportional to leakage and it is one of the main contributing factors for a leakage, thus depending on the network profile reducing pressure might be an effective method in cost minimization, reduction of leakages and pipe cracks through effective measurement of flows and pressure values which supports to find average pressure(Saghi & Aval, 2015)

- **Age of Pipes Network:**

Pipe age and material are important factors contributing to the burst probability of pipes that as a result cause lots of water loss and it is mostly not available especially for aged pipes, it is usually estimated using the history of the urban development. Newer systems may have as little as 5 percent leakages, while older systems may have 40 percent leakage or higher(Saghi & Aval, 2015).

- **Effects of Corrosion:**

Corrosion is the problem that is created as water supply pipelines are in continuous contact with soil surrounding it and the water moving through it. The water itself or the surrounding soil may cause problems that will affect the performance and life of the distribution pipes in the system. Therefore, ductile-iron or steel pipelines placed in aggressive soils must be protected by coatings with corrosive resistant materials (Saghi & Aval, 2015)

### 2.5.2. System of Water Balance

Findings of strongly suggest that discussion on water losses must be preceded by a clear definition of water balance components(Kingdom et al., 2006).The water balance calculation provides a tool for water utility to estimate how much water is being lost due to number of reasons. According to the International Water Association (IWA) represents the best practice water balance with accepted terminology which is illustrated in Table 2.4

Table 2. 4: Water Balance Showing Water Losses and NRW Components:(IWA, 2000).

<table>
<tr><th colspan="5">‘IWA Best practice’ Water balance terminology</th></tr>
<tr><td rowspan="5">System Input Volume</td><td rowspan="4">Authorised Consumption</td><td rowspan="2">Billed Authorised Consumption</td><td>Billed Metered Consumption (including) Water exported</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Unbilled Metered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorised Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="3">Non-Revenue Water</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td></td><td>Apparent Losses</td><td>Unauthorised Consumption</td></tr>
</table>

| | | | | |
|---|---|---|---|---|
| | Water Losses | | Metering inaccuracies | |
| | | Real Losses | Leakage on Transmission and/or Distribution Mains | |
| | | | Leakage and Overflows at utility's storage Tank | |
| | | | Leakage on service Connection up to point of Customer Metering | |

According to IWWA the above terminologies are defined as below

**Real or Physical Losses:** - Physical losses, sometimes called 'real losses or 'leakage', includes the total volume of water losses minus commercial losses. Real losses are "the annual volumes lost from transmission and distribution system through all types of leaks, bursts and overflows on mains, service reservoirs and service connections up to the point of customer metering" .Real losses are attributed to varying pressure, inefficient leak detection system, poor workmanship and maintenance of the distribution network(Sharma, 2008).

**Apparent Losses:-**Apparent losses are commercial losses. It includes water that is consumed but not paid for by the user. which are from an improper recording of total water consumed due to meter errors, inaccurate assumption of unmeasured and unauthorized consumption and these deficiencies is attributed to administrative inefficiencies of the water utility(Motiee, H., McBean, E., & Motiei, 2007). Apparent loss may consider as all water that was successfully delivered to the consumer but which is not metered or recorded correctly and these causes an error of consumer consumption(Lambert, A., & Taylor, 2010).

**Authorized Consumption:-**Authorized consumption is the volume consumption by the registered consumers; also it is referred as revenue water because of it produce revenue and depending on the country low it can be metered or unmetered for the items of firefighting, flushing of mains, street cleaning, watering of municipal gardens, building water, etc. (Farley et al., 2010).

**Unauthorized Consumption:-**It is that quantity of water which is removed from the system without authorization. Unauthorized consumption includes theft by illegal meter by-passes, vandalism, or unmetered hydrant use for construction or recreation (Farley et al., 2010).

**Unbilled Metered Consumption**:-It is the quantity of water that does not generate revenues but which is accounted and not lost from the system. Water used in the treatment process or water provided without charges are examples of these quantities. The Public Water System does not bill a charge for this water.

**Unbilled authorized consumption:-**It's include water used by the utility for operational purposes like water that is used to flush the mains after fixing a break, water provided for free to certain consumer groups, water that is used for street cleaning, firefighting and fire flow tests. Unbilled authorized consumption consists metered and unmetered consumption and it can be assessed using the metering and billing output (Farley et al., 2010).

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

**Non-Revenue Water (NRW):-**It is water that is not billed and no payment is received. It can be either authorized, or result from apparent and real losses

Unavoidable Annual Real Losses:-Real losses cannot be eliminated totally. The lowest technically achievable annual volume of real losses for well-maintained and well-managed systems is known as unavoidable annual real losses (UARL). It represents the minimum level of real losses that could technically be reached, for most utilities it will not be economic to reduce real losses to this level. According to (AWWA,2013) the UARL volume is given by equation

$$UARL\left(\frac{l}{d}\right) = (18 * Lm + 0.8 * Nc + 25 * Lp) * p \quad \ldots 2.1$$

Where: Lm = length of transmission and distribution system (km)

NC= number of service connection

LP= total length of private pipe between the street property boundary and customer meters (Km) and P= average pressure in the zone (m)

### 2.6. Components of Water Distribution Networks

#### 2.6.1. Pipes

The main components of water distribution system are the pipes. They can be found in different lengths, material and diameter lay down in the network. The pipes are mainly grouped into three such as, transmission line pipe, distribution line pipes and service pipes. The transmission line pipe is the pipe between the source and the storage element; it carries water from the source or pump station to the storage tank while the capacity is enough for both serving the consumers and carrying excess water to the storage tank.(Bohan, 2012)

#### 2.6.2. Pumps

A pump is a hydraulic machine that adds energy to the water flow by converting the mechanical energy into potential energy to overcome the friction loss and hydraulic grade different within the system. Most pump used in the water supply systems are centrifugal in nature ,and are installed to improve the water distribution ,if gravity is insufficient to supply water at an adequate pressure. The pump characteristics are presented by various performance curves such as, power head and efficiency requirements that are developed for the friction rate.(Maharashtra, 2012)

#### 2.6.3. Reservoir and Storage Tanks

In water distribution system reservoir and storage tanks are mainly provided to store excess water during low demand periods in order to meet the fluctuation of water demand, to stabilize pressure and reserve water for emergency requirements. A storage tanks oscillations are directly integrated with the demand and pumping working rate (Nyirenda & Tanyimboh, 2018).

#### 2.6.4. Accessory equipment

The Accessory equipment's in the water distribution system can be classified as valves, hydrants fittings, drainage facility, flow meter etc. all these accessories has been installed at a place where necessary for connecting the network ,controlling and management of the system and for maintenance purposes during failure is occurred(Bohan, 2012)

### 2.7. Performance Evaluation of Urban Water Distribution System

Performance of a water distribution system can be defined as its ability to deliver a required quantity of water under sufficient pressure and an acceptable level of quality during different normal and abnormal operational situations (Tabesh, M., & Doulatkhah, 2006). The system performance can be classified as physical and chemical characteristics of the supplied water into two primary aspects of quantity and quality(Jalal et al., 2008). The other main performance indicators are the amount of water loss in the systems and reliability of the systems within the given service life. The performance of a WDS depends on efficient and reliable working of all physical components of the system including pipes, pumps, control valves, reservoirs and tanks(Mehta, 2016). This thesis was focused on the physical characteristics of water distribution systems. The physical characteristics of the system performance can be evaluated by using computational prediction based on simulation models and field measurements. And also, it helps to operational studies to solve problems, such as evaluating storage capacity, investigating control schemes, and finding ways to deliver water under difficult operating scenarios (Bhoyar, R. D., & Mane, 2017).

### 2.7.1. Performance Indicators

According to (Abate, 2016) performance indicator are variables whose objective is to measure a change in a process that is monitoring the steps in the research changes the results in the target of evaluating the results with the specified outcome of the process.

Table 2. 5: Performance Indicators Used in the Study (MoWR, 2006)

| Performance Indicator | Description | Selected Target |
|---|---|---|
| Pressure | Minimum and maximum pressure in pipes | 15 m to 70 m |
| Unit head loss | Head loss in water pipes | < 15 m/km |
| Velocity | The flow velocity in distribution system | 0.6 -2 m/sec |
| Water loss | The volume of water loss as a percentage of water supplied | 20% |

### 2.7.2. Head Losses

There are different factors that cause the energy losses. The main reason of energy loss is due to internal friction between fluid particles traveling at different velocities (Zyoud, 2003). Also minor loss and water hammer are the cause of energy loss. The head loss in a pipe is expressed by equation

$$hl = \frac{CfLQ^{1.85}}{2C^{1.852}D^{4.87}} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots .. 2.2$$

Where:

hl=head loss due to friction (m)

L=Length of the pipe (m)

C=Hazen-Williams friction factor

D=pipe internal diameter (m)

Q=flow rate in pipes (cms)

Cf=unit conversion factor

**2.8. Basic principles of hydraulic modeling**

The main reason for modeling a system is to assist designers, managers and planners to explore the governing laws of such systems and accurately analyze their behavior. Hence, models are employed to resolve problems in the systems design and operation (Bogale,2016). Water flow in a distribution network satisfies two basic hydraulic principles such as: conservation of mass, and conservation of energy.

- **Conservation of Mass**

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

$$\sum pipes\ Qi - u = 0 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 2.3$$

Where, $Qi = inflow\ to\ node\ in\ i - th\ pipe$ ($M^3$/T)

$U = water\ used\ at\ node$($M^3$/T)

The conservation of mass equation is applied to all junction nodes and tanks in a network, and one equation is written for each of them(Walski et al., 2003).

During extended-period simulations; terms to the accumulation of water at certain nodes are considered, because water can be stored and withdrawn from storage tanks. (Walski et al., 2003)

$$\sum pipes\ Qi\ - u - \frac{ds}{dt} = 0 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 2.4$$

Where. $ds/\ dt$ =Change in storage

- **Conservation of Energy**

The principle of Conservation of Energy dictates that the difference in energy between two points must be the same regardless of the path that is taken. For convenience within the hydraulic analysis, the equation is written in terms of head as:

$$Z_1 + \frac{P1}{\gamma} + \frac{V^2}{2g} + \sum hp = Z_2 + \frac{p_2}{\gamma} + \frac{V^2}{2g} + \sum hL + \sum h \ldots\ldots \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.5$$

Where Z = elevation (M)

P = pressure ($M/L/T^2$)

γ = fluid specific weight ($M/L^2/T^2$)

V = velocity (M/T)

g = gravitational acceleration constant ($M/T^2$)

$h_P$ = head added at pumps (M)

$h_L$ = head loss in pipes (M)

hm = head loss due to minor losses (M)

Thus the difference in energy at any two points connected in a network is equal to the energy gains from pumps and energy losses in pipes and fittings that occur in the path between them. This equation can be written for any open path between any two points. of particular interest are paths between reservoirs or tanks (where the difference in head is known), or paths around loops since the changes in energy must sum to zero (Walski et al., 2003).

## 2.9. Modeling a System Using WaterGEMS

The analyses of the hydraulics in this study have been carried out using Bentley's WaterGEMS v8i software.WaterGEMs software After Water Cad, EPANET and loop, the most advanced and powerful software for designing water supply networks. It is the modified version of Water Cad software that is designed by Haestade and Bently companies (Mahmood. M & Mohsen.I, 2016) .

Bentley WaterGEMS V8i is user-friendly software which can be utilized as a decision support tool for water distribution network. This soft computing tool is useful to understand the behaviour of infrastructure as a system and its responses to operational strategies. A water supply system should develop as population and demand increases and this software simulates the same interoperability, geospatial model building, optimization and asset management tools. It provides an easy to use environment for engineers to analyze, design and optimize water distribution network from fire flow, water quality simulation and constituent concentration analysis to criticality, energy consumption and capital cost management(Udhane et al., 2018).

According to (Bentley, 2015) the parameters that need to be defined for each model components include:

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

After all the parameters required to run the simulation are entered into the model, the successful simulation run provides solution for the pressure at every single element in the system, flows at every point of time in the system , velocities in the pipes, levels in the tanks and Pump cycles.

### 2.10. Types of Water Distribution Simulation

According to (Walski et al., 2003) the term simulation is the process of using a mathematical representation or real system, called a model. According to them there are two most basic types of simulations that a model may perform, depending on what the modeler is trying to observe or predict. These are Steady state simulation and extended period simulation (EPS).

- **Steady State Simulation: -** represent a particular view of point in time and are used to determine the operating behavior of a system under static conditions. It computes the hydraulic parameters such as flows, pressures, pump operating characteristics and others by assuming that demands and boundary conditions were not change with respect to time (Walski et al., 2003)
- **Extended Period Simulation: -** is determining the dynamic behaviour of a system over a period of time, and it analyses the system on assumption that the hydraulic demands and boundary conditions were change with respect to time. Hence, extended period analysis used to evaluate system performance over time and allows the user to model pressures and flow rates changing, tanks filling and draining, and regulating valves opening and

closing throughout the system in response to varying demand conditions and automatic control strategies formulated by the modeller (Walski et al., 2003).

## 2.11. Model Calibration and Validation

### 2.11.1. Model Calibration

Calibration is the process of comparing the model results to field observations and adjusting the model parameters until they reasonably agree with measured system performances. This information, once discovered through the calibration process, can explain operational difficulties and identify distribution system problems that require the development of solutions to resolve and improve system operation (AWWA, 2017). A water distribution model can predict the behavior of a water distribution system, providing an effective tool to help utility service providers meet goals. The AWWA engineering computer applications committee (ECAC) developed calibration guidelines for water distribution system modeling as shown in Table 2.6.

Table 2. 6: Criteria for Hydraulic Network Model Calibration (Source: AWWA, 1999)

| Intended Use | Level of Detail | Number of pressures reading | Accuracy of pressure reading |
|---|---|---|---|
| Long-range Planning | Low | 10%of nodes | ±5 Psi for 100% of Readings |
| Design | moderate to high | 5%-2%of nodes | ±2 Psi for 90% of Readings |
| Operations | low to high | 10%-2% of nodes | ±2 Psi for 90% of Readings |
| Water Quality | High | 2%of nodes | ±3Psi for 70% of Readings |

### 2.11.2. Model Validation

**A) Coefficient of Determination ($R^2$)**

The coefficient of determination describes the degree of linearity between simulated and observed pressure. $R^2$ describes the proportion of variance in measured data explained by the model. $R^2$ ranges from zero to one, with higher values indicating less error variance and typically value 0.5-1 (1 inclusive) are considered acceptable.

**B) Degree of Accuracy (Error of Difference**):- The degree of accuracy varies depending on the size of the system and the amount of field data and testing available to the modeler. (Behute, 2016), states that the average difference of ±1.5 m to maximum of ±5 m represents for good data set and ± 3 m to 10 m far bad data set would be a reasonable target. This is in terms of comparing the observed versus the calculated pressure heads in the system.

# CHAPTER THREE

# 3. MATERIALS AND METHODS

## 3.1. Description of the Study Area

Werabe is found in the north-eastern part of SNNPRS in the Stile Zone. It is the capital City of Silte zone , SNNPRS, Ethiopia. Geographically, it is located: 7º48'00" to 7º58'30" N Latitude and 38º8'30" to 38º15'30" E Longitude at elevation range of 1935m and 2250 M.A.S.L. Werabe Town can be accessible from Hawassa City by 201 km asphalt road, and is also accessible from Addis Ababa by 177 km asphalt road. The total area of Werabe town is about 15,734 hectare. Geographically Werabe is located at average altitude of 2060m. The topography in and surrounding Werabe Town is relatively flat as it is situated on the flat plateau of the left rift bank. The location map of the Werabe Town is presented in the figure below.

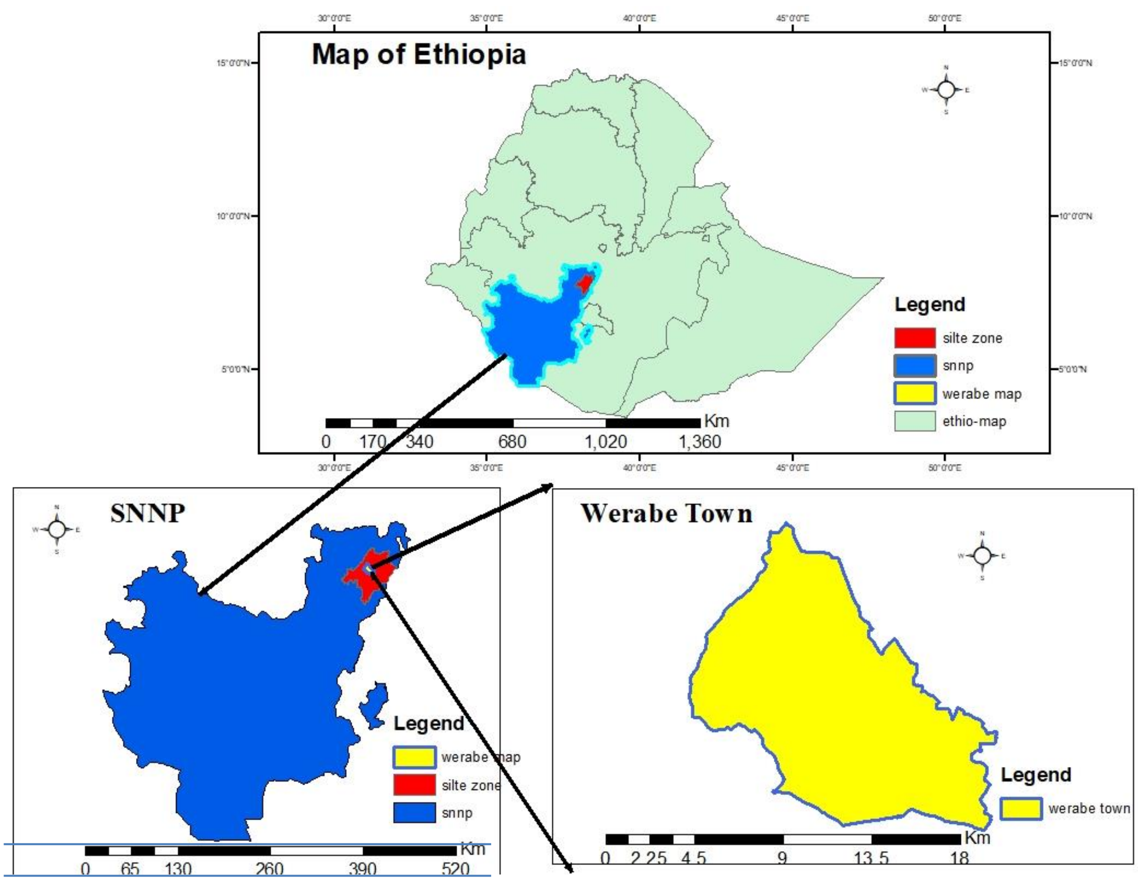


Figure 3. 1: Location of Werabe Town

### 3.1.1. Climate

The nearest metrological station to the Werabe town is Wulbareg and it is located 403265mE and 855389m N, 1992mZ. The station has data since 1972. The average rainfall of the town is 1262mm and the maximum rainfall 2196mm recorded in 1979 and the minimum rainfall 672mm recorded 1981.The temperature data also recorded since 1978 and the average temperature is $18.4^0$C and Maximum temperature is 34.8 $^o$C and minimum temperature is $0.4^o$C.

### 3.1.2. Economic Development of the Town and Basic Infrastructure

Being one of the youngest and emerging towns in the region, Werabe has registered significant socio-economic development and tremendous demographic growth in a very short period. It has been able to expand its basic social services such as asphalt and cobblestone roads, telecommunication services, educational and health facilities. The tremendous increase in population and the huge economic transformation being witnessed in Werabe town have not been matched by proportionate expansion in the water supply infrastructure. Inadequate supply of water to meet the domestic and institutional water demands is one of the critical problems of the town. Water shortage has become a major development bottleneck and one of the major concerns of the local authority and the community.

### 3.1.3. Population Size

The number of serving population in the study areas was estimated using the 2007 national census conducted by the Central Statistical Agency of Ethiopia (CSA, 2007). Based on CSA data 2007 its population of Werabe Town was 21,067 persons. According to the data obtained from the projection, the current total population size of Werabe town is 39,366 in 2022.These values were applied in the demand calculation.

- **Population distribution by mode of service**

Table 3. 1: Population Percentage Distribution by Mode of Services (Source: WTWSSSO)

| Customer users | Percentage of the population served by mode of service type | Total number of population served |
|---|---|---|
| House connection | 12% | 4723 |
| Yard connection | 79% | 31099 |
| Public tap | 9% | 3543 |
| Total | 100% | 39366 |

### 3.2. Material

The source of data was involved both primary and secondary data. For the study, the primary data were collected through a face-to-face interview with utility worker, field survey such as field observations and data measured by GPS, Water meter and Pressure gage, photographs of relevant sites and infrastructures. While, secondary data are collected from different literature reviews, design report, the town water supply service office existing documents and annual reported papers. Based on the research objectives and questions in the introduction the materials of the research are presented here. The methods of data collection and data preparation are also discussed.

The existing Water distribution Network of Werabe Town.

- ArcGIS for delineation of the study area, locating study area
- Topographic map to determine geographic location of study area and elevation
- WaterGEMSV8i. Software to determine velocity, nodal pressure and other parameter,
- GPS to check coordinates points of reservoir and sources of water supply,
- Water meter: to measure the flow of water in the pipe,
- Pressure gauge to measure the pressure at the selected nodes
- Microsoft Excel was used for data preparation and to analysis the data obtained from office

### 3.3 Existing Water Supply System of the Town

The tremendous increase in population and the huge economic transformation being witnessed in Werabe town have not been matched by proportionate expansion in the water supply infrastructure. Inadequate supply of water to meet the domestic and institutional water demands is one of the critical problems of the town. Water shortage has become a major development bottleneck and one of the major concerns of the local authority and the community.

#### 3.3.1. Water Distribution Network and Service Reservoirs of the Town

- **Service Reservoirs**

Werabe town is supplied from two different directions in which, $100m^3$ reservoir located at higher elevations currently receive water from Doro- Erbata BH, Sojat BH, Duna BH-1 and Duna BH-2, and in another direction $100m^3$& $50m^3$ reservoirs located at higher elevations are receives water from Amuste spring and Alwebe BH. In addition, there is one $500m^3$ reservoir constructed in south-western hills to supply water intended to be supplied from Chancho spring, however, this service reservoir and one 100m$^3$ reservoir built around the spring are not functional.

Table 3. 2: Tank information of the system

| Schemes | Capacity ($m^3$) | Tank D. (m) | Height (m) | Elevation (m) |
|---|---|---|---|---|
| Concrete Service Reservoir at Duna | 100 | 6 | 3.5 | 2131 |
| Masonry Service Reservoir at Alewab | 50 | 5 | 2.5 | 2125 |
| Concrete Service Reservoir at Alewab | 100 | 6 | 3.5 | 2206 |

- **Pipe Network**

Pipe length summary, diameter and pipe material in the study area was collected from the any possible utilities like town water services sector, design documents and by field observations. In the existing water supply system of the town there exist about 61.93 km pipe laid transmission and distribution pipe systems. The sizes ranging from 2 to 6 inches for development of model for this research work, of this total length, about 77% is GI, 23% is HDPE as per the information provided by the Utility. Distribution pipe Information, like Pipe material and diameter with its length have been taken from utility.

Table 3. 3: Summary of distribution pipe material

| Pipe material | Diameter(mm) | Length(m) |
|---|---|---|
| GI | 152.4 | 1,255 |
| GI | 101.6 | 13,148 |
| GI | 76.2 | 15,430 |
| GI | 63.5 | 17,501 |
| HDPE | 50.8 | 14,411 |
| SUM | | 61,929 |

- **Existing Transmission Main**:-

Table 3. 4: Existing Pressure Lines or Transmission Mains of Werabe Town

| Existing Water source | Existing transmission mains | Service Reservoir capacity, $m^3$ |
|---|---|---|
| Amuste Spring | 4 inch GI pipe with total length of 6.3 km | 100 & 50 |
| Alewab BH | 3 inch GI pipe with total length of 2.6 km | |
| Duna BH-1 | 3 inch GI pipe with total length of 4.6 km | 100 |
| Duna BH-2 | 3 inch GI pipe with total length of 4.1 km | |
| Doro-Erbata BH | 3 inch GI pipe with total length of 1.2 km | |
| Sojat BH | 3 inch GI pipe with total length of 1.35 km | |

The existing source and transmission main types for the town under consideration have been solely observed. Accordingly, the information grasped from the town water supply service office and field observation, there are two separate zones of transmission mains as the existing system has two different sources from two opposite directions. Accordingly, Alewab sub system has source from Amuste spring and Alewab BH was conveyed through 4" GI pipe of about 6.3Km. The second sub system is from Duna BHs to the service reservoir near Hospital with 3" GI pipe of about 4.6Km. However, during the site visit, I have identified that the existing source and nature of their transportation and depicted on the above table.

- **Node Elevation**

Obtaining elevation is one of the significant requirements to model the hydraulic characteristics of water in the distribution networks. Elevation data was collected from the Google Earth Pro, DEM 30 x 30 and when necessary and field measurement using Global Positioning Systems.

- **Type of the supply sources, locations and yields**

**T**able 3. 5: Existing water source (Own Field Observation and WTWSSDR**)**

| Source | ID | X | Y | Z | Depth(m) | SWL(m) | DWL (m) | Expected Yield (l/s) |
|---|---|---|---|---|---|---|---|---|
| BH | Duna BH#1 | 408815 | 864691 | 2097 | 165 | 94 | 116 | 4 |
| BH | Duna BH#2 | 409067 | 865035 | 2105 | 183 | 97 | 130 | 4 |
| BH | AlewabBH#3 | 408859 | 869384 | 2134 | 177 | 72 | 76 | 4 |
| BH | Sojat BH#4 | 410498 | 872023 | 2164 | 196 | 43 | 49 | 4 |
| BH | Doroerbata | 40850 | 865700 | 2016 | 220 | 48 | 72 | 5 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Spring | Amuste Spring | 410003 | 873210 | 2260 | | 4 |

In general, the Town gets 4 l/s from spring and about 18 l/s from the two old boreholes and the new boreholes as per the original pump test data, and additional about 4 l/s from Alewab boreholes. The total existing water source of the town is about 25 l/s.

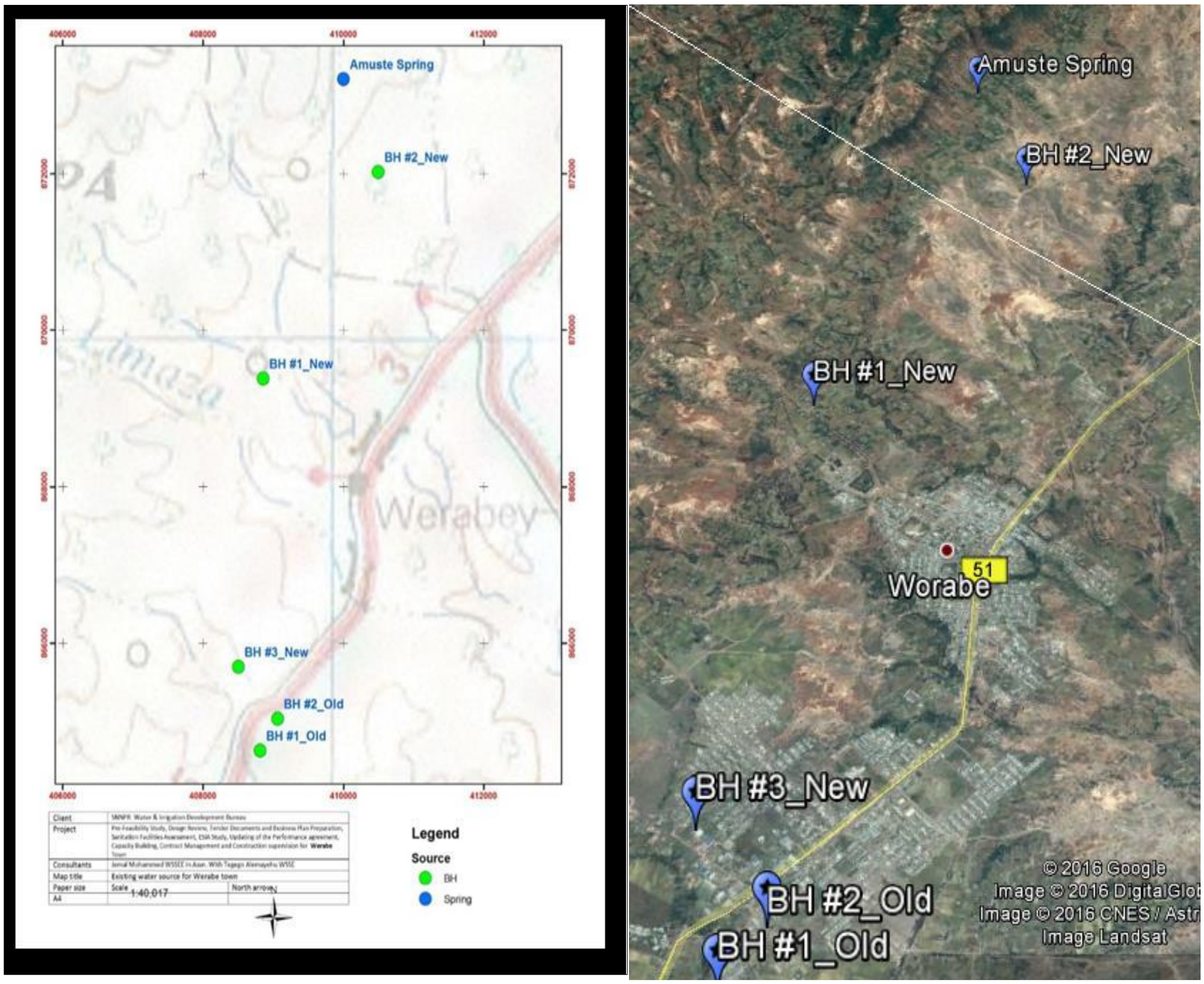


Figure 3. 2: General layout of existing water source (2016)

- **Existing Electro-Mechanical Situation Assessment**

According to the information collected from Werabe Town Water Supply Services, the boreholes are equipped with submersible pumps have been giving function in line with the Amuste spring source with gravity. The submersible pumps are driven by EEPCO power and Duna BH-1& 2 has stand by power source from diesel generating set. Pump Information's, like head and discharge have been taken from Werabe Town Water Supply Services are as follows.

Table 3. 6: Pump Characteristic from Werabe Town Water Supply Services

| Link Label | Pump Head (M) | Pump Power (KW) | Power of Generator (KVA) | Discharge (L/S) |
|---|---|---|---|---|
| Pump 1 at Duna BH1 | 136 | 22 | 85 | 4 |
| Pump 2 at Duna BH2 | 136 | 22 | 85 | 4 |
| Pump3 at Alewab BH | 45 | 45 | 119 | 4 |
| Pump3 at Doroerbata BH | 112 | 20 | 65 | 5 |
| Pump3 at Sojat BH | 112 | 20 | 65 | 4 |

- **Roughness coefficients for pipeline**

The formula uses a pipe carrying capacity factor. The value of roughness coefficient, C-factor is depending on pipe materials and its age Hazen-Williams equation was developed for the action of friction at the pipe wall, because it's (Walski et al., 2003).Typical pipe roughness values are shown below. These values may vary depending on the manufacturer, workman ship, age, and many other factors

Table 3. 7: Pipe Roughness for Different Pipe Material (Source: (MoWR, 2006)

| Pipe diameter for C-Value | | | |
|---|---|---|---|
| Pipe types | UPVC | Steel | DCI/GI |
| New pipe | 130 | 101 | 120 |
| Existing | 100-110 | 90-110 | 100-110 |

### 3.3.2. Average water demand

The average water demand is the sum of domestic, non-domestic, and unaccounted for water (losses). There are several mathematical methods of estimating the water demands of town; including extrapolating historical trends and correlating demand with the socio-economic variables of the town. But, the most common means of forecasting future water demand is estimating current per capita water consumption, and multiply this by the projected population. Therefore, during 2022 the average water demand for Werabe town was calculated as:

$$Qave = Per\ capita\ water\ consumption\ \times Total\ population\ of\ the\ town \ldots\ldots\ldots\ldots\ldots .3.1$$

Where, Qave = Average day Demand ($m^3$/sec)

$$Total\ daily\ demand\left(\frac{m^3}{day}\right) = Average\ day\ demand\ + NRW \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.2$$

$$Adjusted\ total\ domestic\ demand\ \left(\frac{m^3}{day}\right) =$$
$$Total\ domestic\ demand\ \times$$
$$Climate\ adjustmen\ factor\ Socioeconomic\ adjustment\ factor) \ldots\ldots\ldots\ldots\ldots\ 3.3$$

**A) Assigning base water demand in each supply node**

To estimate the existing water demand of each node in the distribution network, it was necessary following the steps below; once the average daily water demand of the system was determined, to calculate base water demand for each particular supply node, the following equation was used(Zewdu, 2014).

$$Base\ demand\ for\ supply\ = \frac{Population\ served\ by\ that\ node}{Total\ Population} \times ADD\ (pcd) \ldots\ldots 3.4$$

**B) Identification of number a of houses around each supply node**

To assign base demand to each supply node, it is necessary to determine the houses around each supply node. Therefore, the number of houses in each census block was physically counted and assign to the nearest supply node. Average people per houses was estimated the number of the total current population divided by the town number of house. An excel sheet was created for demand allocation. The first column counted all the 112 demand nodes. The second column showed the number of houses assigned to those nodes. The estimated population in 2022 is 39,366 the total number of the residential house was identified in 9153 giving an average count of 4.3 people per house. In detailed calculation is shown in Annex- 2.

$$Average\ people\ per\ House\ = \frac{Total\ Current\ Population}{Total\ Number\ of\ the\ House} \ldots\ldots\ldots\ldots\ldots\ldots 3.5$$

**C) Determination number of peoples served in each supply node**

The total number of population served for each supply node was calculated using the following equation:

$$Pop.Served\ node = (no\ of\ the\ house\ near\ to\ node) \times (avg.people\ per\ house). \ldots\ldots 3.6$$

### 3.3.3. Demand Factors

Water demand in a distribution system fluctuates over time. For modeling; peak hour demand scenario was adopted. Demand for each supply node was performed by taken demand multiplier factors of 24 hour flow duration and computed with assessed base demand. Therefore, for this study by considering the peak flow time, minimum flow condition and the actual condition of population served from the system; the demand multiplier factors were adopted data obtained from the Werabe town water supply service office. Therefore, the variation in water consumption over a 24-hour period was adopted; and the offered peak factor (pf) and patterns for demand multiplier factors were listed in appendix-10.

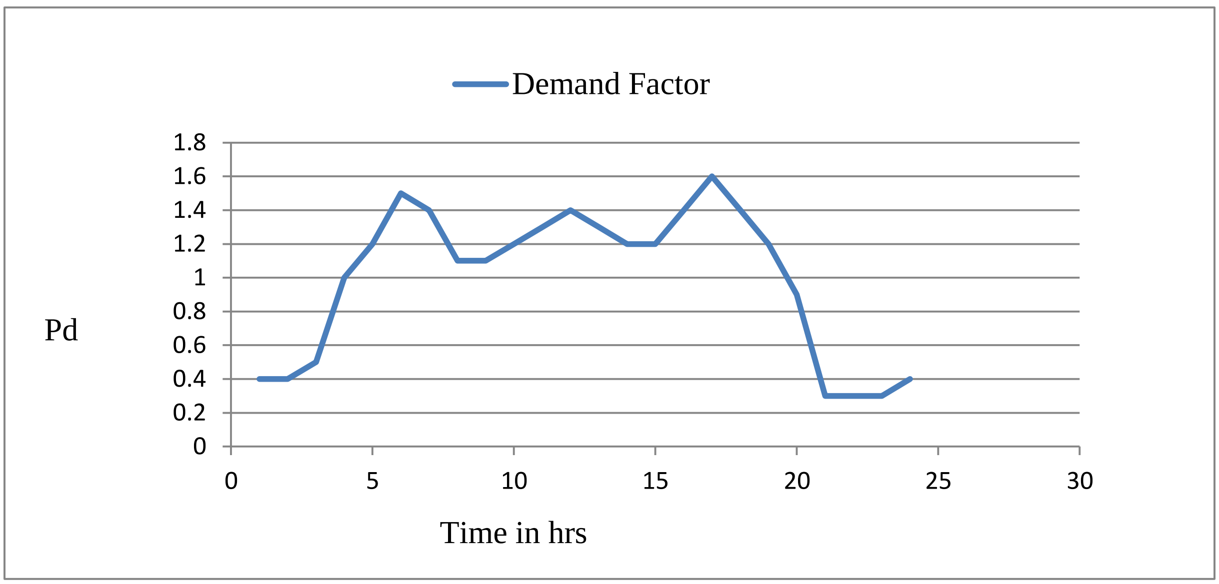


Figure 3. 3: Demand multiplier of Werabe Town water supply in 24 hour (WWS, 2022)

## 3.4. Forecasting the Population of the Town

### 3.4.1. Population Growth Rate

In order to avoid over or under estimation of the future population, using and applying the medium variants growth rates set for SNNP region according to the Analytical Report 1999 volume 2 by CSA up to the year 2037. Table 3.8 shows the medium variants growth rates for the future urban population projection in SNNP Regional State.

Table 3. 8: Medium Variant Growth Rate (%) for (SNNP Region

| Medium Variant | 2008-2010 | 2011-15 | 2016-20 | 2021-25 | 2026-30 | 2031-37 |
|---|---|---|---|---|---|---|
| Urban | 4.83% | 4.27% | 3.80% | 3.33% | 2.85% | 2.35% |

(Source CSA 1999 Analytical Report, Volume 2)

Exponential population forecasting method is expressed as follows;

$$\boldsymbol{p}t = Po \ (1 + \frac{R}{100})^{t}$$

Where: Pt = Population at year t

Po= Base year population

R = Population growth rate (%)

t = Projection year (1 yearly basis)

### 3.5. Hydraulic Modeling in Water GEMS

Among software's developed models for a water distribution network WaterGEMS is chosen due to its availability, functionality, user interference, compatibility, and interoperability. This software is the most advanced and powerful software for designing water supply networks. It is the modified version of Water Cad software that is designed by Haestade and Bently companies (Mahmood. M & Mohsen.I, 2016) .Bentley WaterGEMS V8i is user-friendly software which can be utilized as a decision support tool for water distribution network Water GEMS is a tool for engineering design, scenario analysis, comparison of scenarios, and optimization of water distribution systems. Features of Water GEMS include steady state and extended-period simulations, constituent-concentration analysis, water-age, and fire flow analyses. Controls can be rule-based or logical, and pumps can be single or variable speed. These tools help users find operational bottlenecks, minimize energy consumption and model real-time operations. Criticality Analysis is another important feature that permits users to discover the weak links and valves in the water distribution system. (Bentley,2015).

### 3.6. Model Skeletonization

All the distribution system components model skeletonization has been sketched using the following considerations: Selection of pipelines for modeling have been based on the primary line, all pipelines of the system have a diameter greater than or equal to 50 mm.  The network of the system have been sketched out using Water GEMS software, like reservoirs, tanks, pumps, valves, pipes and so on. In accordance with the requirements of the model, a node has been located at all points where the pipeline diameter changed or where three or more pipelines joined(Walski et al., 2003).

### 3.7. Construction of Model

The model is constructed using WaterGEMS software by giving all the necessary input data. For hydraulic analysis in the software all the required input data was collected like; Pipe data such as pipe diameter, pipe material type, C-value and length, tank data, source type and all necessary data are assigned to the network. Inputs for nodes are elevation, water demand and time pattern. Pump head and flow are required data for the construction of pump curve. Figure3.4. Show the image of the constructed network or constructed model of water distribution system of Werabe town.

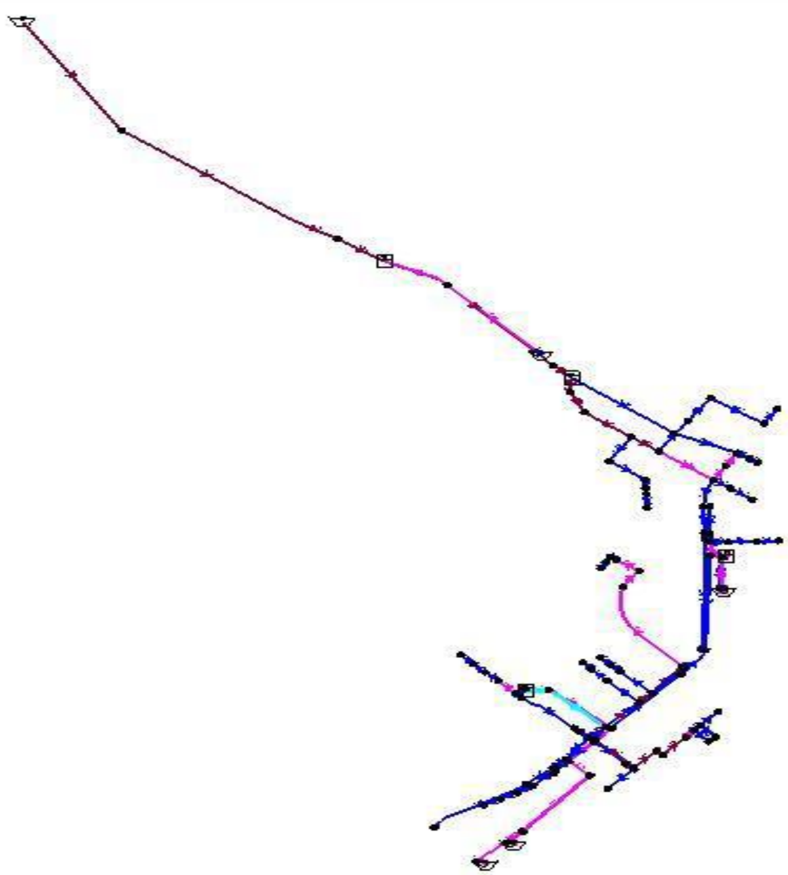

Figure 3. 4: Constructed model of the Werabe town WDN (Own Observation, 2022)

### 3.8. Water Supply Coverage and Water loss analysis

To analyze the data which is collected from different sources, quantitative methods was used. From the quantitative methods, the descriptive statistical methods, percentage and graphs were used in order to come up with the appropriate result. Use Micro soft excel to analyze the data obtained from the office.

**A. Water Supply Coverage**

In this study effort is made to evaluate the coverage related to the quantity of the supply and level of connection that are related to the performance. The number of domestic connections per family and the average daily per capita consumption is used to analyze the water supply coverage for the entire study area. But before calculating supply coverage the town population should be projected to current year by using Exponential increase method. In this method percentage error is the lowest value (minimum value) than other methods and this method is good for fast growing town like Werabe Town.

**B. Water loss**

The total water loss in the town water supply distribution system was evaluated based on the percentage of Non-revenue Water, Water loss per pipe length, water loss per number of connections. The data obtained from the town water service office, the yearly (2021 to 2022) and monthly water production and consumption (billed water in the system was identified.

### 3.9. Hydraulic Performance Analysis

The field survey data for distribution system was evaluated by using the engineering software WaterGEMS. The method of analysis was based on nodal pressure and velocity parameters. During data analysis, nodal pressure and pipe link velocity will have determined to identify higher or lower pressure zone of the area. WaterGems software was used for the purpose of calculating pressure for customer's demand, velocity, and head loss. The modeling process was model building, data entry, model test and problem analysis. The first step for model water distribution system using WaterGEMS software is importing of all the existing data. After importing water distribution network next step is entering of all relevant data like pipe characteristics (material, diameter, length and roughness coefficient), junction (elevation and demand), pump elevation, tank and reservoir elevation data. Except junction demand and elevation of some boundary elements (like pumps, reservoirs and tank), All of those data were collected from town water service office.

## 3.10. Model Calibration and Validation

Before any use, the model must be calibrated to establish its reliability and allow decisions about physical and operational developments in the real system to be made with as high a degree of confidence as possible. This information, once discovered through the calibration process, can explain operational difficulties and identify distribution system problems that require the development of solutions to resolve and improve system operation (AWWA, 2017). Once developed and calibrated, a water distribution model can predict the behavior of a water distribution system, providing an effective tool to help utility service providers meet goals. Ideally, during the water distribution model calibration process is adjusted for each link and each node. However, only a small percentage of representative sample measurements can be made available for the use of model calibration due to the limited financial and labor requirements for data collection.

### 3.10.1. Sampling size of Pressure Calibration:

To select the sampling size of the junction and pressure reading first specify the intended use. According to the international proposed pressure calibration standard for this study, the entire numeral of junctions in the network system of Werabe town is 112 junctions, Hence as per as (AWWA, 1999) the number of pressure reading ranges from 10% to 2% of all nodes. By taking the average value the acceptable sample equal to 6% of all the junctions in the system. Hence, the sample size is 6.72, which are approximately seven (7) junctions.

**Sampling Location and Pressure Measurement:**

In this research, the pressures data were measured at or near to node home faucet of the system is used to assess the model performance. The model performance measure Such as the degree of accuracy (error of difference) and the coefficient of determination ($R^2$) are two techniques to be considered for the calibration. The Pressure readings were taken with a pressure gauge and for each node the records were taken four times in single days. The locations of the representative sample node for calibration is presented in table 3.9:

Table 3. 9: Locations of the representative sample node

| S.No | Pressure Junction (Id) | Latitude (°) | Longitude (°) | Z (m) |
|---|---|---|---|---|
| 1 | J-44 | 7.833857 | 38.178835 | 2109 |

| | | | | |
|---|---|---|---|---|
| 2 | J-48 | 7.839651 | 38.172266 | 2126 |
| 3 | J-79 | 7.844972 | 38.187393 | 2,085 |
| 4 | J-90 | 7.854898 | 38.189515 | 2,083 |
| 5 | J-97 | 7.851958 | 38.189303 | 2,078 |
| 6 | J-108 | 7.851286 | 38.183109 | 2,092 |
| 7 | J-112 | 7.859214 | 38.190686 | 2071 |

Seven representative sample measurements to the water main spread throughout the study area have been selected for the calibration based on AWWA developed calibration criteria. It was difficult to take measurement at a direct connection to the water main nodes, due to size of pressure gauge available in the town.

### 3.10.2. Model Validation

Coefficient of Determination ($R^2$):

The coefficient of determination describes the degree of linearity between simulated and observed pressure. ($R^2$) describes the proportion of variance in measured data explained by the model. $R^2$ ranges from Zero to one, with higher values indicating less error variance and typically value greater than 0.5-1 (1 inclusive) are considered acceptable. The model performance was taken manually using coefficient of determination (R2) method.

$$R^2 = \frac{\Sigma(x - xavg)(y - yavg)}{\sqrt{\Sigma(x - xavg)^2 \Sigma(y - yavg)^2}} \dots\dots\dots 3.9$$

Where: $R^2$= is the Correlation coefficient, X and Y are measured and simulated values, X mean and Y mean are the average value of measured and simulated data respectively

**Degree of Accuracy (Error of Difference):**

The degree of accuracy varies depending on the size of the system and the amount of field data and testing available to the modeler.(Behute, 2016) states that the average difference of ±1.5 m to maximum of ±5 m represents for good data set and ± 3 m to 10 m far bad data set would be a reasonable target. This is in terms of comparing the observed versus the calculated pressure heads in the system

# CHAPTER FOUR

# 4. RESULTS AND DISCUSSIONS

## 4.1 Estimated water demand

Estimating the expected water demand of the town were used for assessing and sizing system components such as pumping station, reservoirs, and transmission and distribution pipe line.

### 4.1.1 Population forecasting

The water demand of a particular town is proportionally related with the population to be served. The population of Werabe town from the Werabe town administration office, which is carried out in the year 2007, was indicate 21,067 and it was used as the base population for current estimation. Using the above CSA 2007 census data as a base and by using medium variant growth rate 4.83 (%) for SNNP Region for the urban, and applying the exponential population forecasting method, the current (2022) estimated population figure for Werabe town was presented in the following table 4.1. The water demand of a town is proportionally related to the population to be served.

Table 4. 1: Werabe town projected population (2022-2042)

| Description | 2007 | 2022 | 2027 | 2032 | 2037 | 2042 |
|---|---|---|---|---|---|---|
| Growth rate urban | 4.83% | 4.27% | 3.8% | 3.33% | 2.85% | 2.35 |
| Werabe Town | 21,067 | 39,366 | 47,651 | 56,386 | 65,192 | 73,578 |

From the Table 4.1 concerning the growth rate, the total population of Werabe town was 39,366 in 2022 with a population growth rate of 4.27%. In the above Figure Population were remain a major basis of water demand and a main consideration of any water supply system.

### 4.1.2. Average Daily Per Capita Consumption

The annual consumption data has been converted to average daily per capita consumption using the number of populations. The average daily Per capita consumption of town was derived using the following expressions:

$$Per\ capita\ consumption\ (l/c/d) = \left(\frac{599{,}102m^3 x\ 1000\ l/m^3}{(39{,}366x365\ days)}\right) \dots\dots\dots\dots\dots. = \ 41.7\ l/c/d$$

Table 4. 2: Water supply coverage of Werabe Town (2021-2022)

| Year | Production ($m^3$/year) | Consumption ($m^3$/year) | Population (No.) | Consumption l/person/day |
|---|---|---|---|---|
| April2021 to March 2022 | 855,864 | 599,105 | 39,366 | 41.7 |

As shown from the above table 4.2, the distribution of average domestic water supply coverage of Werabe town is found to be 41.7 l/capital /day. This average per capita consumption is lower when compared to the targeted or standard of the town water consumption is 60 *l*/capita/day (MoWR, 2006).The water supply coverage in existing status is 69.5% and existing water supply gaps in is 30.5%. Per capita demand depends on, size of the city, climate conditions, habits of people, industrial and commercial activities, quality of water, pressure in distribution system & cost of water (Santosh K, 2012).

### 4.2. Water Supply Coverage Analysis

There are a total number of 4766 customers including residential, commercial, institutional, and industrial. To identify the gap between demand and supply the most important ways are followed, using annual domestic consumption identifying per capita demand by level of connection and by the design criteria calculating the overall demand coverage of the existing design reports of the town.

Table 4. 3: Customers water coverage information system in Werabe town

| Customer's | Active customers |
|---|---|
| Private | 4436 |
| Commercial | 248 |
| Factory | 24 |
| Pub.Institution | 18 |
| Gov.Institution | 40 |
| Total | 4766 |

### 4.2.1. Level of Connection per Family

The total number of connections is 4766 within the Werabe town, and the typical number of persons per housing unit 4.3 in Werabe Town. To calculate the percentage of the level of connection using the population data, it gives the following expression:

Connection per family=4766/ (39,366/ (4.3) =52.1%

Table 4. 4: level of connection per family

| Year | Population | Average Family size | Total number of connection | Level of connection |
|---|---|---|---|---|
| April 2021 to 2022 March | 39366 | 4.3 | 4766 | 52.1% |

From Table 4.4, the level of the connection per family for the entire town is found to be 52.1%. This event is that at average the water consumption is explained by level of the population size.

### 4.2.2. Water Balance System of Werabe Town

Essentially a head of assigning nodal water demand, it is very common to quantify water loss in water supply distribution network the number of water losses in the system from the system input meter to the customers billed authorized consumption is in the quantity of water loss crossways the system is estimated by doing water balance analysis.

Table 4. 5: Percentage of Non-Revenue Water (2020-2022)

| Year | Production (m3/year) | Consumption (m3/year) | NRW ($m^3$) | % |
|---|---|---|---|---|
| 2020 | 839936 | 566116 | 273820 | 32.6% |
| 2021 | 845896 | 581976 | 263920 | 31.2% |
| 2022 | 855864 | 599105 | 256762 | 30% |

(Source: Werabe town water supply service office, existing document (2022)

But, as shown in table 4.5 above; due to the constant production/supply of water to the system, and accordingly the increases of water consumption in the town were the reason for reduction of total volume of NRW in recent years.

Table 4. 6: Monthly water balance and NRW based on the cumulative value

| Month | Production (m3/month) | Bill Consumption | Cumulative Production | Cumulative Consumption | water balance | Comm. NRW |
|---|---|---|---|---|---|---|

| | | (m3/month) | | | (m3) | (%) |
|---|---|---|---|---|---|---|
| Apr | 64512 | 45458 | 64512 | 45458 | 19054 | 29.54 |
| May | 68472 | 48851 | 132984 | 94309 | 38675 | 29.08 |
| Jun | 81962 | 56273 | 214946 | 150582 | 64364 | 29.94 |
| Jul | 83121 | 57385 | 298067 | 207967 | 90100 | 30.23 |
| Aug | 80460 | 54982 | 378527 | 262949 | 115578 | 30.53 |
| Sep | 76352 | 54124 | 454879 | 317073 | 137806 | 30.30 |
| Oct | 73260 | 52182 | 528139 | 369255 | 158884 | 30.08 |
| Nov | 70380 | 49365 | 598519 | 418620 | 179899 | 30.06 |
| Dec | 67241 | 46895 | 665760 | 465515 | 200245 | 30.08 |
| Jan | 63781 | 45546 | 729541 | 511061 | 218480 | 29.95 |
| Feb | 61462 | 42754 | 791003 | 553815 | 237188 | 29.99 |
| Mar | 64861 | 45287 | 855864 | 599102 | 256762 | **30.00** |

The cumulative average water loss of Werabe town is shown in the Table 4.6 above, the cumulative water balance or water loss usually expressed in terms of percentage (NRW), percentage is calculated using the cumulative production minus cumulative consumption. It observed from the Table 4.6 above, the estimated annual volume of NRW in Werabe town water utilities; water balance for the year April 2021 to March 2022 is provided accordingly total water supply production is 855,864m$^3$/year while the corresponding consumption is 599,102m$^3$/year the resulting water loss is 256,762m$^3$/year. In the Table 4.6 based on the analysis results the total water loss from the system is 256,762m$^3$/year and is the Non -revenue water 30% of the system

**4. 3. Water Demand Estimation Analysis**

The estimation of water demand per the mode of service and estimation of the population by mode of service was used to calculate the average consumption. The average per capita domestic water demands by mode of services for the estimated current demand in a period of 2022 presented in Appendix – 2 Summarizing current and projected water demand in the study area Werabe Town Population and demand projection

The water supply and demand gap between production and demand consumption is $= supply -$demand =2345m$^3$ /day – 2501.75m$^3$ /day = -156.75 m$^3$ /day. The negative sign indicates that additional water quantity required in the system per day to balance the system supply and demand gaps. It has been identified that the estimated average day water demands for the study area are 2501.75$m^3$/day. However, the yield of the existing sources is for supply is, 2345$m^3$/ day.

This shows that the estimated demands and yield of the existing sources are not parallel. Let alone satisfying the ultimate demands, the current supply does not even satisfy the present demand of the area, which is estimated to be about -156.75$m^3$/day therefore, the existing measured production of the water supply system to Werabe town is 2345$m^3$/ day with their total population of 39,366 persons. This water is supply in 24 hours and 16 hours at lower and higher elevation area with a total amount of non- revenue water is 30% for supplying water 24 hrs. To fill the gap additional 156.75 $m^3$/day amount of water is required to satisfy the customer demands to cover the shortage of supply system of Werabe town.

Table 4. 7: Existing water supply gaps in Werabe town

| Indicators | Target | Existing Status | Gap Calculated |
|---|---|---|---|
| Per-capita water supply- demand | 60 l/c/day | 41.7 l/c/day | 18.3 l/c/day |
| Existing demand and supply condition | 2501.75$m^3$/day | 2345 $m^3$/day | -156 $m^3$/day |
| Extent of Non-revenue water | 20% | 30% | 10% |

### 4.4. Water loss Analysis

One of the major challenges of water utilities is high volume of water loss in their distribution networks. If a large quantity of supplied water is lost; it is difficult to meet the required quantity to demands. Whereby, water loss for Werabe Town was assessed and discussed as below;

#### 4.4.1. Percentage of water loss

Non-Revenue Water includes water losses in the water distribution system, illegal connections, and improper metering and recording. The amount is expressed as percentage of the total produced water from the water supply system. The percentage usually varies and depending on the age of the pipes and complexity of the system. Unaccounted water loss is the sum of real loss and apparent losses. It was found that unaccounted water losses estimated for the year. This loss accounts 30% of the total daily water demand of Werabe Town in the predicted years. Water losses can be either real (physical) losses or apparent losses. Real losses are mainly due to leakage from joints in water pipes, service connections, pipe bursts, pipe cracks and overflows from storage tanks. As evidenced during the field visit the main cause of water losses for Werabe

Town seems more likely due to operation and maintenance of distribution network such pipe bursts and pipe cracks. Due to installation of under size pipe system, the pressure becomes beyond permissible limit in the distribution system at the minimum consumption period

### 4.5. Water Distribution Network Simulation

#### 4.5.1 Model Calibration and Validation

Before any use, the model must be calibrated to establish its reliability and allow decisions about physical and operational developments in the real system to be made with high degree of confidence as possible. In this research, the pressures data were measured at or near to node home faucet of the system is used to assess the model performance. The model performance measure; such as the degree of accuracy (error of difference) and the coefficient of determination (R2) are two techniques to be considered for the calibration model check as mentioned below the results.

Table 4. 8: Locations of the representative sample node

| S.No | Pressure Junction (Id) | Latitude (°) | Longitude (°) | Z (m) |
|---|---|---|---|---|
| 1 | J-44 | 7.833857 | 38.178835 | 2109 |
| 2 | J-48 | 7.833857 | 38.178835 | 2109 |
| 3 | J-79 | 7.844972 | 38.187393 | 2,085 |
| 4 | J-90 | 7.854898 | 38.189515 | 2,083 |
| 5 | J-97 | 7.851958 | 38.189303 | 2,078 |
| 6 | J-108 | 7.851286 | 38.183109 | 2,092 |
| 7 | J-112 | 7.859214 | 38.190686 | 2071 |

**A) The degree of accuracy (error of difference)**

The comparison of simulated pressure results with field-measured data's are presented in the table 4.9 below. Junction pressure calibration based on degree of accuracy criteria

Table 4. 9: Comparison of simulated pressure results with field-measured data

| Time (hr.) | Pressure Junction Id | Observed Pressure (m) | Simulated Pressure (m) | Difference Pressure Error (m) | Elevation (m) |
|---|---|---|---|---|---|
| 8:00 AM | J-44 | 22 | 26 | -4 | 2109 |
| | J-48 | 1 | 3 | -2 | 2126 |

| | | | | | |
|---|---|---|---|---|---|
| | J-79 | 17 | 21 | -4 | 2085 |
| | J-90 | 28 | 31 | -3 | 2083 |
| | J-97 | 27 | 30 | -3 | 2078 |
| | J-108 | 11 | 15 | -4 | 2092 |
| | J-112 | 35 | 36 | -1 | 2071 |
| 10:00AM | J-44 | 25 | 27 | -2 | 2109 |
| | J-48 | 3 | 5 | -2 | 2126 |
| | J-79 | 26 | 23 | 3 | 2085 |
| | J-90 | 36 | 35 | 1 | 2083 |
| | J-97 | 34 | 35 | -1 | 2078 |
| | J-108 | 17 | 20 | -3 | 2092 |
| | J-112 | 40 | 41 | -1 | 2071 |
| 2:00 PM | J-44 | 24 | 27 | -3 | 2109 |
| | J-48 | 4 | 5 | -1 | 2126 |
| | J-79 | 24 | 23 | 1 | 2085 |
| | J-90 | 32 | 35 | -3 | 2083 |
| | J-97 | 33 | 35 | -2 | 2078 |
| | J-108 | 23 | 20 | 3 | 2092 |
| | J-112 | 39 | 41 | -2 | 2071 |
| 6:00 PM | J-44 | 23 | 25 | -2 | 2109 |
| | J-48 | 2 | 1 | 1 | 2126 |
| | J-79 | 16 | 20 | -4 | 2085 |
| | J-90 | 27 | 30 | -3 | 2083 |
| | J-97 | 27 | 28 | -1 | 2078 |
| | J-108 | 9 | 12 | -3 | 2092 |
| | J-112 | 29 | 33 | -4 | 2071 |
| Average | | | | -1.75 | |

The average pressure difference error is (-1.75) from the table above observed pressure value to predicted or simulated pressure value. Hence the model is acceptable calibrated with in satisfied the setting pressure calibration and validation criteria under average level. (± 1.5 m and maximum difference ± 5 m) so our value is between the allowable range and it indicates it is a good data observed pressure Vs. simulated pressure.

**B) The coefficient of determination ($R^2$)**

Pressures were measured in the field in order to compare with the simulated water distribution model. The measurements covered the low, medium, and high-pressure areas of the distribution system of the town. Junction pressure reading values were measured at J-44, J-48, J-79, J-90, J-97, J-108 and J-112, and the records for each node were taken four times in single day at times of 8:00 AM, 10:00AM, 2:00 PM, and 6:00 PM. Figure 4.1 shows, the variation of the simulated and observed pressure, at the sample nodes.

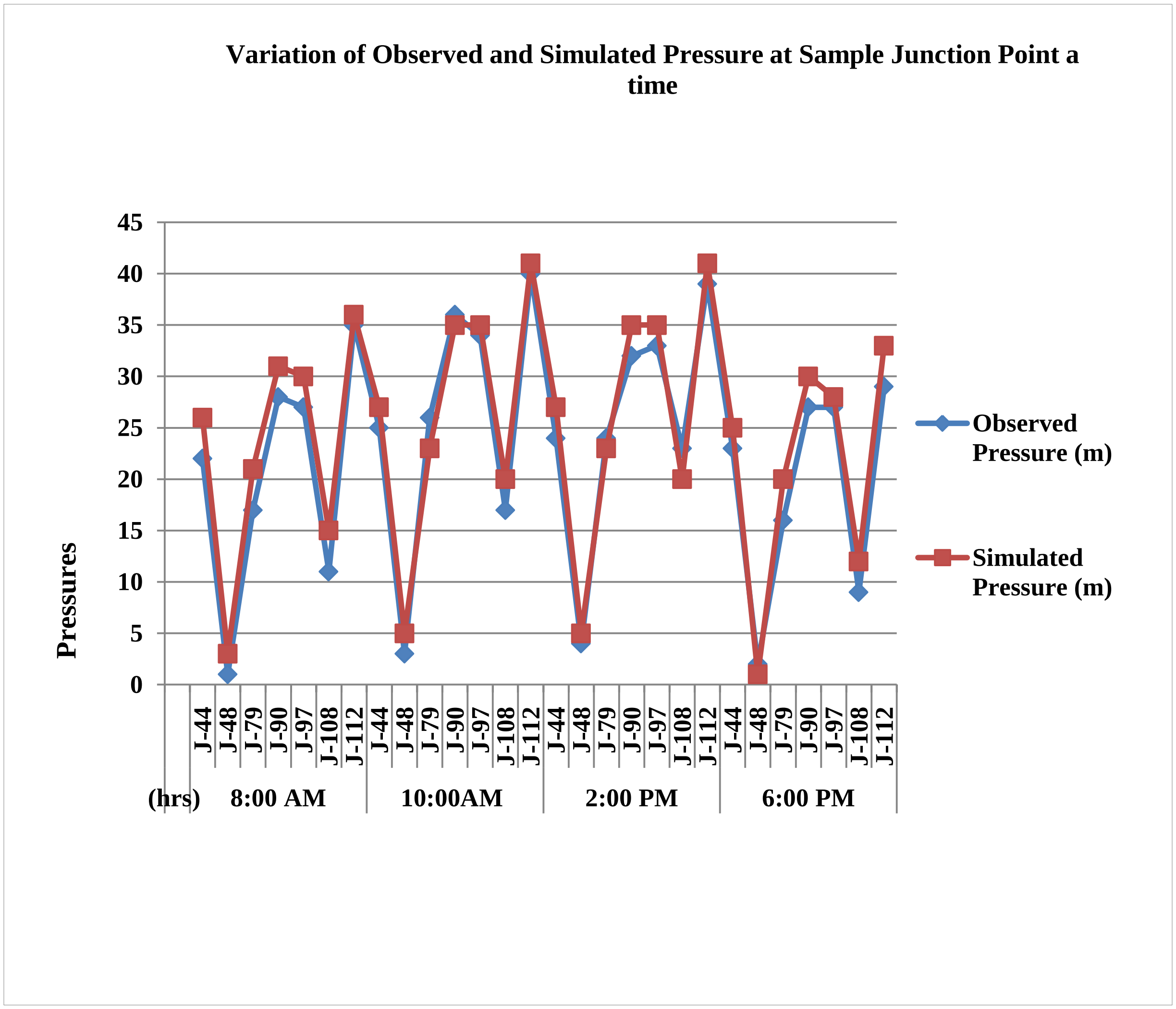


Figure 4. 1: Variations of Observed and Simulated Pressure at Sample Junction

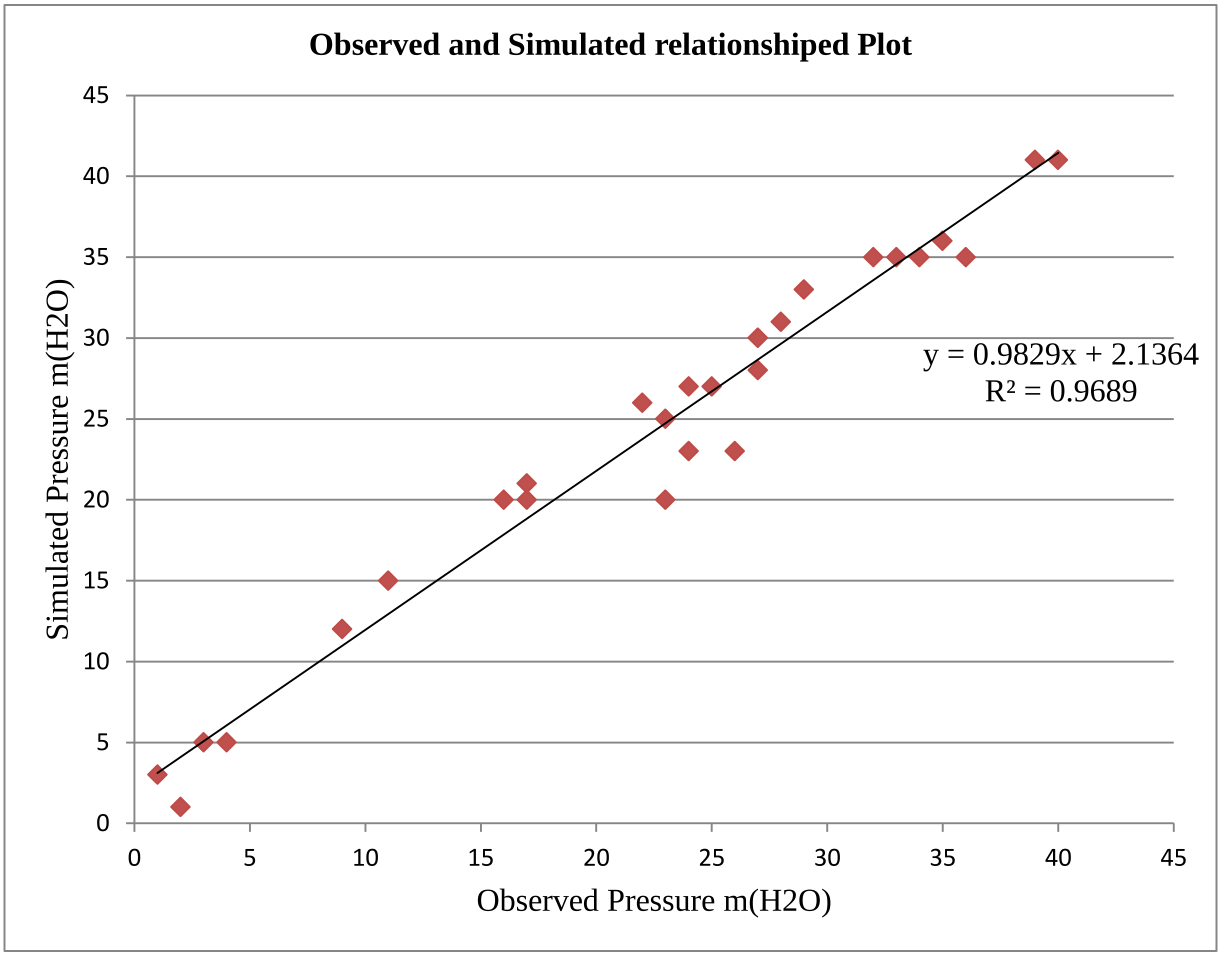


Figure 4. 2: Correlation between Observed and Simulated Pressure Relationship Plot

The observed and simulated pressure give a correlation coefficient of the determination which ranges between 0 and 1, describing the proportion of the variance in the measured data which is explained by the model, with higher values indicating less error variance. the diagonal line on the plot represents the line of perfect correlation in Figure 4.2. Generally, all the points should align themselves on this line, and all observed pressure should be equal to computed pressure, giving a relationship coefficient of 1, which is the best correlation between observed and simulated. It is necessary to validate every model before applying the model to new problem identification. And shows there is no problems were found in order to use the model for analysis. From the figure 4.2, the coefficient of determination ($R^2$) value was 0.9689. Since the value of $R^2$ approaches 1, which indicates that there is a good correlation between fields measured pressure and simulated pressure, and shows the observed pressure and simulated pressure relationship is strong as values tend to one.

### 4.5.2. Model Development

The constructed of the existing WDN model of Werabe town for hydraulic analysis using WaterGEMS software by giving all the necessary input data is shown in Figure 4.3:

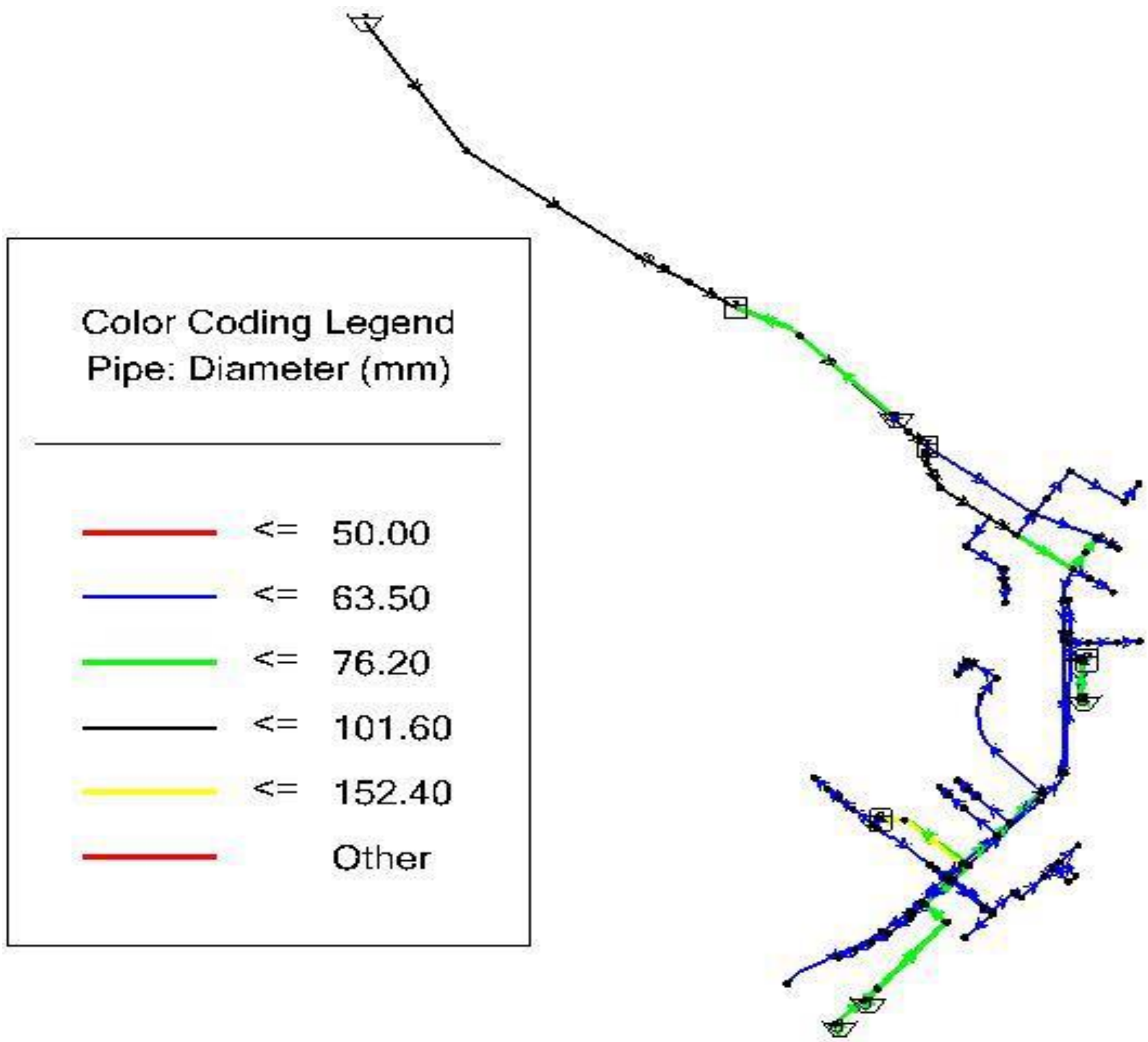


Figure 4. 3: Water Distribution Network Model of Werabe Town

### 4.5.3. Pressure

- **Pressure Distribution at Peak Hour Consumption**

In Ethiopia's water supply distribution system network, the minimum and maximum operating pressures are 15 m and 70 m, respectively (MoWR, 2006). Pressure influences the water supply capacity of the distribution system. During hydraulic modeling of water pressure of Werabe town, with regard to current simulation the result of pressure at peak consumption (at 7 A.M.) in the morning, is given in table 4.10, and detailed in appendix-3. As described in Table 4.10, 66% of junctions are below the recommended pressure, 6.25% above the recommended pressure, and only 27.68% of junctions are within the recommended pressure ranges of minimum 15 m and maximum 70 m H2O. It is observed

Table 4. 10: Distribution of Pressure at Peak Hour Consumption

| Pressure range in (m) | Total No. of Junctions (No.) | Percentage % |
|---|---|---|
| < 15 | 74 | 66 |
| 15-70 | 31 | 27.68 |
| >70 | 7 | 6.25 |
| Total | 112 | 100.00 |

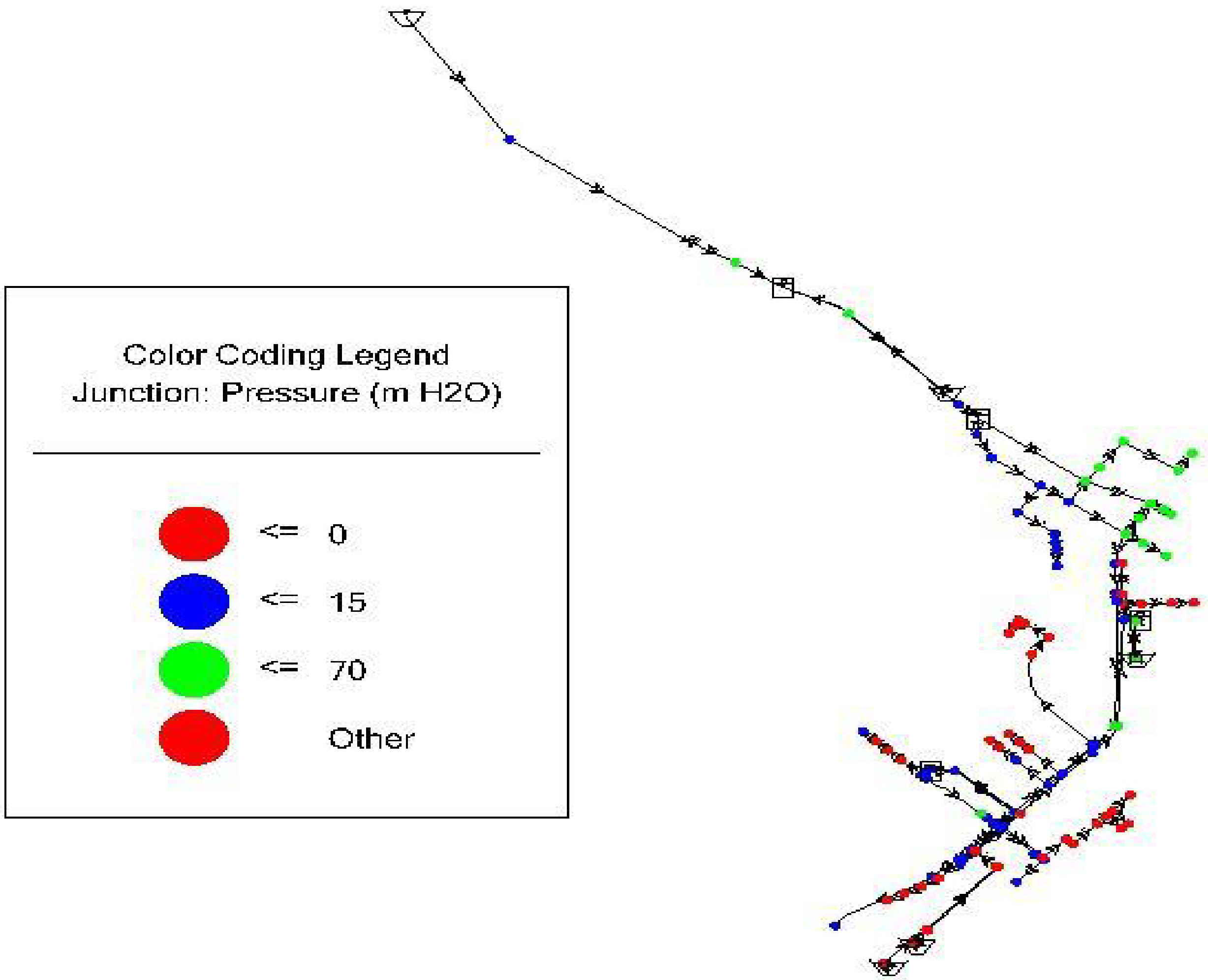


Figure 4. 4: Distribution of Pressure Color Coding at Peak Hour Consumption

Color coding helps to understand the difference in pressure range at various junctions and also helps with the identification of critical points. In Figure 4.4, the red-color nodes denote the critical points in the distribution network with negative pressure and pressure > 70 m, which need improvement in the existing water distribution system to attain the permissible pressure.

- **Pressure Distribution at Minimum Hour Consumption**

The simulation result of pressure at minimum consumption hour, when most of the consumers were sleeping and not using water at night (2 A.M.), was summarized in Table 4.11, and detailed in appendix-4.

Table 4. 11: Pressure Distribution at Minimum Consumption Time

| Pressure range (m H2O) | Total No. of Junctions (No.) | Percentage (%) |
|---|---|---|
| <15 | 11 | 9.82 |
| 15-70 | 92 | 82.14 |
| >70 | 9 | 8.04 |
| Total | 112 | 100.00 |

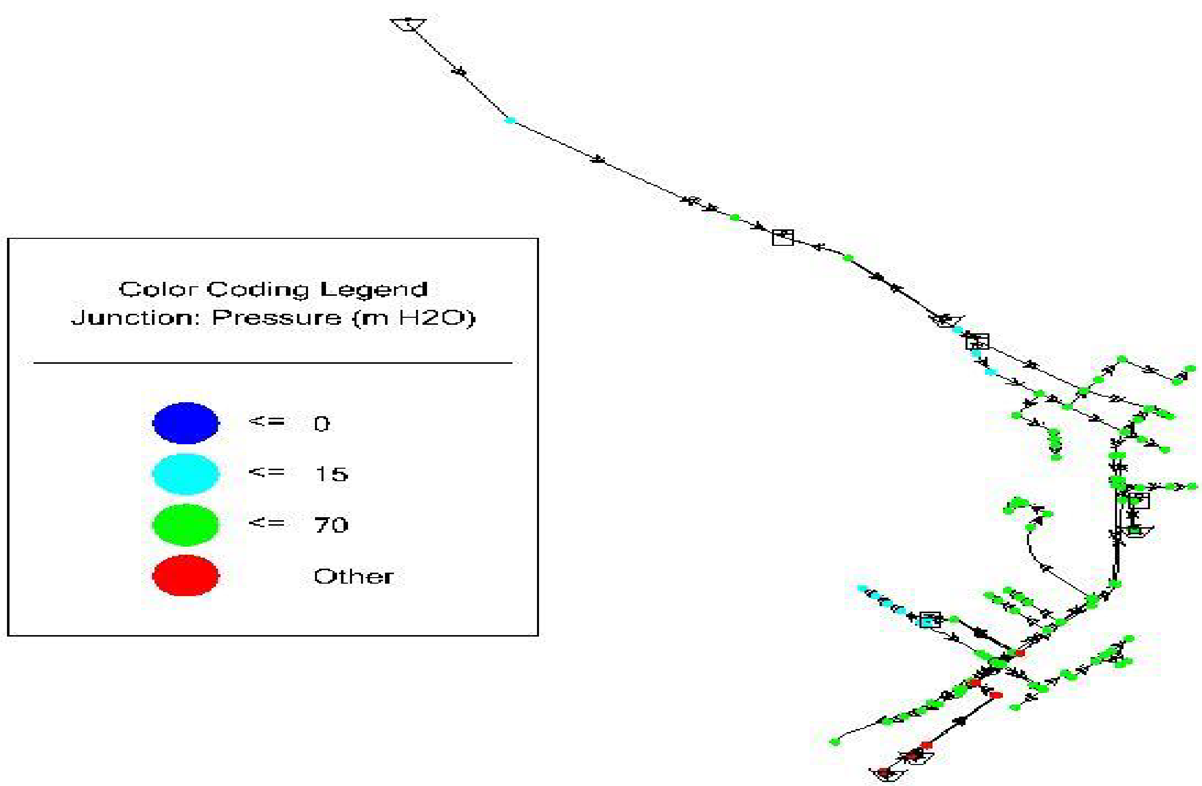


Figure 4. 5 : Distribution of Pressure Color Coding at Min Hour Consumption

#### 4.5.4. Velocity

The velocity of water flow in a pipe is also one of the important parameters in hydraulic modeling performance evaluation of the efficiency of water supply distribution and transmission line. The velocity ranges can also be adopted as the design criteria, low velocities for hygienic, while too high-velocity cause exceptional head loss reason are not preferred velocity distribution is also varying with demand pattern changes. There are specific standards for velocity and head loss in WDS. The result of velocity and head loss of Werabe town is not desirable or adequate with response to (MoWE, 2006) of urban water supply design criteria. These types of hydraulic indicators are as if a pressure unfortunate as the result of the strategy description. Performance at the peak time demand, the values are different as compare to minimum consumption hour.

Table 4. 12: distribution of actual pipe velocity at peak consumption hour

| Velocity in (m/sec) | Pipe (number) | Percentage % |
|---|---|---|
| >2 | 1 | 0.79 |
| 0.6-2 | 59 | 46.46 |
| 0.3-0.6 | 32 | 25.2 |
| 0.1-0.3 | 29 | 23.38 |
| <0.1 | 6 | 4.7 |
| Total | 127 | 100 |

As shown in Table 4.12 through minimum hour consumption conditions 46.46% of pipes are in the allowable velocity range, and 53.54 % of pipes are below the minimum velocity. Generally, the above stated problems with respect to hydraulic network modeling such as under sized service pipe diameter, oversized service pipe diameter, low pressure, high pressure, high velocity and low velocity. Generally,Werabe town water distribution system has the major problems; which are high pressure, Low pressure, undersized pipe and oversized pipe. If a pipe is too small, it may become a problem only during high flow conditions; the best time for identifying problems would likely be the model simulation during peak hour flow. Undersized pipes can usually be found by looking for pipes with high velocities. Increasing the diameter of the pipe in the model should result in a corresponding decrease in velocity and increase in pressure. The water velocity in systems can range from 0.6 to 2.0 m/s according to the guideline, depending on the relative size of the peak and average flow rates (MoWR, 2006).

- **Resulting Head Loss**

The main reason for head loss (energy loss), is due to internal friction between fluid particles traveling at different velocities. So, head loss is related to velocity and pipe roughness; and the resulting head loss with therefore be governed by the different velocity ranges. According to, Ethiopia's urban water supply design guidelines; head loss gradient in (m/km) through the pipes line of water supply system should be lower than 15 m/km. The resulting head loss gradient (m/km) for the pipe velocity at peak consumption hours has been shown in Table 4.13 by considering Ethiopian head loss gradient criteria.

As indicated in Table 4.13, 33.86% of head loss exceeds the maximum allowable head loss gradient during peak consumption hours. While 66.14% of the pipes head loss is in the recommended range of below 15m/km (MoWR, 2006).

As a result, the existing water distribution network in Werabe town should be modified or improved based on certain design criteria. Undersized pipes can usually be found by looking for pipes with high velocity, which is the main reason for head loss. Increasing the diameter of the pipe in the model should result in a corresponding decrease in velocity and decrease in head loss.

Table 4. 13: Result of Head Loss Gradient at Peak Consumption Hour

| Head loss Gradient (m/km) | Pipe (No.) | Percentage (%) |
|---|---|---|
| <15 | 84 | 66.14 |
| 15-30 | 28 | 22.05 |
| >30 | 15 | 11.81 |
| Total | 127 | 100 |

### 4.6. Hydraulic Network Improvement

In improving a system, there are sets of design criteria to be considered. These are: pressure, velocity and head loss. And, in improving process of the existing water supply distribution system of Werabe town, Ethiopia’s urban water supply design criteria was considered and used. Modification to the problems is made by creating new alternatives and scenario, trial and error procedure until a solution appeared to meet the design criteria. The procedures were:

- At peak hour demand, the velocities out of the design range are modified by resizing pipe diameters.
- At peak hour, the pressures at junction of lower portion were high and reduction to the desired pressure has been made by using pressure reducer valves (PRVs).

### 4.6.1. Adding pressure reducing valve in the network

The best operational practice to optimize the operation of water distribution system was controlling the pressure in the network. This management of pressure has been reflected in the aspect of reducing excessive pressure by installing a pressure-reducing valve (PRV). By controlling the pressure it is possible to reduce the amount of water loss from the system, the occurrence of internal damage and power consumption related to high pressure. At minimum hour demand pressure was high at lower elevation area. Installing PRV at locations shown in Table 4.14, which have maximum pressure was used to reducing excessive pressure to the desired allowable value and consequently, pressure values after adding PRVs were given in Table 4.15.

Table 4. 14: Pressure Reducer Valves in the Improved System

| S.No. | Label | Elevation (m) | Diameter (mm) | X | Y |
|---|---|---|---|---|---|
| 1 | PRV-1 | 2093 | 76.2 | 7.823256° | 38.173448° |
| 2 | PRV-2 | 2098 | 76.2 | 7.824762° | 38.175158° |

Table 4. 15: Pressure Adjustment at Minimum Consumption Hour

| S.No | Junction | Elevation (m) | Pressure before adding PRV (m H2O) | Pressure after adding PRV (m H2O) |
|---|---|---|---|---|
| 1 | J-1 | 2,093.00 | 135 | 45 |
| 2 | J-2 | 2,097.00 | 116 | 41 |
| 3 | J-3 | 2,097.00 | 91 | 41 |
| 4 | J-4 | 2,101.00 | 79 | 37 |
| 5 | J-6 | 2,098.00 | 145 | 40 |
| 6 | J-7 | 2,097.00 | 139 | 41 |
| 7 | J-8 | 2,097.00 | 106 | 41 |
| 8 | J-9 | 2,101.00 | 92 | 37 |
| 9 | J-10 | 2,099.00 | 74 | 39 |

During minimum hour, demand pressure was high in the lower elevation areas. Installing pressure reduced valves at links that have maximum pressure was used to reduce excessive pressure to the desired allowable value as shown in Table 4.16. By controlling the pressure, it is possible to reduce the amount of water loss from the system, the occurrence of internal damage, and power consumption related to high pressure. After modifying the existing water distribution system by adding a pressure reducing valve, 90.18% of the junctions are in the recommended pressure range of a minimum of 15 m of H2O and a maximum of 70 m of H2O, and only 9.82% of the junctions are not in the recommended pressure range.

Table 4. 16: Pressure Improved System at Minimum Consumption Time

| Pressure range (m H2O) | Total No. of Junctions (No.) | Percentage (%) |
|---|---|---|
| <15 | 11 | 9.82 |
| 15-70 | 101 | 90.18 |
| >70 | 0 | 0 |
| Total | 112 | 100.00 |

Figure 4.6 also shows the distribution of junction pressures at Minimum Consumption by using color coding; which helps to understand the difference in pressure after modifying the existing water distribution system by adding a pressure reducing valve,

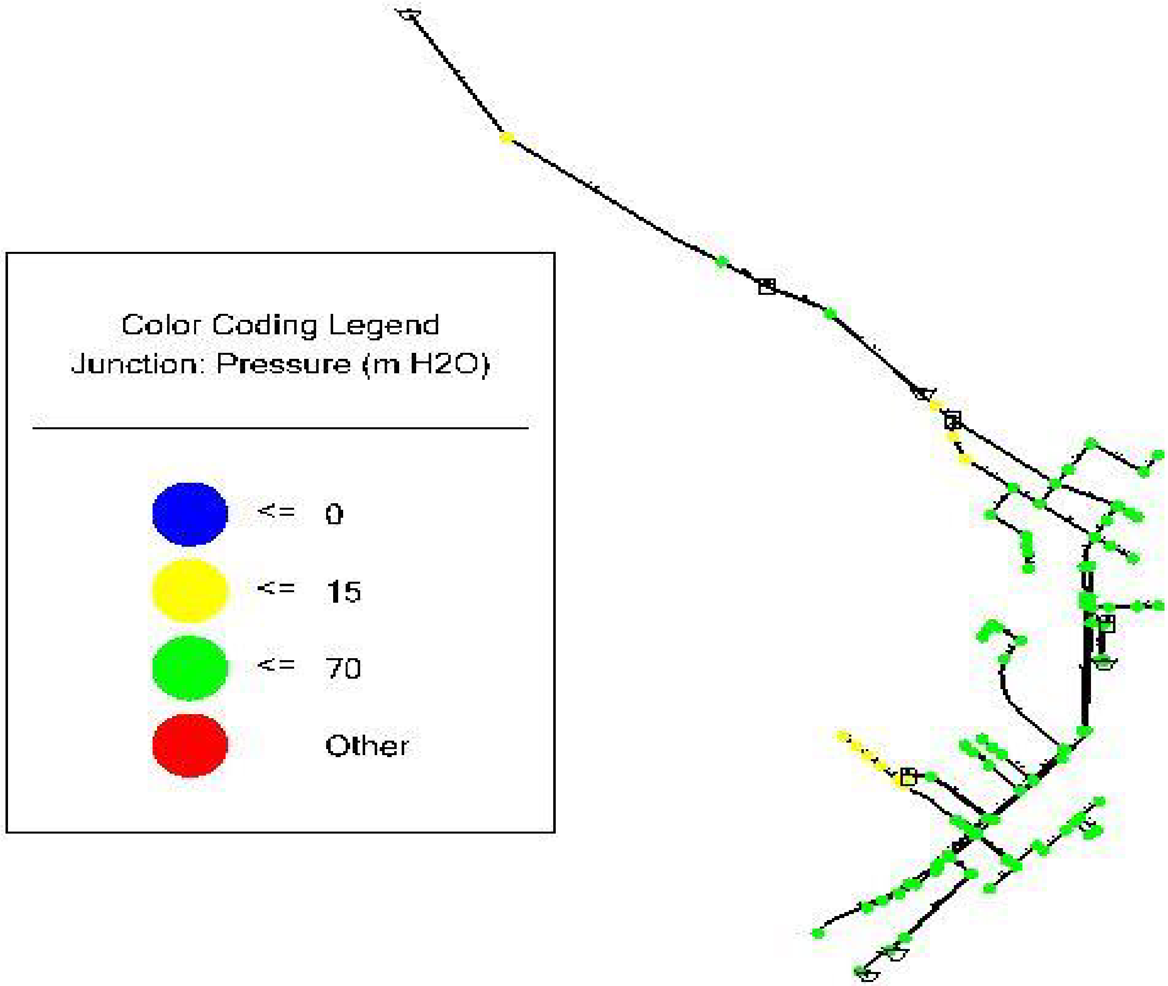


Figure 4. 6: Pressure Improved System at Minimum Consumption Time

**4.6.2. Modifying pipe size**

An increase in the diameter of the pipe in a water distribution model results in a corresponding decrease in velocity and an increase in pressure. At peak hour consumption, the excess head loss exceeds the allowable value has been modified by resizing pipe diameters. The modified pipe size in the existing water supply distribution system of Werabe town is shown in Table 4.15; resulting in decreases in velocity of flow and resulting head losses. The pipe was selected of maximum velocity which are higher than with all other velocities obtained during simulation at Peak Hour Consumption for the modification to improve the exising water supply distribution system.

Table 4. 17: Modified pipe size in main distribution system

| S.No. | Label | Existing pipe size(mm) | | Modified pipe size(mm) | |
|---|---|---|---|---|---|
| | | Diameter (mm) | Velocity (m/s) | Diameter (mm) | Velocity (m/s) |
| 1 | P-26 | 76.2 | 1.09 | 101.6 | 0.75 |
| 2 | P-27 | 76.2 | 1.09 | 101.6 | 0.75 |
| 3 | P-28 | 76.2 | 0.76 | 88.9 | 0.56 |
| 4 | P-29 | 63.5 | 0.68 | 76.2 | 0.67 |
| 5 | P-30 | 63.5 | 0.77 | 76.2 | 0.53 |
| 6 | P-31 | 63.5 | 0.62 | 76.2 | 0.43 |
| 7 | P-47 | 63.5 | 0.49 | 88.9 | 0.34 |
| 8 | P-50 | 50.8 | 0.46 | 76.2 | 0.35 |
| 9 | P-51 | 50.8 | 0.46 | 63.5 | 0.37 |
| 10 | P-57 | 50.8 | 0.83 | 63.5 | 0.53 |
| 11 | P-58 | 50.8 | 0.64 | 63.5 | 0.41 |
| 12 | P-59 | 50.8 | 0.43 | 63.5 | 0.28 |
| 13 | P-60 | 50.8 | 0.24 | 63.5 | 0.15 |
| 14 | P-69 | 50.8 | 1.53 | 76.2 | 0.68 |
| 15 | P-70 | 50.8 | 0.55 | 63.5 | 0.35 |
| 16 | P-72 | 63.5 | 1.32 | 88.9 | 0.68 |
| 17 | P-72 | 63.5 | 1.15 | 88.9 | 0.59 |
| 18 | P-73 | 63.5 | 0.99 | 88.9 | 0.50 |
| 19 | P-74 | 63.5 | 0.83 | 88.9 | 0.42 |
| 20 | P-75 | 63.5 | 0.69 | 88.9 | 0.48 |
| 21 | P-76 | 63.5 | 1.59 | 76.2 | 0.80 |
| 22 | P-88 | 50.8 | 0.75 | 76.2 | 0.48 |
| 23 | P-89 | 50.8 Pages | 1.09 | 63.5 | 0.75 |

**Head Loss:** The resulting improved head loss gradient (m/km) is shown in Table 3.18.

Table 4. 18: Improved Head Loss Gradient at Peak Hour Consumption

| Head loss Gradient (m/km) | Pipe (No.) | Percentage (%) |
|---|---|---|
| <15 | 111 | 86.05 |
| 15-30 | 6 | 4.65 |
| >30 | 12 | 9.30 |
| Total | 129 | 100 |

The resulting improved head loss gradient (m/km) for the pipe velocity at peak consumption hours has been shown in Table 4.16. As indicated in this table, the improved head loss percentage value of 86.05% of the pipe head loss is in the recommended range of below 15m/km. While 13.95% of head loss exceeds the maximum allowable value, after modifying the pipe sizes in the existing distribution system of Werabe town as shown in the table above, 86.05% of the pipe head loss gradients are in the recommended head loss gradient of less than 15m/km, and only 13.95% of the pipes are not in the recommended velocity range. According to the above procedures, the distribution main pipes are modified and Pressure reducer valves (PRVs) are added to reduce the maximum pressure. And, the head loss exceeds the maximum allowable value has been adjusted or modified by resizing pipe diameters. As a result, 18.11% of the total distribution networks had been resizes.

# CHAPTER FIVE

# 5. SUMMARYS AND CONCLUSIONS

## 5.1. CONCLUSIONS

The primary aim of this research was to assess the performance of water supply system beside existing water supply system, demand of the town and water loss in Werabe Town.

- ❖ Both the water supply coverage and the Town distribution were evaluated based on the daily per-capital consumption and level of connection using the population data of the Town.
- ❖ The research has confirmed that there is high gap between demand and supply. This gap is due to not only low water production, but also urban expansion. Moreover, a lot of unplanned connection along the gravity main line.
- ❖ The nodal pressure in all distribution system especially at the point of lower and higher elevation areas of the distribution system has been checked.
- ❖ The town water balance indicated that 30% of treated water was lost as a total Non-Revenue Water.
- ❖ The existing WDS is simulated through the construction of a model using Bentley WaterGEMS software

Generally, it is observed that insufficient pressures in some of the junctions in the distribution network occur due to inadequacy of pipe.Adequate pressures can be obtained by adding parallel pipes of equivalent diameters or replacing the pipe with higher diameters. Adding parallel pipes can be more feasible as the older pipes can be retained in the network and the network can be improved with new pipes. Replacing the older pipes can cause difficulties for the users as water supply is cut off and higher costs are likely to incur. Finally, it was concluded that the current water distribution network of Werabe town was in poor performance and were not conducted adequate water to the various demand categories of the town.

## 5.2. RECOMMENDATIONS

Based on the analyzed findings the following recommendations were mentioned to Werabe town existing water supply system:

- As the current water demand in the town is much greater of the daily water production of the system, so it is necessary revising the design and rehabilitates the water distribution system by improving the size of reservoirs capacity and replacing the new pumps with the required hydraulic performance

- Manage the demand by controlling waste or loss from pipe leakage and consumption through the use of meters and tariffs that are set in accordance with the volume of water consumption.
- A planned and scheduled rationing system should be implemented to supply water equally for residents of the town.
- Pressure Reducer Valve (PRV) is added in the system to overcoming the problems of high pressure effects on water supply line.
- The system of water supply system needs detail study before distribution pipe expansion.
- The water utility should work towards making water to be available for the whole day by developing additional sources to increase the water production and by reducing the high water loss.
- The deficit of water supply in the system should be reduced by minimizing the large amount of unaccounted for water.
- In this study water quality was not analyzed due to time and financial constraints; hence the future research should give attention for better performance evaluation.
- Setting of PRV devices, which decrease excessive pressures are recommended as solution to control occurrences of maximum pressures for isolated parts of network.

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# APPENDIX

Annex- 1: Monthly water production and Consumption from (April 2021 - March 2022)

| Monthly | Water Production ($m^3$/month) | Consumption Bill ( m3/month) |
|---|---|---|
| Apr | 64512 | 45158 |
| May | 68472 | 47930 |
| Jun | 81962 | 57373 |
| Jul | 83121 | 58185 |
| Aug | 80460 | 56322 |
| Sep | 76352 | 53446 |
| Oct | 73260 | 51282 |
| Nov | 70380 | 49266 |
| Dec | 67241 | 47069 |
| Jan | 63781 | 44647 |
| Feb | 61462 | 43023 |
| Mar | 64861 | 45403 |
| Monthly Average (m3/month) | 71322 | 49925 |
| Average Daily (m3/day) | 2345 | 1641.38 |
| Average Yearly (m3/year) | 855864 | 599105 |

Annex- 2: Werabe Town Population and demand projection (2022-2042)

| Description | Unit | 2022 | 2032 | 2042 |
|---|---|---|---|---|
| 1.Population | | | | |
| Population growth rate | % | 4.27% | 3.33% | 2.35% |
| Total population | No. | 39366 | 56386 | 73578 |
| 1.3.Percentage Coverage by mode of services | | | | |
| HTU | % | 12% | 13.00% | 15.50% |
| YTU | % | 79% | 81.84% | 84.68% |
| PTU | % | 9% | 6.00% | 0.50% |
| 1.4.Population served by different types of mode | | | | |
| HC | % | 4724 | 7330 | 11404.56 |
| YC | % | 31099 | 46146 | 62305.85 |
| PT | % | 3543 | 3383 | 367.89 |
| Total Popultion | No. | 39366 | 56386 | 73578 |
| 1.5.Housing Units | No. | 9153 | 13113 | 17946 |
| 1.6.Person per Housing Unit | No. | 4.3 | 4.3 | 4.1 |
| 1.7.No. of Connections | No. | 4766 | 7329 | 12350 |
| 2. Demand | | | | |
| 2.1 Domestic | | | | |
| Total Domestic demand | m3/d | 1410 | 2648 | 4352 |
| Climatic and Socio-Economic factor (1.0*1.05) | | 1.05 | 1.05 | 1.05 |
| Total adjusted domestic demand | m3/d | 1480.33 | 2780.84 | 4569.21 |
| 2.2 Non-domestic | | | | |
| Commercial& Institutional, Industrial, Public demand (30%) | m³/day | 444.10 | 834.25 | 1370.76 |
| Average Daily Demand | m³/day | 1924.43 | 3886.69 | 6396.47 |
| 3.Non-revenue Water (NRW) | % | 30% | 20.00% | 18.00% |
| | m³/day | 577.33 | 777.34 | 1151.36 |

| | | | | |
|---|---|---|---|---|
| 4. Total Average Day Demand=DD+NDD+NRW | $m^3$/day | 2501.75 | 4664.03 | 7547.84 |
| Maximum daily factor | | 1.15 | 1.15 | 1.15 |
| 5. Maximum Day Demand | $m^3$/day | 2877.02 | 5363.63 | 8680.01 |
| Peak hourly factor | | 1.65 | 1.65 | 1.56 |
| 6. Peak Hour Demand | $m^3$/day | 4753.33 | 8861.65 | 13586.11 |

Annex- 3: Hydraulic Model Output for EPS at Peak Hour (Junction Report at 7:00AM)

| Label | Elevation (m) | Demand (L/s) | Hydraulic Grade (m) | Pressure (m H2O) |
|---|---|---|---|---|
| J-1 | 2,093.00 | 0.00 | 2,206.64 | 113 |
| J-2 | 2,097.00 | 0.00 | 2,195.54 | 98 |
| J-3 | 2,097.00 | 0.00 | 2,176.00 | 79 |
| J-4 | 2,101.00 | 0.00 | 2,170.54 | 69 |
| J-5 | 2,099.00 | 0.00 | 2,158.67 | 60 |
| J-6 | 2,098.00 | 0.00 | 2,214.43 | 116 |
| J-7 | 2,097.00 | 0.00 | 2,209.76 | 113 |
| J-8 | 2,097.00 | 0.00 | 2,185.41 | 88 |
| J-9 | 2,101.00 | 0.00 | 2,178.47 | 77 |
| J-10 | 2,099.00 | 0.00 | 2,163.62 | 64 |
| J-11 | 2,122.00 | 0.34 | 2,135.28 | 13 |
| J-12 | 2,100.00 | 0.35 | 2,125.53 | 25 |
| J-13 | 2,102.00 | 0.51 | 2,113.11 | 11 |
| J-14 | 2,101.50 | 0.28 | 2,109.41 | 8 |
| J-15 | 2,101.50 | 0.40 | 2,108.05 | 7 |
| J-16 | 2,102.00 | 0.46 | 2,107.25 | 5 |
| J-17 | 2,101.00 | 0.34 | 2,106.71 | 6 |
| J-18 | 2,102.00 | 0.29 | 2,107.98 | 6 |
| J-19 | 2,102.00 | 0.37 | 2,107.83 | 6 |
| J-20 | 2,101.00 | 0.46 | 2,107.58 | 7 |
| J-21 | 2,105.00 | 0.32 | 2,112.90 | 8 |
| J-22 | 2,099.00 | 0.39 | 2,113.71 | 15 |
| J-23 | 2,098.00 | 0.36 | 2,111.32 | 13 |
| J-24 | 2,090.00 | 0.34 | 2,106.36 | 16 |
| J-25 | 2,088.00 | 0.44 | 2,085.08 | -3 |
| J-26 | 2,087.00 | 0.37 | 2,082.20 | -5 |
| J-27 | 2,091.00 | 0.44 | 2,080.26 | -11 |

| | | | | |
|---|---|---|---|---|
| J-28 | 2,090.00 | 0.39 | 2,080.01 | -10 |
| J-29 | 2,091.00 | 0.33 | 2,079.91 | -11 |
| J-30 | 2,092.00 | 0.28 | 2,079.87 | -12 |
| J-31 | 2,090.00 | 0.23 | 2,106.36 | 16 |
| J-32 | 2,104.00 | 0.39 | 2,109.18 | 5 |
| J-33 | 2,104.00 | 0.34 | 2,108.27 | 4 |
| J-34 | 2,104.00 | 0.26 | 2,108.16 | 4 |
| J-35 | 2,100.00 | 0.32 | 2,112.94 | 13 |
| J-36 | 2,100.00 | 0.36 | 2,110.55 | 11 |
| J-37 | 2,098.00 | 0.43 | 2,106.35 | 8 |
| J-38 | 2,099.00 | 0.40 | 2,101.62 | 3 |
| J-39 | 2,098.00 | 0.32 | 2,101.08 | 3 |
| J-40 | 2,097.00 | 0.28 | 2,100.93 | 4 |
| J-41 | 2,130.50 | 0.46 | 2,137.64 | 7 |
| J-42 | 2,131.50 | 0.42 | 2,135.57 | 4 |
| J-43 | 2,131.00 | 0.39 | 2,135.28 | 4 |
| J-44 | 2,109.00 | 0.29 | 2,134.65 | 26 |
| J-45 | 2,132.00 | 0.38 | 2,130.79 | -1 |
| J-46 | 2,132.00 | 0.32 | 2,128.92 | -3 |
| J-47 | 2,130.00 | 0.44 | 2,128.04 | -2 |
| J-48 | 2,126.00 | 0.32 | 2,127.85 | 2 |
| J-49 | 2,100.00 | 0.46 | 2,112.18 | 12 |
| J-50 | 2,101.00 | 0.39 | 2,108.25 | 7 |
| J-51 | 2,106.00 | 0.35 | 2,100.07 | -6 |
| J-52 | 2,107.00 | 0.39 | 2,097.15 | -10 |
| J-53 | 2,107.00 | 0.37 | 2,095.82 | -11 |
| J-54 | 2,106.00 | 0.44 | 2,095.39 | -11 |
| J-55 | 2,097.00 | 0.44 | 2,110.54 | 14 |
| J-56 | 2,098.00 | 0.42 | 2,110.24 | 12 |
| J-57 | 2,097.00 | 0.46 | 2,109.96 | 13 |

| | | | | |
|---|---|---|---|---|
| J-58 | 2,100.00 | 0.38 | 2,108.44 | 8 |
| J-59 | 2,099.00 | 0.47 | 2,105.88 | 7 |
| J-60 | 2,093.00 | 0.43 | 2,101.49 | 8 |
| J-61 | 2,081.00 | 0.26 | 2,100.98 | 20 |
| J-62 | 2,092.00 | 0.44 | 2,099.68 | 8 |
| J-63 | 2,094.00 | 0.44 | 2,085.34 | -9 |
| J-64 | 2,093.00 | 0.51 | 2,084.09 | -9 |
| J-65 | 2,088.00 | 0.51 | 2,082.92 | -5 |
| J-66 | 2,095.00 | 0.51 | 2,082.62 | -12 |
| J-67 | 2,094.50 | 0.47 | 2,073.49 | -21 |
| J-68 | 2,094.00 | 0.46 | 2,071.17 | -23 |
| J-69 | 2,094.00 | 0.42 | 2,064.93 | -29 |
| J-70 | 2,094.00 | 0.40 | 2,063.59 | -30 |
| J-71 | 2,094.00 | 0.38 | 2,063.22 | -31 |
| J-72 | 2,093.50 | 0.35 | 2,063.10 | -30 |
| J-73 | 2,093.50 | 0.46 | 2,063.06 | -30 |
| J-74 | 2,093.00 | 0.41 | 2,062.76 | -30 |
| J-75 | 2,085.00 | 0.00 | 2,134.01 | 49 |
| J-76 | 2,085.00 | 0.00 | 2,132.58 | 47 |
| J-77 | 2,092.00 | 0.00 | 2,114.33 | 22 |
| J-78 | 2,092.00 | 0.49 | 2,106.30 | 14 |
| J-79 | 2,085.00 | 0.49 | 2,105.24 | 20 |
| J-80 | 2,091.00 | 0.49 | 2,081.64 | -9 |
| J-81 | 2,086.00 | 0.44 | 2,079.46 | -7 |
| J-82 | 2,078.00 | 0.46 | 2,078.99 | 1 |
| J-83 | 2,162.00 | 0.00 | 2,216.00 | 54 |
| J-84 | 2,329.00 | 0.20 | 2,334.05 | 5 |
| J-85 | 2,215.00 | 0.24 | 2,230.48 | 15 |
| J-86 | 2,130.00 | 0.36 | 2,135.47 | 5 |
| J-87 | 2,093.00 | 0.37 | 2,117.35 | 24 |

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|---|---|---|---|---|
| J-88 | 2,086.00 | 0.40 | 2,114.10 | 28 |
| J-89 | 2,084.00 | 0.39 | 2,113.30 | 29 |
| J-90 | 2,083.00 | 0.37 | 2,113.17 | 30 |
| J-91 | 2,124.00 | 0.38 | 2,124.95 | 1 |
| J-92 | 2,117.00 | 0.44 | 2,121.29 | 4 |
| J-93 | 2,104.00 | 0.42 | 2,115.35 | 11 |
| J-94 | 2,098.00 | 0.41 | 2,113.66 | 16 |
| J-95 | 2,089.00 | 0.40 | 2,107.41 | 18 |
| J-96 | 2,084.00 | 0.28 | 2,106.72 | 23 |
| J-97 | 2,078.00 | 0.27 | 2,106.50 | 28 |
| J-98 | 2,086.00 | 0.28 | 2,107.31 | 21 |
| J-99 | 2,086.00 | 0.22 | 2,107.30 | 21 |
| J-100 | 2,089.00 | 0.29 | 2,105.41 | 16 |
| J-101 | 2,093.00 | 0.30 | 2,104.43 | 11 |
| J-102 | 2,093.00 | 0.24 | 2,103.98 | 11 |
| J-103 | 2,080.00 | 0.20 | 2,100.99 | 21 |
| J-104 | 2,104.00 | 0.33 | 2,112.35 | 8 |
| J-105 | 2,097.00 | 0.31 | 2,106.12 | 9 |
| J-106 | 2,096.00 | 0.31 | 2,105.33 | 9 |
| J-107 | 2,094.00 | 0.29 | 2,105.08 | 11 |
| J-108 | 2,092.00 | 0.25 | 2,104.94 | 13 |
| J-109 | 2,089.00 | 0.31 | 2,108.61 | 20 |
| J-110 | 2,085.00 | 0.28 | 2,106.64 | 22 |
| J-111 | 2,080.00 | 0.30 | 2,105.08 | 25 |
| J-112 | 2,071.00 | 0.15 | 2,105.00 | 34 |

Annex- 4: Hydraulic Model Output at Min. Consumption Hour (Junction Report at 2:00AM)

| Label | Elevation (m) | Demand (L/s) | Hydraulic Grade (m) | Pressure (m H2O) |
|---|---|---|---|---|
| J-1 | 2,093.00 | 0.00 | 2,206.64 | 113 |
| J-2 | 2,097.00 | 0.00 | 2,195.54 | 98 |
| J-3 | 2,097.00 | 0.00 | 2,176.00 | 79 |
| J-4 | 2,101.00 | 0.00 | 2,170.54 | 69 |
| J-5 | 2,099.00 | 0.00 | 2,158.67 | 60 |
| J-6 | 2,098.00 | 0.00 | 2,214.43 | 116 |
| J-7 | 2,097.00 | 0.00 | 2,209.76 | 113 |
| J-8 | 2,097.00 | 0.00 | 2,185.41 | 88 |
| J-9 | 2,101.00 | 0.00 | 2,178.47 | 77 |
| J-10 | 2,099.00 | 0.00 | 2,163.62 | 64 |
| J-11 | 2,122.00 | 0.19 | 2,137.30 | 15 |
| J-12 | 2,100.00 | 0.20 | 2,133.98 | 34 |
| J-13 | 2,102.00 | 0.28 | 2,129.63 | 28 |
| J-14 | 2,101.50 | 0.15 | 2,128.52 | 27 |
| J-15 | 2,101.50 | 0.23 | 2,128.12 | 27 |
| J-16 | 2,102.00 | 0.26 | 2,127.88 | 26 |
| J-17 | 2,101.00 | 0.19 | 2,127.72 | 27 |
| J-18 | 2,102.00 | 0.16 | 2,128.10 | 26 |
| J-19 | 2,102.00 | 0.21 | 2,128.05 | 26 |
| J-20 | 2,101.00 | 0.26 | 2,127.98 | 27 |
| J-21 | 2,105.00 | 0.18 | 2,129.56 | 25 |
| J-22 | 2,099.00 | 0.22 | 2,130.28 | 31 |
| J-23 | 2,098.00 | 0.20 | 2,129.52 | 31 |
| J-24 | 2,090.00 | 0.19 | 2,127.93 | 38 |
| J-25 | 2,088.00 | 0.25 | 2,121.59 | 34 |
| J-26 | 2,087.00 | 0.21 | 2,120.73 | 34 |
| J-27 | 2,091.00 | 0.25 | 2,120.15 | 29 |
| J-28 | 2,090.00 | 0.22 | 2,120.08 | 30 |

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|---|---|---|---|---|
| J-29 | 2,091.00 | 0.18 | 2,120.05 | 29 |
| J-30 | 2,092.00 | 0.16 | 2,120.03 | 28 |
| J-31 | 2,090.00 | 0.13 | 2,127.92 | 38 |
| J-32 | 2,104.00 | 0.22 | 2,128.93 | 25 |
| J-33 | 2,104.00 | 0.19 | 2,128.66 | 25 |
| J-34 | 2,104.00 | 0.15 | 2,128.63 | 25 |
| J-35 | 2,100.00 | 0.18 | 2,129.58 | 30 |
| J-36 | 2,100.00 | 0.20 | 2,128.96 | 29 |
| J-37 | 2,098.00 | 0.24 | 2,127.90 | 30 |
| J-38 | 2,099.00 | 0.23 | 2,126.49 | 27 |
| J-39 | 2,098.00 | 0.18 | 2,126.34 | 28 |
| J-40 | 2,097.00 | 0.16 | 2,126.29 | 29 |
| J-41 | 2,130.50 | 0.26 | 2,138.13 | 8 |
| J-42 | 2,131.50 | 0.23 | 2,137.51 | 6 |
| J-43 | 2,131.00 | 0.22 | 2,137.43 | 6 |
| J-44 | 2,109.00 | 0.16 | 2,137.24 | 28 |
| J-45 | 2,132.00 | 0.21 | 2,136.09 | 4 |
| J-46 | 2,132.00 | 0.18 | 2,135.53 | 4 |
| J-47 | 2,130.00 | 0.24 | 2,135.27 | 5 |
| J-48 | 2,126.00 | 0.18 | 2,135.21 | 9 |
| J-49 | 2,100.00 | 0.26 | 2,129.35 | 29 |
| J-50 | 2,101.00 | 0.22 | 2,128.18 | 27 |
| J-51 | 2,106.00 | 0.20 | 2,125.74 | 20 |
| J-52 | 2,107.00 | 0.22 | 2,124.87 | 18 |
| J-53 | 2,107.00 | 0.21 | 2,124.48 | 17 |
| J-54 | 2,106.00 | 0.25 | 2,124.35 | 18 |
| J-55 | 2,097.00 | 0.25 | 2,128.86 | 32 |
| J-56 | 2,098.00 | 0.24 | 2,128.77 | 31 |
| J-57 | 2,097.00 | 0.26 | 2,128.69 | 32 |
| J-58 | 2,100.00 | 0.21 | 2,127.49 | 27 |

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|---|---|---|---|---|
| J-59 | 2,099.00 | 0.26 | 2,126.28 | 27 |
| J-60 | 2,093.00 | 0.24 | 2,119.14 | 26 |
| J-61 | 2,081.00 | 0.14 | 2,117.45 | 36 |
| J-62 | 2,092.00 | 0.24 | 2,111.46 | 19 |
| J-63 | 2,094.00 | 0.25 | 2,107.19 | 13 |
| J-64 | 2,093.00 | 0.28 | 2,106.81 | 14 |
| J-65 | 2,088.00 | 0.29 | 2,106.47 | 18 |
| J-66 | 2,095.00 | 0.28 | 2,119.35 | 24 |
| J-67 | 2,094.50 | 0.26 | 2,116.64 | 22 |
| J-68 | 2,094.00 | 0.26 | 2,115.94 | 22 |
| J-69 | 2,094.00 | 0.24 | 2,114.08 | 20 |
| J-70 | 2,094.00 | 0.23 | 2,113.69 | 20 |
| J-71 | 2,094.00 | 0.21 | 2,113.57 | 20 |
| J-72 | 2,093.50 | 0.20 | 2,113.54 | 20 |
| J-73 | 2,093.50 | 0.26 | 2,113.53 | 20 |
| J-74 | 2,093.00 | 0.23 | 2,113.44 | 20 |
| J-75 | 2,085.00 | 0.00 | 2,134.01 | 49 |
| J-76 | 2,085.00 | 0.00 | 2,132.58 | 47 |
| J-77 | 2,092.00 | 0.00 | 2,114.33 | 22 |
| J-78 | 2,092.00 | 0.27 | 2,111.80 | 20 |
| J-79 | 2,085.00 | 0.27 | 2,111.49 | 26 |
| J-80 | 2,091.00 | 0.28 | 2,106.09 | 15 |
| J-81 | 2,086.00 | 0.25 | 2,105.43 | 19 |
| J-82 | 2,078.00 | 0.26 | 2,105.29 | 27 |
| J-83 | 2,162.00 | 0.00 | 2,216.00 | 54 |
| J-84 | 2,329.00 | 0.11 | 2,334.83 | 6 |
| J-85 | 2,215.00 | 0.13 | 2,230.91 | 16 |
| J-86 | 2,130.00 | 0.20 | 2,135.68 | 6 |
| J-87 | 2,093.00 | 0.21 | 2,124.41 | 31 |
| J-88 | 2,086.00 | 0.23 | 2,123.44 | 37 |

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|---|---|---|---|---|
| J-89 | 2,084.00 | 0.22 | 2,123.20 | 39 |
| J-90 | 2,083.00 | 0.21 | 2,123.16 | 40 |
| J-91 | 2,124.00 | 0.21 | 2,126.63 | 3 |
| J-92 | 2,117.00 | 0.25 | 2,125.47 | 8 |
| J-93 | 2,104.00 | 0.23 | 2,123.58 | 20 |
| J-94 | 2,098.00 | 0.23 | 2,123.03 | 25 |
| J-95 | 2,089.00 | 0.23 | 2,120.88 | 32 |
| J-96 | 2,084.00 | 0.16 | 2,120.68 | 37 |
| J-97 | 2,078.00 | 0.15 | 2,120.61 | 43 |
| J-98 | 2,086.00 | 0.15 | 2,120.85 | 35 |
| J-99 | 2,086.00 | 0.12 | 2,120.85 | 35 |
| J-100 | 2,089.00 | 0.16 | 2,120.08 | 31 |
| J-101 | 2,093.00 | 0.17 | 2,119.65 | 27 |
| J-102 | 2,093.00 | 0.13 | 2,119.43 | 26 |
| J-103 | 2,080.00 | 0.11 | 2,117.47 | 37 |
| J-104 | 2,104.00 | 0.19 | 2,122.69 | 19 |
| J-105 | 2,097.00 | 0.17 | 2,120.83 | 24 |
| J-106 | 2,096.00 | 0.18 | 2,120.60 | 25 |
| J-107 | 2,094.00 | 0.16 | 2,120.52 | 26 |
| J-108 | 2,092.00 | 0.14 | 2,120.48 | 28 |
| J-109 | 2,089.00 | 0.18 | 2,121.53 | 32 |
| J-110 | 2,085.00 | 0.15 | 2,120.94 | 36 |
| J-111 | 2,080.00 | 0.17 | 2,120.48 | 40 |
| J-112 | 2,071.00 | 0.09 | 2,120.45 | 49 |

Annex- 5: Hydraulic Model Output at Peak Hour (Pipe report at 7:00AM)

| Label | Length (m) | Diameter (mm) | Material | HazenWilliam C | Velocity (m/s) | Head loss Gradient (m/km) |
|---|---|---|---|---|---|---|
| P-1 | 26 | 76.20 | Galvanized iron | 120.0 | 0.88 | 15.20 |
| P-2 | 67 | 76.20 | Galvanized iron | 120.0 | 0.88 | 15.20 |
| P-3 | 730 | 76.20 | Galvanized iron | 120.0 | 0.88 | 15.20 |
| P-4 | 1,285 | 76.20 | Galvanized iron | 120.0 | 0.88 | 15.20 |
| P-5 | 359 | 76.20 | Galvanized iron | 120.0 | 0.88 | 15.20 |
| P-6 | 781 | 76.20 | Galvanized iron | 120.0 | 0.88 | 15.20 |
| P-7 | 1,338 | 76.20 | Galvanized iron | 120.0 | 0.88 | 15.20 |
| P-8 | 50 | 76.20 | Galvanized iron | 120.0 | 0.98 | 18.74 |
| P-9 | 38 | 76.20 | Galvanized iron | 120.0 | 0.98 | 18.74 |
| P-10 | 250 | 76.20 | Galvanized iron | 120.0 | 0.98 | 18.74 |
| P-11 | 1,300 | 76.20 | Galvanized iron | 120.0 | 0.98 | 18.74 |
| P-12 | 370 | 76.20 | Galvanized iron | 120.0 | 0.98 | 18.74 |
| P-13 | 792 | 76.20 | Galvanized iron | 120.0 | 0.98 | 18.74 |
| P-14 | 1,349 | 76.20 | Galvanized iron | 120.0 | 0.98 | 18.74 |
| P-15 | 293 | 152.40 | Galvanized iron | 120.0 | 1.11 | 10.46 |
| P-16 | 962 | 152.40 | Galvanized iron | 120.0 | 1.09 | 10.13 |
| P-17 | 289 | 101.60 | Galvanized iron | 120.0 | 1.84 | 42.93 |
| P-18 | 456 | 63.50 | Galvanized iron | 120.0 | 0.56 | 8.11 |
| P-19 | 229 | 63.50 | Galvanized iron | 120.0 | 0.47 | 5.92 |
| P-20 | 427 | 63.50 | Galvanized iron | 120.0 | 0.25 | 1.87 |
| P-21 | 1,405 | 63.50 | Galvanized iron | 120.0 | 0.11 | 0.38 |
| P-22 | 88 | 50.80 | Galvanized iron | 120.0 | 0.14 | 0.83 |
| P-23 | 641 | 63.50 | Galvanized iron | 120.0 | 0.56 | 8.22 |
| P-24 | 48 | 63.50 | Galvanized iron | 120.0 | 0.44 | 5.35 |
| P-25 | 184 | 50.00 | Galvanized iron | 120.0 | 0.16 | 1.11 |
| P-26 | 600 | 76.20 | Galvanized iron | 120.0 | 1.01 | 19.70 |

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|---|---|---|---|---|---|---|
| P-27 | 234 | 76.20 | Galvanized iron | 120.0 | 0.71 | 10.21 |
| P-28 | 603 | 76.20 | Galvanized iron | 120.0 | 0.63 | 8.21 |
| P-29 | 1,685 | 63.50 | Galvanized iron | 120.0 | 0.71 | 12.63 |
| P-30 | 342 | 63.50 | Galvanized iron | 120.0 | 0.57 | 8.42 |
| P-31 | 351 | 63.50 | Galvanized iron | 120.0 | 0.45 | 5.52 |
| P-32 | 90 | 63.50 | Galvanized iron | 120.0 | 0.31 | 2.80 |
| P-33 | 89 | 63.50 | Galvanized iron | 120.0 | 0.19 | 1.13 |
| P-34 | 144 | 63.50 | Galvanized iron | 120.0 | 0.09 | 0.27 |
| P-35 | 12 | 63.50 | Galvanized iron | 120.0 | 0.09 | 0.29 |
| P-36 | 555 | 50.80 | Galvanized iron | 120.0 | 0.49 | 8.16 |
| P-37 | 279 | 50.80 | Galvanized iron | 120.0 | 0.30 | 3.25 |
| P-38 | 158 | 50.80 | Galvanized iron | 120.0 | 0.13 | 0.71 |
| P-39 | 16 | 63.50 | Galvanized iron | 120.0 | 0.65 | 10.86 |
| P-40 | 300 | 63.50 | Galvanized iron | 120.0 | 0.55 | 7.94 |
| P-41 | 816 | 63.50 | Galvanized iron | 120.0 | 0.44 | 5.15 |
| P-42 | 610 | 63.50 | Galvanized iron | 120.0 | 0.02 | 0.01 |
| P-43 | 555 | 50.80 | Galvanized iron | 120.0 | 0.50 | 8.51 |
| P-44 | 162 | 50.80 | Galvanized iron | 120.0 | 0.30 | 3.30 |
| P-45 | 190 | 50.80 | Galvanized iron | 120.0 | 0.14 | 0.80 |
| P-46 | 32 | 63.50 | Galvanized iron | 120.0 | 0.95 | 21.78 |
| P-47 | 129 | 63.50 | Galvanized iron | 120.0 | 0.80 | 16.04 |
| P-48 | 83 | 50.80 | HDPE | 130.0 | 0.33 | 3.51 |
| P-49 | 859 | 50.80 | HDPE | 130.0 | 0.14 | 0.73 |
| P-50 | 329 | 50.80 | HDPE | 130.0 | 0.72 | 14.54 |
| P-51 | 226 | 50.80 | HDPE | 130.0 | 0.53 | 8.29 |
| P-52 | 205 | 50.80 | HDPE | 130.0 | 0.37 | 4.29 |
| P-53 | 222 | 50.80 | HDPE | 130.0 | 0.16 | 0.87 |
| P-54 | 55 | 50.80 | Galvanized iron | 120.0 | 0.72 | 16.88 |
| P-55 | 472 | 50.80 | Galvanized iron | 120.0 | 0.49 | 8.32 |
| P-56 | 201 | 50.80 | Galvanized iron | 120.0 | 0.30 | 3.35 |

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|---|---|---|---|---|---|---|
| P-57 | 394 | 50.80 | Galvanized iron | 120.0 | 0.77 | 19.05 |
| P-58 | 247 | 50.80 | Galvanized iron | 120.0 | 0.59 | 11.82 |
| P-59 | 234 | 50.80 | Galvanized iron | 120.0 | 0.40 | 5.71 |
| P-60 | 231 | 50.80 | Galvanized iron | 120.0 | 0.22 | 1.84 |
| P-61 | 621 | 63.50 | HDPE | 130.0 | 0.42 | 4.14 |
| P-62 | 152 | 63.50 | HDPE | 130.0 | 0.28 | 1.95 |
| P-63 | 473 | 63.50 | HDPE | 130.0 | 0.15 | 0.59 |
| P-64 | 65 | 63.50 | Galvanized iron | 120.0 | 1.80 | 71.42 |
| P-65 | 41 | 63.50 | Galvanized iron | 120.0 | 1.68 | 62.84 |
| P-66 | 1,568 | 63.50 | Galvanized iron | 120.0 | 0.31 | 2.80 |
| P-67 | 526 | 63.50 | Galvanized iron | 120.0 | 0.18 | 0.97 |
| P-68 | 1,636 | 63.50 | Galvanized iron | 120.0 | 0.16 | 0.79 |
| P-69 | 243 | 50.80 | Galvanized iron | 120.0 | 1.41 | 58.94 |
| P-70 | 143 | 50.80 | Galvanized iron | 120.0 | 0.50 | 8.73 |
| P-71 | 478 | 50.80 | Galvanized iron | 120.0 | 0.25 | 2.44 |
| P-72 | 671 | 63.50 | Galvanized iron | 120.0 | 1.22 | 34.66 |
| P-73 | 396 | 63.50 | HDPE | 130.0 | 1.06 | 23.02 |
| P-74 | 115 | 63.50 | Galvanized iron | 120.0 | 0.91 | 20.16 |
| P-75 | 426 | 63.50 | Galvanized iron | 120.0 | 0.77 | 14.64 |
| P-76 | 151 | 63.50 | HDPE | 130.0 | 0.63 | 8.86 |
| P-77 | 119 | 63.50 | HDPE | 130.0 | 0.36 | 3.13 |
| P-78 | 337 | 63.50 | HDPE | 130.0 | 0.11 | 0.35 |
| P-79 | 267 | 50.80 | Galvanized iron | 120.0 | 0.23 | 1.98 |
| P-80 | 283 | 50.80 | Galvanized iron | 120.0 | 0.20 | 1.63 |
| P-81 | 21 | 76.20 | Galvanized iron | 120.0 | 1.36 | 34.09 |
| P-82 | 24 | 76.20 | Galvanized iron | 120.0 | 1.36 | 34.09 |
| P-83 | 42 | 76.20 | Galvanized iron | 120.0 | 1.36 | 34.09 |
| P-84 | 535 | 76.20 | Galvanized iron | 120.0 | 1.36 | 34.09 |
| P-85 | 57 | 76.20 | Galvanized iron | 120.0 | 1.36 | 34.09 |
| P-86 | 72 | 50.80 | HDPE | 130.0 | 1.86 | 84.86 |

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|---|---|---|---|---|---|---|
| P-87 | 551 | 50.80 | HDPE | 130.0 | 0.24 | 1.93 |
| P-88 | 136 | 50.80 | HDPE | 130.0 | 1.38 | 48.65 |
| P-89 | 235 | 50.80 | Galvanized iron | 120.0 | 0.69 | 15.71 |
| P-90 | 361 | 50.80 | HDPE | 130.0 | 0.45 | 6.05 |
| P-91 | 272 | 50.80 | HDPE | 130.0 | 0.23 | 1.74 |
| P-92 | 25 | 63.50 | Galvanized iron | 120.0 | 0.85 | 17.92 |
| P-93 | 1,681 | 76.20 | Galvanized iron | 120.0 | 0.59 | 7.38 |
| P-94 | 903 | 76.20 | Galvanized iron | 120.0 | 0.59 | 7.38 |
| P-95 | 2,248 | 101.60 | Galvanized iron | 120.0 | 1.57 | 32.01 |
| P-96 | 2,672 | 101.60 | Galvanized iron | 120.0 | 1.55 | 31.07 |
| P-97 | 662 | 101.60 | Galvanized iron | 120.0 | 1.55 | 31.06 |
| P-98 | 705 | 101.60 | Galvanized iron | 120.0 | 1.52 | 29.99 |
| P-99 | 2,830 | 101.60 | Galvanized iron | 120.0 | 1.41 | 26.10 |
| P-100 | 328 | 101.60 | Galvanized iron | 120.0 | 1.36 | 24.61 |
| P-101 | 1,617 | 63.50 | Galvanized iron | 120.0 | 0.48 | 6.22 |
| P-102 | 869 | 63.50 | Galvanized iron | 120.0 | 0.37 | 3.74 |
| P-103 | 185 | 50.80 | HDPE | 130.0 | 0.37 | 4.33 |
| P-104 | 117 | 50.80 | HDPE | 130.0 | 0.18 | 1.13 |
| P-105 | 240 | 101.60 | Galvanized iron | 120.0 | 0.85 | 10.21 |
| P-106 | 398 | 101.60 | Galvanized iron | 120.0 | 0.80 | 9.20 |
| P-107 | 737 | 101.60 | Galvanized iron | 120.0 | 0.75 | 8.07 |
| P-108 | 422 | 101.60 | Galvanized iron | 120.0 | 0.51 | 3.99 |
| P-109 | 862 | 76.20 | Galvanized iron | 120.0 | 0.59 | 7.26 |
| P-110 | 248 | 50.80 | Galvanized iron | 120.0 | 0.27 | 2.77 |
| P-111 | 345 | 50.80 | HDPE | 130.0 | 0.13 | 0.63 |
| P-112 | 291 | 76.20 | Galvanized iron | 120.0 | 0.11 | 0.32 |
| P-113 | 246 | 76.20 | HDPE | 130.0 | 0.05 | 0.06 |
| P-114 | 477 | 63.50 | Galvanized iron | 120.0 | 0.39 | 4.18 |
| P-115 | 450 | 63.50 | HDPE | 130.0 | 0.30 | 2.19 |
| P-116 | 121 | 50.80 | HDPE | 120.0 | 0.31 | 3.66 |

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|---|---|---|---|---|---|---|
| P-117 | 1,914 | 50.80 | HDPE | 120.0 | 0.20 | 1.56 |
| P-118 | 42 | 50.80 | Ductile Iron | 130.0 | 0.10 | 0.37 |
| P-119 | 500 | 63.50 | Galvanized iron | 120.0 | 0.47 | 5.98 |
| P-120 | 559 | 50.80 | Galvanized iron | 120.0 | 0.57 | 11.16 |
| P-121 | 145 | 50.80 | HDPE | 130.0 | 0.42 | 5.45 |
| P-122 | 108 | 50.80 | HDPE | 130.0 | 0.27 | 2.35 |
| P-123 | 244 | 50.80 | HDPE | 130.0 | 0.13 | 0.57 |
| P-124 | 645 | 50.80 | HDPE | 130.0 | 0.51 | 7.84 |
| P-125 | 486 | 50.80 | HDPE | 130.0 | 0.36 | 4.05 |
| P-126 | 803 | 50.80 | Galvanized iron | 120.0 | 0.22 | 1.94 |
| P-127 | 313 | 50.80 | Galvanized iron | 120.0 | 0.08 | 0.26 |

Annex- 6: Hydraulic Model Output at Min. Consumption Hour (Pipe report at 2:00AM)

| Label | Length (m) | Diameter (mm) | Material | HazenWilliam C | Velocity (m/s) | Head loss Gradient (m/km) |
|---|---|---|---|---|---|---|
| P-1 | 26 | 76.20 | Galvanized iron | 120.0 | 0.88 | 15.20 |
| P-2 | 67 | 76.20 | Galvanized iron | 120.0 | 0.88 | 15.20 |
| P-3 | 730 | 76.20 | Galvanized iron | 120.0 | 0.88 | 15.20 |
| P-4 | 1,285 | 76.20 | Galvanized iron | 120.0 | 0.88 | 15.20 |
| P-5 | 359 | 76.20 | Galvanized iron | 120.0 | 0.88 | 15.20 |
| P-6 | 781 | 76.20 | Galvanized iron | 120.0 | 0.88 | 15.20 |
| P-7 | 1,338 | 76.20 | Galvanized iron | 120.0 | 0.88 | 15.20 |
| P-8 | 50 | 76.20 | Galvanized iron | 120.0 | 0.98 | 18.74 |
| P-9 | 38 | 76.20 | Galvanized iron | 120.0 | 0.98 | 18.74 |
| P-10 | 250 | 76.20 | Galvanized iron | 120.0 | 0.98 | 18.74 |
| P-11 | 1,300 | 76.20 | Galvanized iron | 120.0 | 0.98 | 18.74 |
| P-12 | 370 | 76.20 | Galvanized iron | 120.0 | 0.98 | 18.74 |
| P-13 | 792 | 76.20 | Galvanized iron | 120.0 | 0.98 | 18.74 |
| P-14 | 1,349 | 76.20 | Galvanized iron | 120.0 | 0.98 | 18.74 |
| P-15 | 293 | 152.40 | Galvanized iron | 120.0 | 0.62 | 3.55 |
| P-16 | 962 | 152.40 | Galvanized iron | 120.0 | 0.61 | 3.45 |
| P-17 | 289 | 101.60 | Galvanized iron | 120.0 | 1.04 | 15.05 |
| P-18 | 456 | 63.50 | Galvanized iron | 120.0 | 0.29 | 2.42 |
| P-19 | 229 | 63.50 | Galvanized iron | 120.0 | 0.24 | 1.76 |
| P-20 | 427 | 63.50 | Galvanized iron | 120.0 | 0.13 | 0.56 |
| P-21 | 1,405 | 63.50 | Galvanized iron | 120.0 | 0.06 | 0.11 |
| P-22 | 88 | 50.80 | Galvanized iron | 120.0 | 0.07 | 0.25 |
| P-23 | 641 | 63.50 | Galvanized iron | 120.0 | 0.29 | 2.45 |
| P-24 | 48 | 63.50 | Galvanized iron | 120.0 | 0.23 | 1.60 |
| P-25 | 184 | 50.00 | Galvanized iron | 120.0 | 0.09 | 0.33 |
| P-26 | 600 | 76.20 | Galvanized iron | 120.0 | 0.54 | 6.16 |

| | | | | | | |
|---|---|---|---|---|---|---|
| P-27 | 234 | 76.20 | Galvanized iron | 120.0 | 0.38 | 3.26 |
| P-28 | 603 | 76.20 | Galvanized iron | 120.0 | 0.34 | 2.64 |
| P-29 | 1,685 | 63.50 | Galvanized iron | 120.0 | 0.37 | 3.76 |
| P-30 | 342 | 63.50 | Galvanized iron | 120.0 | 0.30 | 2.51 |
| P-31 | 351 | 63.50 | Galvanized iron | 120.0 | 0.24 | 1.64 |
| P-32 | 90 | 63.50 | Galvanized iron | 120.0 | 0.16 | 0.83 |
| P-33 | 89 | 63.50 | Galvanized iron | 120.0 | 0.10 | 0.34 |
| P-34 | 144 | 63.50 | Galvanized iron | 120.0 | 0.05 | 0.08 |
| P-35 | 12 | 63.50 | Galvanized iron | 120.0 | 0.07 | 0.16 |
| P-36 | 555 | 50.80 | Galvanized iron | 120.0 | 0.25 | 2.43 |
| P-37 | 279 | 50.80 | Galvanized iron | 120.0 | 0.15 | 0.97 |
| P-38 | 158 | 50.80 | Galvanized iron | 120.0 | 0.07 | 0.21 |
| P-39 | 16 | 63.50 | Galvanized iron | 120.0 | 0.32 | 2.90 |
| P-40 | 300 | 63.50 | Galvanized iron | 120.0 | 0.27 | 2.07 |
| P-41 | 816 | 63.50 | Galvanized iron | 120.0 | 0.21 | 1.29 |
| P-42 | 610 | 63.50 | Galvanized iron | 120.0 | 0.03 | 0.03 |
| P-43 | 555 | 50.80 | Galvanized iron | 120.0 | 0.26 | 2.54 |
| P-44 | 162 | 50.80 | Galvanized iron | 120.0 | 0.15 | 0.98 |
| P-45 | 190 | 50.80 | Galvanized iron | 120.0 | 0.07 | 0.24 |
| P-46 | 32 | 63.50 | Galvanized iron | 120.0 | 0.49 | 6.49 |
| P-47 | 129 | 63.50 | Galvanized iron | 120.0 | 0.42 | 4.78 |
| P-48 | 83 | 50.80 | HDPE | 130.0 | 0.17 | 1.05 |
| P-49 | 859 | 50.80 | HDPE | 130.0 | 0.07 | 0.22 |
| P-50 | 329 | 50.80 | HDPE | 130.0 | 0.37 | 4.33 |
| P-51 | 226 | 50.80 | HDPE | 130.0 | 0.28 | 2.47 |
| P-52 | 205 | 50.80 | HDPE | 130.0 | 0.19 | 1.28 |
| P-53 | 222 | 50.80 | HDPE | 130.0 | 0.08 | 0.26 |
| P-54 | 55 | 50.80 | Galvanized iron | 120.0 | 0.37 | 5.03 |
| P-55 | 472 | 50.80 | Galvanized iron | 120.0 | 0.25 | 2.48 |
| P-56 | 201 | 50.80 | Galvanized iron | 120.0 | 0.16 | 1.00 |

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|---|---|---|---|---|---|---|
| P-57 | 394 | 50.80 | Galvanized iron | 120.0 | 0.40 | 5.68 |
| P-58 | 247 | 50.80 | Galvanized iron | 120.0 | 0.31 | 3.52 |
| P-59 | 234 | 50.80 | Galvanized iron | 120.0 | 0.21 | 1.70 |
| P-60 | 231 | 50.80 | Galvanized iron | 120.0 | 0.11 | 0.55 |
| P-61 | 621 | 63.50 | HDPE | 130.0 | 0.22 | 1.23 |
| P-62 | 152 | 63.50 | HDPE | 130.0 | 0.15 | 0.58 |
| P-63 | 473 | 63.50 | HDPE | 130.0 | 0.08 | 0.17 |
| P-64 | 65 | 63.50 | Galvanized iron | 120.0 | 1.18 | 32.70 |
| P-65 | 41 | 63.50 | Galvanized iron | 120.0 | 1.12 | 29.57 |
| P-66 | 1,568 | 63.50 | Galvanized iron | 120.0 | 0.41 | 4.56 |
| P-67 | 526 | 63.50 | Galvanized iron | 120.0 | 0.34 | 3.20 |
| P-68 | 1,636 | 63.50 | Galvanized iron | 120.0 | 0.36 | 3.66 |
| P-69 | 243 | 50.80 | Galvanized iron | 120.0 | 0.73 | 17.56 |
| P-70 | 143 | 50.80 | Galvanized iron | 120.0 | 0.26 | 2.60 |
| P-71 | 478 | 50.80 | Galvanized iron | 120.0 | 0.13 | 0.73 |
| P-72 | 671 | 63.50 | Galvanized iron | 120.0 | 0.63 | 10.32 |
| P-73 | 396 | 63.50 | HDPE | 130.0 | 0.55 | 6.86 |
| P-74 | 115 | 63.50 | Galvanized iron | 120.0 | 0.47 | 6.01 |
| P-75 | 426 | 63.50 | Galvanized iron | 120.0 | 0.40 | 4.36 |
| P-76 | 151 | 63.50 | HDPE | 130.0 | 0.33 | 2.64 |
| P-77 | 119 | 63.50 | HDPE | 130.0 | 0.19 | 0.93 |
| P-78 | 337 | 63.50 | HDPE | 130.0 | 0.06 | 0.10 |
| P-79 | 267 | 50.80 | Galvanized iron | 120.0 | 0.12 | 0.59 |
| P-80 | 283 | 50.80 | Galvanized iron | 120.0 | 0.11 | 0.49 |
| P-81 | 21 | 76.20 | Galvanized iron | 120.0 | 1.36 | 34.09 |
| P-82 | 24 | 76.20 | Galvanized iron | 120.0 | 1.36 | 34.09 |
| P-83 | 42 | 76.20 | Galvanized iron | 120.0 | 1.36 | 34.09 |
| P-84 | 535 | 76.20 | Galvanized iron | 120.0 | 1.36 | 34.09 |
| P-85 | 57 | 76.20 | Galvanized iron | 120.0 | 1.36 | 34.09 |
| P-86 | 72 | 50.80 | HDPE | 130.0 | 0.53 | 8.30 |

| | | | | | | |
|---|---|---|---|---|---|---|
| P-87 | 551 | 50.80 | HDPE | 130.0 | 0.13 | 0.58 |
| P-88 | 136 | 50.80 | HDPE | 130.0 | 0.28 | 2.53 |
| P-89 | 235 | 50.80 | Galvanized iron | 120.0 | 0.36 | 4.68 |
| P-90 | 361 | 50.80 | HDPE | 130.0 | 0.23 | 1.80 |
| P-91 | 272 | 50.80 | HDPE | 130.0 | 0.12 | 0.52 |
| P-92 | 25 | 63.50 | Galvanized iron | 120.0 | 0.85 | 17.92 |
| P-93 | 1,681 | 76.20 | Galvanized iron | 120.0 | 0.59 | 7.38 |
| P-94 | 903 | 76.20 | Galvanized iron | 120.0 | 0.59 | 7.38 |
| P-95 | 2,248 | 101.60 | Galvanized iron | 120.0 | 1.56 | 31.66 |
| P-96 | 2,672 | 101.60 | Galvanized iron | 120.0 | 1.55 | 31.17 |
| P-97 | 662 | 101.60 | Galvanized iron | 120.0 | 1.55 | 31.17 |
| P-98 | 705 | 101.60 | Galvanized iron | 120.0 | 1.53 | 30.61 |
| P-99 | 2,830 | 101.60 | Galvanized iron | 120.0 | 1.40 | 26.03 |
| P-100 | 328 | 101.60 | Galvanized iron | 120.0 | 1.38 | 25.25 |
| P-101 | 1,617 | 63.50 | Galvanized iron | 120.0 | 0.25 | 1.85 |
| P-102 | 869 | 63.50 | Galvanized iron | 120.0 | 0.19 | 1.11 |
| P-103 | 185 | 50.80 | HDPE | 130.0 | 0.19 | 1.29 |
| P-104 | 117 | 50.80 | HDPE | 130.0 | 0.09 | 0.34 |
| P-105 | 240 | 101.60 | Galvanized iron | 120.0 | 0.45 | 3.22 |
| P-106 | 398 | 101.60 | Galvanized iron | 120.0 | 0.43 | 2.91 |
| P-107 | 737 | 101.60 | Galvanized iron | 120.0 | 0.40 | 2.56 |
| P-108 | 422 | 101.60 | Galvanized iron | 120.0 | 0.28 | 1.31 |
| P-109 | 862 | 76.20 | Galvanized iron | 120.0 | 0.33 | 2.49 |
| P-110 | 248 | 50.80 | Galvanized iron | 120.0 | 0.14 | 0.82 |
| P-111 | 345 | 50.80 | HDPE | 130.0 | 0.07 | 0.19 |
| P-112 | 291 | 76.20 | Galvanized iron | 120.0 | 0.06 | 0.10 |
| P-113 | 246 | 76.20 | HDPE | 130.0 | 0.03 | 0.02 |
| P-114 | 477 | 63.50 | Galvanized iron | 120.0 | 0.24 | 1.67 |
| P-115 | 450 | 63.50 | HDPE | 130.0 | 0.19 | 0.95 |
| P-116 | 121 | 50.80 | HDPE | 120.0 | 0.22 | 1.86 |

| | | | | | | |
|---|---|---|---|---|---|---|
| P-117 | 1,914 | 50.80 | HDPE | 120.0 | 0.16 | 1.02 |
| P-118 | 42 | 50.80 | Ductile Iron | 130.0 | 0.11 | 0.42 |
| P-119 | 500 | 63.50 | Galvanized iron | 120.0 | 0.25 | 1.78 |
| P-120 | 559 | 50.80 | Galvanized iron | 120.0 | 0.30 | 3.33 |
| P-121 | 145 | 50.80 | HDPE | 130.0 | 0.22 | 1.62 |
| P-122 | 108 | 50.80 | HDPE | 130.0 | 0.14 | 0.70 |
| P-123 | 244 | 50.80 | HDPE | 130.0 | 0.07 | 0.17 |
| P-124 | 645 | 50.80 | HDPE | 130.0 | 0.27 | 2.33 |
| P-125 | 486 | 50.80 | HDPE | 130.0 | 0.19 | 1.21 |
| P-126 | 803 | 50.80 | Galvanized iron | 120.0 | 0.12 | 0.58 |
| P-127 | 313 | 50.80 | Galvanized iron | 120.0 | 0.04 | 0.08 |

Annex- 7: Hydraulic Model Output at Peak Hour (Pipe report at 7:00AM) at Peak Hour (Pipe Report)

| Label | Length (m) | Diameter (mm) | Material | HazenWilliam C | Velocity (m/s) | Head loss Gradient (m/km) |
|---|---|---|---|---|---|---|
| P-1 | 26 | 76.20 | Galvanized iron | 120.0 | 0.00 | 0.00 |
| P-2 | 67 | 76.20 | Galvanized iron | 120.0 | 0.00 | 0.00 |
| P-3 | 730 | 76.20 | Galvanized iron | 120.0 | 0.00 | 0.00 |
| P-4 | 1,285 | 76.20 | Galvanized iron | 120.0 | 0.00 | 0.00 |
| P-5 | 359 | 76.20 | Galvanized iron | 120.0 | 0.00 | 0.00 |
| P-6 | 781 | 76.20 | Galvanized iron | 120.0 | 0.00 | 0.00 |
| P-7 | 1,338 | 76.20 | Galvanized iron | 120.0 | 0.00 | 0.00 |
| P-8 | 50 | 76.20 | Galvanized iron | 120.0 | 0.00 | 0.00 |
| P-9 | 38 | 76.20 | Galvanized iron | 120.0 | 0.00 | 0.00 |
| P-10 | 250 | 76.20 | Galvanized iron | 120.0 | 0.00 | 0.00 |
| P-11 | 1,300 | 76.20 | Galvanized iron | 120.0 | 0.00 | 0.00 |
| P-12 | 370 | 76.20 | Galvanized iron | 120.0 | 0.00 | 0.00 |
| P-13 | 792 | 76.20 | Galvanized iron | 120.0 | 0.00 | 0.00 |
| P-14 | 1,349 | 76.20 | Galvanized iron | 120.0 | 0.00 | 0.00 |
| P-15 | 293 | 152.40 | Galvanized iron | 120.0 | 1.09 | 10.07 |
| P-16 | 962 | 152.40 | Galvanized iron | 120.0 | 1.07 | 9.75 |
| P-17 | 289 | 101.60 | Galvanized iron | 120.0 | 1.80 | 41.05 |
| P-18 | 456 | 63.50 | Galvanized iron | 120.0 | 0.44 | 5.18 |
| P-19 | 229 | 63.50 | Galvanized iron | 120.0 | 0.35 | 3.43 |
| P-20 | 427 | 63.50 | Galvanized iron | 120.0 | 0.25 | 1.87 |
| P-21 | 1,405 | 63.50 | Galvanized iron | 120.0 | 0.11 | 0.38 |
| P-22 | 88 | 50.80 | Galvanized iron | 120.0 | 0.19 | 1.12 |
| P-23 | 641 | 63.50 | Galvanized iron | 120.0 | 0.38 | 3.91 |
| P-24 | 48 | 63.50 | Galvanized iron | 120.0 | 0.26 | 1.97 |
| P-25 | 184 | 50.00 | Galvanized iron | 120.0 | 0.16 | 1.11 |

| | | | | | | |
|---|---|---|---|---|---|---|
| P-26 | 600 | 76.20 | Galvanized iron | 120.0 | 1.00 | 19.35 |
| P-27 | 234 | 76.20 | Galvanized iron | 120.0 | 0.70 | 9.95 |
| P-28 | 603 | 76.20 | Galvanized iron | 120.0 | 0.62 | 7.98 |
| P-29 | 1,685 | 63.50 | Galvanized iron | 120.0 | 0.45 | 5.50 |
| P-30 | 342 | 63.50 | Galvanized iron | 120.0 | 0.36 | 3.69 |
| P-31 | 351 | 63.50 | Galvanized iron | 120.0 | 0.29 | 2.41 |
| P-32 | 90 | 63.50 | Galvanized iron | 120.0 | 0.20 | 1.19 |
| P-33 | 89 | 63.50 | Galvanized iron | 120.0 | 0.12 | 0.46 |
| P-34 | 144 | 63.50 | Galvanized iron | 120.0 | 0.06 | 0.12 |
| P-35 | 12 | 63.50 | Galvanized iron | 120.0 | 0.08 | 0.20 |
| P-36 | 555 | 50.80 | Galvanized iron | 120.0 | 0.49 | 8.16 |
| P-37 | 279 | 50.80 | Galvanized iron | 120.0 | 0.30 | 3.25 |
| P-38 | 158 | 50.80 | Galvanized iron | 120.0 | 0.13 | 0.71 |
| P-39 | 16 | 63.50 | Galvanized iron | 120.0 | 0.67 | 11.31 |
| P-40 | 300 | 63.50 | Galvanized iron | 120.0 | 0.56 | 8.33 |
| P-41 | 816 | 63.50 | Galvanized iron | 120.0 | 0.45 | 5.47 |
| P-42 | 610 | 63.50 | Galvanized iron | 120.0 | 0.00 | 0.00 |
| P-43 | 555 | 50.80 | Galvanized iron | 120.0 | 0.50 | 8.51 |
| P-44 | 162 | 50.80 | Galvanized iron | 120.0 | 0.30 | 3.30 |
| P-45 | 190 | 50.80 | Galvanized iron | 120.0 | 0.14 | 0.80 |
| P-46 | 32 | 63.50 | Galvanized iron | 120.0 | 0.57 | 8.49 |
| P-47 | 129 | 63.50 | Galvanized iron | 120.0 | 0.52 | 7.07 |
| P-48 | 83 | 50.80 | HDPE | 130.0 | 0.33 | 3.51 |
| P-49 | 859 | 50.80 | HDPE | 130.0 | 0.14 | 0.73 |
| P-50 | 329 | 50.80 | HDPE | 130.0 | 0.38 | 4.40 |
| P-51 | 226 | 50.80 | HDPE | 130.0 | 0.28 | 2.47 |
| P-52 | 205 | 50.80 | HDPE | 130.0 | 0.19 | 1.28 |
| P-53 | 222 | 50.80 | HDPE | 130.0 | 0.08 | 0.26 |
| P-54 | 55 | 50.80 | Galvanized iron | 120.0 | 0.56 | 10.50 |
| P-55 | 472 | 50.80 | Galvanized iron | 120.0 | 0.33 | 3.95 |

| | | | | | | |
|---|---|---|---|---|---|---|
| P-56 | 201 | 50.80 | Galvanized iron | 120.0 | 0.14 | 0.79 |
| P-57 | 394 | 50.80 | Galvanized iron | 120.0 | 0.31 | 3.66 |
| P-58 | 247 | 50.80 | Galvanized iron | 120.0 | 0.21 | 1.78 |
| P-59 | 234 | 50.80 | Galvanized iron | 120.0 | 0.14 | 0.85 |
| P-60 | 231 | 50.80 | Galvanized iron | 120.0 | 0.08 | 0.28 |
| P-61 | 621 | 63.50 | HDPE | 130.0 | 0.42 | 4.14 |
| P-62 | 152 | 63.50 | HDPE | 130.0 | 0.28 | 1.95 |
| P-63 | 473 | 63.50 | HDPE | 130.0 | 0.15 | 0.59 |
| P-64 | 65 | 63.50 | Galvanized iron | 120.0 | 1.67 | 62.39 |
| P-65 | 41 | 63.50 | Galvanized iron | 120.0 | 1.55 | 54.35 |
| P-66 | 1,568 | 63.50 | Galvanized iron | 120.0 | 0.19 | 1.07 |
| P-67 | 526 | 63.50 | Galvanized iron | 120.0 | 0.05 | 0.10 |
| P-68 | 1,636 | 63.50 | Galvanized iron | 120.0 | 0.03 | 0.04 |
| P-69 | 243 | 50.80 | Galvanized iron | 120.0 | 0.61 | 12.28 |
| P-70 | 143 | 50.80 | Galvanized iron | 120.0 | 0.25 | 2.43 |
| P-71 | 478 | 50.80 | Galvanized iron | 120.0 | 0.13 | 0.67 |
| P-72 | 671 | 63.50 | Galvanized iron | 120.0 | 0.60 | 9.45 |
| P-73 | 396 | 63.50 | HDPE | 130.0 | 0.55 | 6.95 |
| P-74 | 115 | 63.50 | Galvanized iron | 120.0 | 0.45 | 5.40 |
| P-75 | 426 | 63.50 | Galvanized iron | 120.0 | 0.38 | 3.91 |
| P-76 | 151 | 63.50 | HDPE | 130.0 | 0.32 | 2.57 |
| P-77 | 119 | 63.50 | HDPE | 130.0 | 0.19 | 0.93 |
| P-78 | 337 | 63.50 | HDPE | 130.0 | 0.06 | 0.10 |
| P-79 | 267 | 50.80 | Galvanized iron | 120.0 | 0.08 | 0.30 |
| P-80 | 283 | 50.80 | Galvanized iron | 120.0 | 0.07 | 0.25 |
| P-81 | 21 | 76.20 | Galvanized iron | 120.0 | 1.36 | 34.09 |
| P-82 | 24 | 76.20 | Galvanized iron | 120.0 | 1.36 | 34.09 |
| P-83 | 42 | 76.20 | Galvanized iron | 120.0 | 1.36 | 34.09 |
| P-84 | 535 | 76.20 | Galvanized iron | 120.0 | 1.36 | 34.09 |
| P-85 | 57 | 76.20 | Galvanized iron | 120.0 | 1.36 | 34.09 |

| | | | | | | |
|---|---|---|---|---|---|---|
| P-86 | 72 | 50.80 | HDPE | 130.0 | 1.36 | 47.17 |
| P-87 | 551 | 50.80 | HDPE | 130.0 | 0.24 | 1.93 |
| P-88 | 136 | 50.80 | HDPE | 130.0 | 0.87 | 20.85 |
| P-89 | 235 | 50.80 | Galvanized iron | 120.0 | 0.34 | 4.16 |
| P-90 | 361 | 50.80 | HDPE | 130.0 | 0.23 | 1.80 |
| P-91 | 272 | 50.80 | HDPE | 130.0 | 0.12 | 0.51 |
| P-92 | 25 | 63.50 | Galvanized iron | 120.0 | 0.85 | 17.92 |
| P-93 | 1,681 | 76.20 | Galvanized iron | 120.0 | 0.59 | 7.38 |
| P-94 | 903 | 76.20 | Galvanized iron | 120.0 | 0.59 | 7.38 |
| P-95 | 2,248 | 101.60 | Galvanized iron | 120.0 | 1.57 | 32.01 |
| P-96 | 2,672 | 101.60 | Galvanized iron | 120.0 | 1.55 | 31.07 |
| P-97 | 662 | 101.60 | Galvanized iron | 120.0 | 1.55 | 31.06 |
| P-98 | 705 | 101.60 | Galvanized iron | 120.0 | 1.52 | 29.99 |
| P-99 | 2,830 | 101.60 | Galvanized iron | 120.0 | 1.41 | 26.10 |
| P-100 | 328 | 101.60 | Galvanized iron | 120.0 | 1.36 | 24.61 |
| P-101 | 1,617 | 63.50 | Galvanized iron | 120.0 | 0.48 | 6.22 |
| P-102 | 869 | 63.50 | Galvanized iron | 120.0 | 0.37 | 3.74 |
| P-103 | 185 | 50.80 | HDPE | 130.0 | 0.37 | 4.33 |
| P-104 | 117 | 50.80 | HDPE | 130.0 | 0.18 | 1.13 |
| P-105 | 240 | 101.60 | Galvanized iron | 120.0 | 0.82 | 9.65 |
| P-106 | 398 | 101.60 | Galvanized iron | 120.0 | 0.78 | 8.66 |
| P-107 | 737 | 101.60 | Galvanized iron | 120.0 | 0.72 | 7.56 |
| P-108 | 422 | 101.60 | Galvanized iron | 120.0 | 0.48 | 3.63 |
| P-109 | 862 | 76.20 | Galvanized iron | 120.0 | 0.54 | 6.26 |
| P-110 | 248 | 50.80 | Galvanized iron | 120.0 | 0.27 | 2.77 |
| P-111 | 345 | 50.80 | HDPE | 130.0 | 0.13 | 0.63 |
| P-112 | 291 | 76.20 | Galvanized iron | 120.0 | 0.11 | 0.32 |
| P-113 | 246 | 76.20 | HDPE | 130.0 | 0.05 | 0.06 |
| P-114 | 477 | 63.50 | Galvanized iron | 120.0 | 0.32 | 2.97 |
| P-115 | 450 | 63.50 | HDPE | 130.0 | 0.23 | 1.38 |

| | | | | | | |
|---|---|---|---|---|---|---|
| P-116 | 121 | 50.80 | HDPE | 120.0 | 0.21 | 1.77 |
| P-117 | 1,914 | 50.80 | HDPE | 120.0 | 0.10 | 0.41 |
| P-118 | 42 | 50.80 | Ductile Iron | 130.0 | 0.00 | 0.00 |
| P-119 | 500 | 63.50 | Galvanized iron | 120.0 | 0.47 | 5.98 |
| P-120 | 559 | 50.80 | Galvanized iron | 120.0 | 0.57 | 11.16 |
| P-121 | 145 | 50.80 | HDPE | 130.0 | 0.42 | 5.45 |
| P-122 | 108 | 50.80 | HDPE | 130.0 | 0.27 | 2.35 |
| P-123 | 244 | 50.80 | HDPE | 130.0 | 0.13 | 0.57 |
| P-124 | 645 | 50.80 | HDPE | 130.0 | 0.51 | 7.84 |
| P-125 | 486 | 50.80 | HDPE | 130.0 | 0.36 | 4.05 |
| P-126 | 803 | 50.80 | Galvanized iron | 120.0 | 0.22 | 1.94 |
| P-127 | 313 | 50.80 | Galvanized iron | 120.0 | 0.08 | 0.26 |

Annex- 8: Water Demand Allocation of Werabe Town

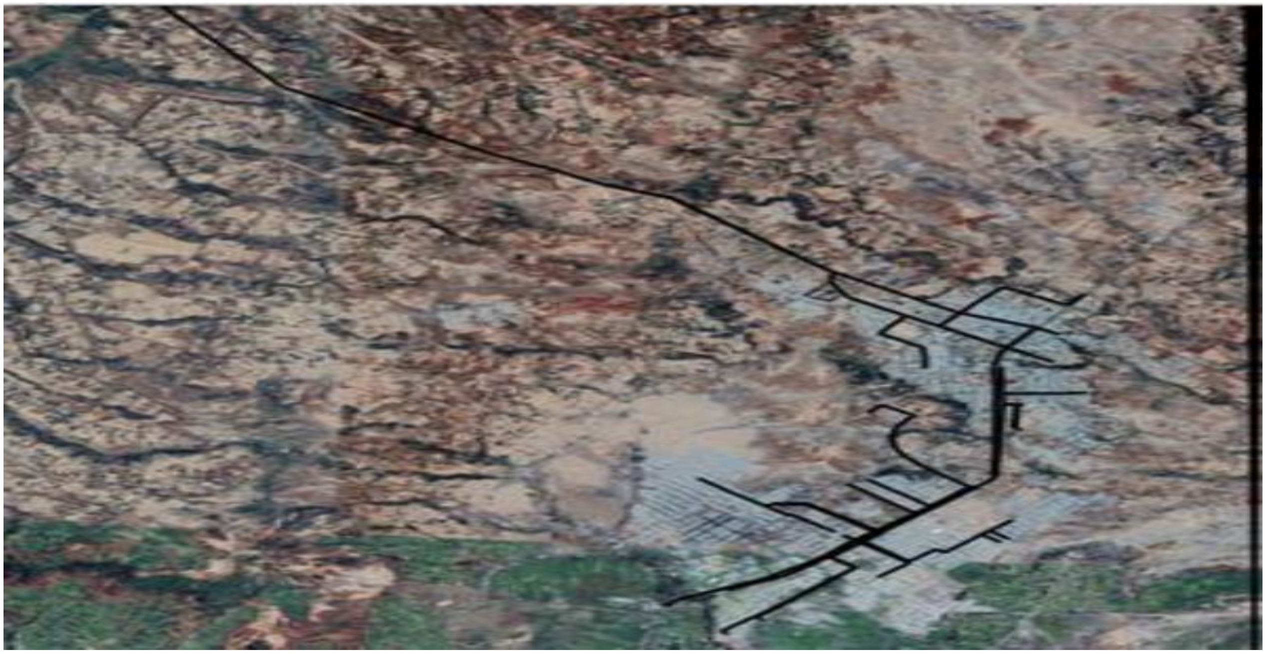
| Label | X (m) | Y (m) | Residence Houses | House Hold Size | Population Served each Node | Total Base Demand (l/s) |
|---|---|---|---|---|---|---|
| J-1 | 7,487.78 | 2,670.85 | 0 | 4.3 | 0 | 0.00 |
| J-2 | 8,006.66 | 3,184.17 | 0 | 4.3 | 0 | 0.00 |
| J-3 | 8,857.58 | 4,147.44 | 0 | 4.3 | 0 | 0.00 |
| J-4 | 8,598.84 | 4,396.67 | 108 | 4.3 | 470 | 0.39 |
| J-5 | 9,143.74 | 4,956.27 | 108 | 4.3 | 470 | 0.39 |
| J-6 | 7,840.62 | 2,998.87 | 109 | 4.3 | 474 | 0.40 |
| J-7 | 8,022.57 | 3,169.67 | 98 | 4.3 | 426 | 0.36 |
| J-8 | 8,880.96 | 4,145.52 | 102 | 4.3 | 444 | 0.37 |
| J-9 | 8,607.96 | 4,395.96 | 0 | 4.3 | 0 | 0.00 |
| J-10 | 9,159.53 | 4,964.40 | 45 | 4.3 | 196 | 0.16 |
| J-11 | 8,349.21 | 5,623.20 | 52 | 4.3 | 226 | 0.19 |
| J-12 | 9,066.90 | 4,984.94 | 79 | 4.3 | 344 | 0.29 |
| J-13 | 8,860.95 | 4,797.92 | 81 | 4.3 | 352 | 0.29 |
| J-14 | 8,564.01 | 4,434.77 | 89 | 4.3 | 387 | 0.32 |
| J-15 | 8,405.68 | 4,269.49 | 86 | 4.3 | 374 | 0.31 |
| J-16 | 8,068.95 | 4,006.55 | 81 | 4.3 | 352 | 0.29 |
| J-17 | 6,900.82 | 3,249.49 | 83 | 4.3 | 361 | 0.30 |
| J-18 | 8,412.77 | 4,181.92 | 98 | 4.3 | 426 | 0.36 |
| J-19 | 8,446.82 | 4,290.95 | 92 | 4.3 | 400 | 0.33 |
| J-20 | 8,446.54 | 4,243.18 | 91 | 4.3 | 396 | 0.33 |
| J-21 | 8,739.00 | 4,908.64 | 89 | 4.3 | 387 | 0.32 |
| J-22 | 9,493.14 | 5,407.42 | 62 | 4.3 | 270 | 0.22 |
| J-23 | 9,654.77 | 5,576.76 | 59 | 4.3 | 257 | 0.21 |
| J-24 | 10,042.35 | 6,040.41 | 61 | 4.3 | 265 | 0.22 |
| J-25 | 9,293.54 | 7,408.68 | 49 | 4.3 | 213 | 0.18 |
| J-26 | 9,497.48 | 7,680.02 | 64 | 4.3 | 278 | 0.23 |

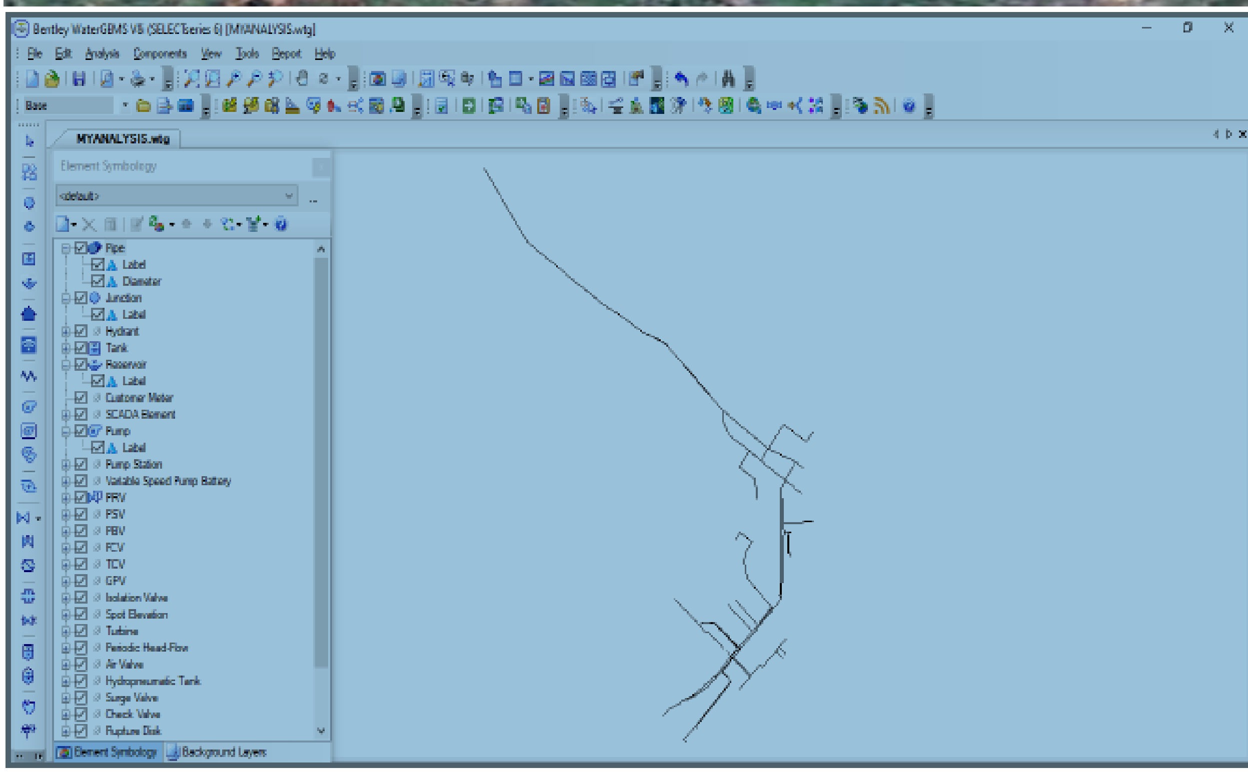
| | | | | | | |
|---|---|---|---|---|---|---|
| J-27 | 9,209.15 | 7,880.60 | 67 | 4.3 | 291 | 0.24 |
| J-28 | 9,135.02 | 7,932.40 | 52 | 4.3 | 226 | 0.19 |
| J-29 | 9,087.77 | 7,856.82 | 45 | 4.3 | 196 | 0.16 |
| J-30 | 9,013.07 | 7,734.23 | 73 | 4.3 | 317 | 0.26 |
| J-31 | 10,067.08 | 6,014.40 | 68 | 4.3 | 296 | 0.25 |
| J-32 | 9,091.54 | 5,790.83 | 69 | 4.3 | 300 | 0.25 |
| J-33 | 8,893.86 | 5,987.05 | 64 | 4.3 | 278 | 0.23 |
| J-34 | 8,783.65 | 6,100.60 | 56 | 4.3 | 244 | 0.20 |
| J-35 | 8,896.39 | 4,775.73 | 69 | 4.3 | 300 | 0.25 |
| J-36 | 9,079.61 | 4,990.28 | 61 | 4.3 | 265 | 0.22 |
| J-37 | 9,658.64 | 5,565.02 | 66 | 4.3 | 287 | 0.24 |
| J-38 | 9,258.31 | 5,949.88 | 34 | 4.3 | 148 | 0.12 |
| J-39 | 9,141.62 | 6,062.90 | 0 | 4.3 | 0 | 0.00 |
| J-40 | 9,004.60 | 6,193.83 | 0 | 4.3 | 0 | 0.00 |
| J-41 | 8,047.84 | 5,651.98 | 0 | 4.3 | 0 | 0.00 |
| J-42 | 7,951.05 | 5,565.19 | 108 | 4.3 | 470 | 0.39 |
| J-43 | 8,008.77 | 5,505.14 | 108 | 4.3 | 470 | 0.39 |
| J-44 | 8,668.93 | 4,970.83 | 109 | 4.3 | 474 | 0.40 |
| J-45 | 7,707.15 | 5,785.56 | 98 | 4.3 | 426 | 0.36 |
| J-46 | 7,539.50 | 5,937.71 | 102 | 4.3 | 444 | 0.37 |
| J-47 | 7,392.43 | 6,079.99 | 0 | 4.3 | 0 | 0.00 |
| J-48 | 7,231.78 | 6,233.29 | 45 | 4.3 | 196 | 0.16 |
| J-49 | 8,908.49 | 4,735.66 | 52 | 4.3 | 226 | 0.19 |
| J-50 | 8,583.17 | 4,390.54 | 79 | 4.3 | 344 | 0.29 |
| J-51 | 8,154.43 | 3,978.79 | 81 | 4.3 | 352 | 0.29 |
| J-52 | 7,945.42 | 3,847.29 | 89 | 4.3 | 387 | 0.32 |
| J-53 | 7,738.17 | 3,738.87 | 86 | 4.3 | 374 | 0.31 |
| J-54 | 7,533.55 | 3,632.05 | 81 | 4.3 | 352 | 0.29 |
| J-55 | 9,321.90 | 4,354.17 | 83 | 4.3 | 361 | 0.30 |
| J-56 | 9,436.84 | 4,253.97 | 98 | 4.3 | 426 | 0.36 |

| | | | | | | |
|---|---|---|---|---|---|---|
| J-57 | 9,101.53 | 3,920.93 | 92 | 4.3 | 400 | 0.33 |
| J-58 | 8,916.98 | 4,738.66 | 91 | 4.3 | 396 | 0.33 |
| J-59 | 8,945.74 | 4,765.89 | 89 | 4.3 | 387 | 0.32 |
| J-60 | 10,026.27 | 5,894.96 | 62 | 4.3 | 270 | 0.22 |
| J-61 | 10,336.38 | 6,313.36 | 59 | 4.3 | 257 | 0.21 |
| J-62 | 10,407.49 | 7,947.45 | 61 | 4.3 | 265 | 0.22 |
| J-63 | 10,395.42 | 8,190.60 | 49 | 4.3 | 213 | 0.18 |
| J-64 | 10,396.88 | 8,333.65 | 64 | 4.3 | 278 | 0.23 |
| J-65 | 10,392.05 | 8,811.33 | 67 | 4.3 | 291 | 0.24 |
| J-66 | 9,431.14 | 4,294.31 | 52 | 4.3 | 226 | 0.19 |
| J-67 | 9,710.88 | 4,575.13 | 45 | 4.3 | 196 | 0.16 |
| J-68 | 9,796.70 | 4,498.13 | 73 | 4.3 | 317 | 0.26 |
| J-69 | 10,085.29 | 4,811.71 | 68 | 4.3 | 296 | 0.25 |
| J-70 | 10,187.47 | 4,922.72 | 69 | 4.3 | 300 | 0.25 |
| J-71 | 10,269.32 | 5,009.68 | 64 | 4.3 | 278 | 0.23 |
| J-72 | 10,500.85 | 5,253.93 | 56 | 4.3 | 244 | 0.20 |
| J-73 | 10,377.84 | 4,735.43 | 69 | 4.3 | 300 | 0.25 |
| J-74 | 10,472.87 | 4,812.69 | 61 | 4.3 | 265 | 0.22 |
| J-75 | 10,576.86 | 7,385.65 | 66 | 4.3 | 287 | 0.24 |
| J-76 | 10,534.97 | 7,385.26 | 34 | 4.3 | 148 | 0.12 |
| J-77 | 10,558.78 | 7,920.17 | 0 | 4.3 | 0 | 0.00 |
| J-78 | 10,541.08 | 7,937.86 | 0 | 4.3 | 0 | 0.00 |
| J-79 | 10,515.67 | 7,387.59 | 0 | 4.3 | 0 | 0.00 |
| J-80 | 10,630.47 | 8,191.78 | 108 | 4.3 | 470 | 0.39 |
| J-81 | 10,991.80 | 8,198.88 | 108 | 4.3 | 470 | 0.39 |
| J-82 | 11,263.55 | 8,209.01 | 109 | 4.3 | 474 | 0.40 |
| J-83 | 7,060.69 | 12,639.89 | 98 | 4.3 | 426 | 0.36 |
| J-84 | 2,926.50 | 15,314.37 | 102 | 4.3 | 444 | 0.37 |
| J-85 | 5,671.90 | 13,427.28 | 0 | 4.3 | 0 | 0.00 |
| J-86 | 8,400.15 | 11,248.95 | 45 | 4.3 | 196 | 0.16 |

| | | | | | | |
|---|---|---|---|---|---|---|
| J-87 | 9,942.39 | 10,067.20 | 52 | 4.3 | 226 | 0.19 |
| J-88 | 10,742.77 | 9,728.78 | 79 | 4.3 | 344 | 0.29 |
| J-89 | 10,897.57 | 9,627.69 | 81 | 4.3 | 352 | 0.29 |
| J-90 | 10,992.57 | 9,559.17 | 89 | 4.3 | 387 | 0.32 |
| J-91 | 8,623.57 | 10,786.92 | 86 | 4.3 | 374 | 0.31 |
| J-92 | 8,800.09 | 10,430.59 | 81 | 4.3 | 352 | 0.29 |
| J-93 | 9,400.37 | 10,002.70 | 83 | 4.3 | 361 | 0.30 |
| J-94 | 9,742.33 | 9,756.08 | 98 | 4.3 | 426 | 0.36 |
| J-95 | 10,443.34 | 9,255.31 | 92 | 4.3 | 400 | 0.33 |
| J-96 | 10,649.38 | 9,116.96 | 91 | 4.3 | 396 | 0.33 |
| J-97 | 10,935.45 | 8,923.65 | 89 | 4.3 | 387 | 0.32 |
| J-98 | 10,596.07 | 9,503.44 | 62 | 4.3 | 270 | 0.22 |
| J-99 | 10,731.29 | 9,708.75 | 59 | 4.3 | 257 | 0.21 |
| J-100 | 10,310.24 | 8,803.12 | 61 | 4.3 | 265 | 0.22 |
| J-101 | 10,325.48 | 8,353.34 | 49 | 4.3 | 213 | 0.18 |
| J-102 | 10,325.16 | 8,232.44 | 64 | 4.3 | 278 | 0.23 |
| J-103 | 10,294.51 | 6,319.97 | 67 | 4.3 | 291 | 0.24 |
| J-104 | 9,117.22 | 9,590.62 | 52 | 4.3 | 226 | 0.19 |
| J-105 | 9,574.68 | 9,269.90 | 45 | 4.3 | 196 | 0.16 |
| J-106 | 9,580.28 | 9,125.38 | 73 | 4.3 | 317 | 0.26 |
| J-107 | 9,591.52 | 9,017.88 | 68 | 4.3 | 296 | 0.25 |
| J-108 | 9,597.44 | 8,774.33 | 69 | 4.3 | 300 | 0.25 |
| J-109 | 10,116.11 | 10,281.13 | 64 | 4.3 | 278 | 0.23 |
| J-110 | 10,402.60 | 10,673.23 | 56 | 4.3 | 244 | 0.20 |
| J-111 | 11,076.69 | 10,237.63 | 69 | 4.3 | 300 | 0.25 |
| J-112 | 11,251.75 | 10,496.92 | 61 | 4.3 | 265 | 0.22 |

Annex- 9: Constructed model of the Werabe town WDN





Annex- 10: Demand multiplier of Werabe Town water supply in 24 hour

| Time | Factor |
|---|---|
| 1 | 0.4 |
| 2 | 0.4 |
| 3 | 0.5 |
| 4 | 1 |
| 5 | 1.2 |
| 6 | 1.5 |
| 7 | 1.4 |
| 8 | 1.1 |
| 9 | 1.1 |
| 10 | 1.2 |
| 11 | 1.3 |
| 12 | 1.4 |
| 13 | 1.3 |
| 14 | 1.2 |
| 15 | 1.2 |
| 16 | 1.4 |
| 17 | 1.6 |
| 18 | 1.4 |
| 19 | 1.2 |
| 20 | 0.9 |
| 21 | 0.3 |
| 22 | 0.3 |
| 23 | 0.3 |
| 24 | 0.4 |