JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIROMENTAL ENGINEERING

HYDRAULIC ENGINEERING MASTER OF SCIENCE PROGRAM

HYDRAULIC MODELLING OF WATER SUPPLY DISTRIBUTION NETWORK, A CASE STUDY IN JIMMA TOWN

BY:

HASSEN AHMED

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

December, 2016

Jimma, Ethiopia

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APPROVAL PAGE

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Abstract

Water supply distribution system modeling is a method of representing the real system, analyzing and approximating the real water supply distribution system behavior and operating conditions using computer softwares to solve short comings facing water utilities.

Some districts like Saris/Sar Sefer/ and some high elevation areas in Jimma Town are facing lack of an access of potable water supply. As a result, the people living in these areas are travelling more than a kilometer to fetch water from springs around Jimma Town, but there are no real evidences which show the real causes of the problems; because there were no studies conducted on the distribution system of Jimma Town. So to identify the main causes for the water shortage at the mentioned areas, to assess the operating condition and hydraulic behavior of the distribution system, to identify problems related to flow and pressure, to evaluate and improve the current performance of the distribution system and to simulate the future condition of the system, it is found crucial to prepare this hydraulic model for Jimma Town Water Supply distribution system. The objective of this study is to model the entire water supply distribution network of Jimma Town from the treatment plant Clear water well to the customers and to analyze and evaluate the performance of the system under various physical and hydraulic conditions including fire flows. The study does not include water quality aspects and energy analysis. The model is prepared using the combination of waterGEMS, AutoCAD, waterCAD and GIS softwares. This study is conducted with the aim of enabling JWSSE operators to ensure the safety of the distribution system without wasting time and energy; because it is possible to manage the system simply on a computer using the model once the WDN model is linked to GIS, water billing and other information management systems of the utility. To prepare the model, different primary and secondary data were collected and analyzed. Then after running the model for both steady state and EPS, low pressure values around Gebrel Tank, high velocity and head loss through the gravity main, and low velocities through most of the pipes were observed. Finally, it's concluded that even though the main problem of potable water shortage is pressure deficit, the main from the old treatment plant to Gebrel Tank might be closed. Then solutions are suggested using different scenarios.

Keywords- GIS, Hydraulic Modeling, Scenario, Simulation, Skeletonization, Water Distribution Network, Water GEMS

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Abbreviations

AWWA	American Water Works Association
CADD	Computer Aided Design and Drafting
DEM	Digital Elevation Model
DTTP	Developmental Team Training Program
EPS	Extended Period Simulation
EPA	Environmental Protection Agency
GIS	Geographic Information System
GPS	Global Positioning System
ISO	Insurance Service Organization
JWSSE	Jimma Town Water Supply and Sanitation Enterprise
MoWR	Ministry of Water Resource
PBT	Pressure Break Tank
PRV	Pressure Reducing Valve
SCADA	Supervisory Control and Data Acquisition
TRex	Terrain Extractor
UFW	Unaccounted For Water
USGS	United States Geological Survey
WDN	Water Distribution Network
WDS	Water Distribution System

Prefixes and Units

AJ-	Aba Jifar
DP-	Discharge Pipe
G-	Ginjo
H-	Hospital
Hr	Hours
L	Liters
Min	Minutes
JK-	Jiren Kela
KPa	Kilo Paskal
m	Meters
mm	Millimeters
PAJ-	Pipe Aba Jifar
PG-	Pipe Ginjo
PH-	Pipe Hospital
PJK-	Pipe Jiren Kela
Psi	Pounds per square inch
R-	Reservoir
SP-	Suction Pipe

1. Introduction

1.1. Background

Transporting water from the source to water customers areas started 3500 years ago and ‘’the history of water distribution technology is just a story’’ (Walski, 2003). It is still being continued and grown to sophisticated model designed water supply distribution networks.

Water supply distribution networks are structures used to convey potable water from treatment plants to the community or water consumers for different demands including firefighting. Even though they may differ in size, most distribution systems have common basic components like pipes, pumps, valves, tanks, reservoirs and other appurtenances. They are designed to deliver water at adequate discharge and pressure according to demands and specific quality (A. Elsheikh Mahmoud *et al.*, 2013). Water Distribution Systems play an important role in modern societies being its proper operation directly related to the population’s wellbeing (Muranho *et al*., 2013). The main issue that makes the water distribution structures to seek the attention of the engineering field is their design, operation and management to serve the community in an efficient and reliable manner now and in the future, which is also a global concern.

In order to ensure sufficient quantity and good quality water, it becomes imperative in the modern society to plan and build suitable water supply schemes so as to provide potable water to various section of the community in accordance with their demand and requirement (Khadri, 2014).

Water supply distribution system modeling is a method of representing the real system, analyzing, approximating and mimicking the real water distribution system behavior and operating conditions using computer softwares to identify problems and solve short comings facing water utilities.

In developing countries like Ethiopia, this modeling technology is at an infant stage. Customer complaints throughout the country about the quality, quantity and the way the water is distributed to the community are evidences for the existence of problems to be resolved by this water distribution system modeling technology; that is why this research is undertaken for Jimma Town Water Supply Distribution System.

1.2. Statement of the problem

Even though all water supply distribution systems are designed to supply adequate potable water to the community whom they are constructed for, potable water shortage is a big issue, especially in developing countries including Ethiopia.

Most of the time, some districts like Saris/Sar Sefer/ in Jimma Town are facing lack of an access of potable water supply. As a result the people living in these areas are travelling more than a kilometer to fetch water from springs developed by Jimma University students on DTTP programs and some are using the Awoito River for home uses as it is. Moreover, kebeles such as Ginjo, Jiren Kela and other high elevation areas are receiving intermittent water supply.

Some people suggested that this shortage of potable water is due to low pressure, since the areas facing this water shortage are high elevation areas. On the other hand, there were other assumptions as closed main might be the reason for dis-functioning of Gebrel storage tank which has been supplying Saris district, the vicinity of Gebrel Church, Bosa Addis Ketema, Bosa Kito and some other areas downstream of the storage tank by gravity. There are no real evidences which show whether the problem is due to pressure deficit, system topological dis-integrity, network structural layout problems, operational problems or others else; because there were no studies conducted on the distribution system of Jimma Town till the time this research was conducted.

To verify or disprove the hypothesis whether low pressure is the main cause for the water shortage at the mentioned areas, to assess the operating condition of the distribution system and its general behavior, to evaluate the current performance, to identify problems related to flow and pressure, to improve the current performance of the distribution system by formulating and suggesting solutions to the identified problems, to simulate the future condition of the system and to improve the way JWSSE is managing the water distribution system and its available data, it was assumed very crucial to prepare this hydraulic model for the distribution system.

1.3. Significance and rational of the study

This study was undertaken on Jimma Town water supply distribution network for modeling the hydraulics of the system. It helps the Jimma Town Water Supply and Sewerage Service Enterprise/JWSSE/ to serve the water customers fairly and efficiently in an easy manner. The model enables the operators to ensure the safety of the distribution system without wasting time and energy; because it is possible to manage the system simply on a computer using the model. Moreover, the model will help the JWSSE to decide where and when to schedule program on expansions for new customers and rehabilitation of the existing network; because number of future customers which the utility will likely to have in the near future are projected in this study. And also structures with potential problem which need rehabilitation are indicated by the model.

Since the model output provides input to many strategic programs of the JWSSE, the WDN model will be linked to GIS, water billing and other information and data management systems. On the broadest sense, this research may be used as a base for those researchers who are aiming to study on Jimma Town Water Supply Distribution system.

In this study waterGEMS software is used. Its package is integrated with GIS and other CAD technologies and its ability to interchange data between ArcGIS, autoCAD and waterCAD softwares was the reason to choose it for this study. These are some among many reasons to choose waterGEMS software over waterCAD, which was proposed to be used for this research. Concerning the Arc GIS software, in addition to its multi-dimensional functions, the ability of ArcMap to extract DEM data for a specific small area from any pre-existed DEM for interpolating elevations of demand nodes, tanks, pumps and reservoirs without surveying, and its versatile nature contributed for ArcGIS to be chosen for this study.

1.4. Objectives

The general objective of this study is to model the entire water supply distribution System of Jimma Town from the treatment plants Clear Wells to the customers' premises, for better long term planning, operation and management of the distribution system.

The specific objectives of this study are;

- to evaluate different hydraulic and physical parameters under various hydraulic loading conditions including fire flows and system topology scenarios
- to characterize problems in the distribution system
- to evaluate the performance of the existing system and suggesting gaps for better modeling that leads to better strategic planning and operational management for the future

1.5. Hypothesis

To distribute the available water equally and efficiently to customers, the pressure condition of distribution systems plays the key role. The problem related to the lack of potable water at high altitude and remote areas in Jimma Town was assumed to be pressure deficit.

1.6. Scope

This study is limited to only the hydraulic part of modeling for the existing water supply distribution system of Jimma Town. It does not include the water quality aspects of the distribution system for the sake of time, availability of water quality data and modeling cost. The modeling is prepared from the treatment plants Clear Wells to distribution mains and sub mains with diameter above 80mm using skeletonization technique. The well at Kito Furdisa campus, which the campus implemented for its own use, is not included in this modelling due to data unavailability. Moreover, analysis related to cost and pumping energy are not included in this hydraulic modelling.

2. Literature Review

2.1. Water supply transport facilities

Distribution system infrastructures are designed to deliver water from the source (usually treatment plants) to the customers in the required quality, quantity, flow and at a satisfactory pressure. These water distribution infrastructures are the major assets of water utilities. To continuously supply water from the source to the consumers, it is must to have storage tanks, pumps, pressure pipes, deferent valves and other appurtenances, which are collectively referred to as the water supply distribution system (Walski *et al*., 2003).

2.2. Key water supply infrastructure components

It is written on different literatures about what water distribution systems must contain to effectively, efficiently and reliably serve a community, whom the water distribution system is designed for. (EPA, 2005) discussed in detail as a water distribution system must have the following key components;

Storage Tanks:

Are used to store water to meet the fluctuating demand, to equalize pressure in the distribution system, to supply water for firefighting and other emergency conditions.

Pipe Network:

The piping system contains transmission main/trunk, distribution mains and service mains to convey water from the source to the consumers .Transmission mains convey large amount of water over a great distance, mostly from the treatment plant to storage tanks, whereas distribution mains are smaller in diameter than transmission mains and deliver water to the end customers following the general topography and the alignment of main streets.

Valves:

The two general valves in water distribution systems are isolating and control valves. Isolating valves are installed to isolate part of a distribution system for maintenance and repair and they should be located so that the area isolated for repair receive the lowest inconvenience throughout the repair and maintenance program. Many utilities have valve turning programs on a regular basis even though it is difficult to implement on large systems. But these valves have to be turned at least once per year to reduce the likelihood of the valves to become inoperative due to corrosion. The other category of valves is the control valves group which consists of pressure reducing valves, pressure sustaining valves, throttling valves, check valves and flow rate control valves to control the flow and pressure in the distribution system.

Pumps:

Are used to impart energy for the water in order to overcome elevation differences and minor head losses. Proper design and operation, routine maintenance and pump test every five to ten years to check head-discharge relationship is required to ensure that pumps meet their specific objectives.

Hydrants and other appurtenances/blow-off and air release valves/:

The primary purpose of hydrants is firefighting. Although water utilities are not legally responsible for firefighting, distribution systems are designed to support needed fire flow since developmental requirements often include fire flow (AWWA, 1998(a)). Fire hydrants are exercised and tested periodically by fire department personnel or by water utilities to satisfy the requirement of the Insurance Service office (ISO) or as water distribution system calibration programs (ISO, 2003).

2.3. Anatomy of a water distribution system

Anatomy is defined as separating a function in to parts for detail examination. Water distribution systems work in a similar way to human circulatory system. Our heart pumps blood through arteries, veins and capillaries to supply blood and oxygen for all parts of the body. Similarly, water pumps supply water for customers and fire protection through primary, secondary and distributary water mains (E.Hickey, 2008).

In spite of their size and complexity, the purpose of all water distribution systems is to convey potable water from the treatment plant to the customers' premises. Before leaving the raw water treatment plant, the treated water enters in to a clear well, which is the buffered storage between the treatment plant and the distribution system during demand fluctuations. The clear well provides also contact time for disinfectants (commonly chlorine) and serves as source for back wash water for cleaning the treatment plant filters (Walski, 2003).

2.4. Design and Operation of Water distribution networks

Although almost all distribution systems are designed to meet peak hour demands, it will create low – flow conditions in some parts of the distribution system and may result in deterioration of microbial and chemical water quality of the system unless they are designed considering these water quality aspects. The purpose of water distribution network systems is to supply water at an adequate pressure and flow for the consumers. However when designing piped water distribution system, excessive system capacity, low flow dead-end and loops, situations that may rise to negative pressure must be considered and avoided (AWWA, 1999).

2.5. Water Distribution system Simulations

Even though water resource modeling is the latest technology in a process of advancement, it began two millennia ago. For serving a community reliably, efficiently and safely, water resource modeling is critical part of design and operation of WDN.

Simulation is the process of using a mathematical representation of the system (model) to imitate the behavior of one system through the function of the other. We use network simulation to replicate the dynamics of an existing or proposed system for the purpose of evaluating a system before it is actually built; because it is risky to subject the real system directly in to experimentation. Using simulations, problems can be anticipated and solutions can be evaluated before time and money invested on the real world project (Walski, 2003).

Simulation is the process of modeling the network, analyzing and evaluating its performance under various physical and hydraulic conditions. Topo-sheets can be used as base map and it is possible to mask and extract images and topo sheets for the required area using Arc GIS. Auto CAD maps can also be converted to GIS file formats and over laid on cartosat-1 imagery; then the pipe networks and nodes will be created on the map and water demands at junctions will be provided (H.Ramesh *et al*., 2012).

Simulations can be steady state or Extended Period Simulation. Steady State Simulations determine the operating behavior of the system under static conditions, but EPS evaluates the system performance over time.

2.6. Water Distribution System Network Hydraulic Modelling

2.6.1. History of Hydraulic Modelling

The use of mathematical methods to calculate flows through a complex pipe network was first proposed by Hardy Cross. For utilizing the Hardy Cross methodology, improved solution methods were developed with the advent of computers and computer based modelling. Initially hydraulic models were simulating flows and pressures in a distribution system under steady state conditions assuming all demands and operations remained constant, but since demands and flows vary over the course of a day, Extended Period Simulation Models which can simulate distribution systems behavior under time-varying conditions were developed (EPA, 2005). Steady state simulations were advanced to EPS using the technique developed by Rao and Bree in the late 1970's (Laura Baumberger *et al*., 2007).

2.6.2. Modeling Theory

In order to effectively utilize the capabilities of WDN simulation softwares, it is must to understand the mathematical principles involved and the principles of hydraulics related to fluid properties. Specific weight, fluid viscosity and compressibility are the most important fluid properties to be considered in WDN Simulations

As thoroughly discussed by different references like (AWWA, 2004) and (Paula, 2000). Models essentially use three types of relations to calculate flows in a complex pipe network system. These relation are;

Conservation of Mass: it is equivalent to conservation of volume and with the assumption that water is an incompressible fluid, this principle requires that the sum of mass flows of all pipes entering a junction must be equal to the sum of mass flows of all pipes leaving that junction.

Conservation of Energy: in water distribution systems, energy is referred to as 'head' and there are three forms of energy of the fluid transported through the pipes; elevation head which is equivalent to potential energy/energy due to elevation difference/energy due to gravity/, velocity head which is equivalent to kinetic energy due to the movement of the fluid, and pressure head which is equivalent to pressure energy/energy imparted by pressure/work done on the fluid/.

Bernoulli equation which is an energy balance equation, best expresses the relation between these heads and it applies to all points on the stream line of the flow.

$$\frac{P}{\gamma} + \frac{V^2}{2g} + Z = H \qquad (2\text{-}1)$$

Where $\frac{P}{\gamma} = Pressure\ head$, $\frac{V^2}{2g} = Velocity\ head$, Z= elevation head, $H = the\ total\ head$

Hydraulic Grade Line/HGL/: is the sum of elevation and pressure heads. In open water sources, the HGL is the water surface, but for piped pressurized flow condition, the HGL is the height to which water will rise in a piezometer or stand pipe if tapping is made.

Hydraulic Gradient: is the slope of the HGL and fluid flows normally occur from high pressure points to low pressure points in the direction of the hydraulic gradient. Any pipe lying above the HGL will cause negative pressure and this adverse pressure gradient results pushing the fluid back, against the direction of flow.

Pipe friction head losses: in WDN, energy losses are called head losses and these head losses are mainly due to pipe frictions. The ability to calculate these friction head losses is the key factor in evaluating the flow through pipe networks. The three common empirical equations, Darcy-Weisbach, Hazen-Williams and Manning's equations relate head losses and pipe friction to the fluid velocity, pipe diameter, pipe length and pipe roughness coefficients to calculate the head losses in a pipe network. Manning's equation is generally used for open channel flows, Hazen William equation is for piped flow and Darcy-Weisbach equation is general purpose. However the difference between the use of Darcy-Weisbach and Hazen-William equations is insignificant. Even though Darcy-Weisbach equation is theoretically thorough and general, it is more complex than the Hazen-Williams equation.

2.6.3. Modeling Process

The task of assembling, testing, calibrating, validating and using the water distribution system model requires breaking the task in to its components and working through each step. Some tasks can be done in parallel and some tasks in series.

2.6.4. Assembling a model

Gathering information describing the WDN is necessary before building the model. System maps, recordings, topographic maps, as-build drawings, electronic maps and recordings, non-graphical data and computer-Aided drafting are potential sources of data. Then model skeletonization and the level of detail to be included should be decided by both the modeler and the utility which administrates the water supply system.

Water distribution networks contain both nodes and links. The WDN nodes are grouped by sources, control and distribution nodes and demand nodes. On the other hand, links are capacitated as transmission and distribution pipes with specified length, diameter and other attributes. Due to operational flow and pressure requirement, pumping cost considerations, flow redirections following failure of major supply path, links in WDN are subjected to occasional changes except pipes attached to a source or sink. To establish realistic correlations between the topology of the network and operational aspects, a comprehensive assessment of WDNs resilience should be taken in to account the non-topological specifications of the network components (Yazdani and Jeffrey, 2011).

2.6.5. Procedures for WDN Modeling and Use

The WDN model should be linked to GIS, water billing and other information management systems; because its output provides input to many strategic programs and policies of water utilities (WaterNewZealand, 2009)

2.6.6. Data requirements for modeling a WDN

2.6.6.1. Sources of data

Electronic maps, recordings and CADD drawings are common target data sources. Non-graphical data such as tracking and inventory data base or text based models can also be used, but with great care; because simple topographic errors in a non-graphical network is very difficult to detect (Walski *et al.*, 2001).

2.6.6.2. Basic Hydraulic Model inputs

Pipe network inputs: The waterGEMS software package requires information on pipe diameters, pipe lengths, pipe roughness factor 'C', pump curves, different valve settings, tank cross-section information, tank elevations, nodal elevations, zonal boundaries and many other information.

Water demand inputs: Data concerning existing demand from water billing systems, spatial allocation of data from billing and GIS, time varying factors, projected future demands and their allocations from the water utility and regional planning documents can be collected.

Operational and model control inputs: Information on source nodes, pump stations, reservoirs, control valves and zonal valves can be collected from the operational staff. It is necessary to define a set of rules that tells how the water system operates in an EPS model. These operation rules may be a set of 'logical controls' in which operations such as pump on/off, valve status, pump speeds, tank water levels, node pressures, demands etc. are controlled using 'what-if…then-else' logical operators (Grayman and Rossman, 1994).

2.6.7. Calibration and validation of a hydraulic network model

The simulation software simply solves continuity and energy equations using the supplied data, so the accuracy of the model depends on the level of calibration. The calibration process may include changing the system demand, fine tuning roughness of pipes, altering pump operating characteristics and adjusting other model attributes that affect simulation results.

In order to determine whether the model represents the real system, it is must to measure various system values like pressure, pipe flows, tank water levels etc. and then compare the field measurements with the model predicted values; this is what we call calibration. Pipe roughness factor, nodal demands, initial settings of different valve types and pump curves are parameters to be adjusted during calibration, but the reasonableness of the values of these parameters should be checked from the beginning. It is possible to minimize the extent and difficulty of calibration by developing accurate sets of basic inputs which represent the real network. The common method of calibration is measuring model simulated tank water level against the actual tank water level during a given period of record (EPA, 2005).

It is recommended on many literatures that the calibrated model have to be validated for independent sets of field data to assure the confidence we have on the model results.

2.6.7.1. Static calibration and dynamic calibration

Steady state/static/ calibration: Fire flow tests and C-factor tests are the two most commonly used methods for static calibration. Field data must be collected under controlled condition in all the cases (EPA, 2005). Steady state models have to be calibrated correctly in terms of elevation, spatial demand distribution and pipe roughness before beginning to calibrate the EPS model (Walski *et al.*, 2003).

Dynamic calibrations: This calibration method is associated with EPS model and it is the comparison of modelled results to field measurements (commonly pressure, flows and tank water level) over time. Generally, tank water level data and flow measurements are most useful data forms for EPS model calibration, but since temporal variations in pressure measurements vary over a relatively small range and only for tank water level changes, they are less useful to calibrate an EPS model under average water use conditions. However, if pressures are to be used for EPS model calibration, the system must be stressed by conducting fire flow tests throughout the field test measurement period (Rahel, 1980).

2.6.7.2. Manual calibration and automated calibration

There may be many parameters which can be adjusted, but the combination of possible parameter values can appear to be overwhelming, but most influential values can be identified and adjusted to see how much change they cause. However, automated calibration approach, which is an extension to the manual calibration process allow the computer to search through different combination of model parameters and select the best sets of parameters that gives the best match between the model predicted and field measured values. This method requires the definition of objective function and the commonly used objective function is the minimization of the square root of the weighted summation of the squares of the difference between observed and simulated values (Walski, 2003).

2.6.8. Calibration standards

Many authors wrote as the amount and degree of calibration of a model should depend on the intended use of the model.

Table 2-1 : Draft Calibration Criteria for Modeling [source: (EPA, 2005)]

Intended Use	Level of detail	Type of simulation	Number of pressure	Accuracy of Pressure Readings	Number of flow readings	Accuracy of flow readings
Long-range planning	Low	Stead or EPS	10% of Nodes	±5psi for 100% readings	1% of Pipes	± 10%
Design	Moderate/high	Steady or EPS	5% - 2% of nodes	±2 psi for 90% Readings	3% of Pipes	± 5%
Operations	Low to High	Steady or EPS	10%- 2% of nodes	±2 psi for 90% Readings	2% of Pipes	± 5%
Water Quality	High	EPS	2% of Nodes	±3 psi for 70% Readings	5% of Pipes	± 2%

2.7. Integrating GIS and Hydraulic modeling

In addition to integrating data base operations like data storage, query and statistical analysis with visual and geographic analysis functions enabled by spatial data, GIS manage large volume of digital data and is a useful analytical tool. In addition to its application for allocating water demand values to the network nodes, GIS can store and manage Pipe network data, population distribution and building data (INTECH, 2010).

2.8. Application of Water Distribution Models

WDN Simulations are used for long range master planning including new developments and rehabilitation, for fire protection studies, water quality investigations, energy management, system design, daily operational uses, operator training and emergency responses. ‘’Properly assembled model is an asset for the water utilities, much like a pipe or fire hydrant’’ (Walski, 2003).

2.8.1. Role of models in operations

Operation personnel have to accept computer simulations as a tool to keep the WDN running smoothly. As a result, they will spend relatively few field observations to identify what is occurring in the distribution system. Models enable operational personnel to formulate solutions that will work correctly for the first time instead of trial and error changes on the actual system for identifying the problems occurred in the system.

2.9. Water demand allocation

2.9.1. Existing water demand allocation

Consumption or water demand is that part of the water leaving the system at customers' faucet, leaky mains or open hydrants. This demand is the driving force behind the hydraulic dynamics in the distribution system (Amdewerk, 2012). It is possible to evenly distribute the overall demand data to each node starting from the bottom/from the customers' billing records/ or from the top/the treatment plant production data/.

Most water distribution system softwares use geocoded billing meter records, production data, census tract, land use zoning, traffic analysis, demand density information and meter routes information for spatially allocate the demands and the spatial analysis capability of GIS softwares is used by these Water distribution hydraulic models (Laura Baumberger *et al.,* 2007).

We can estimate demands by counting the number of structures using representative consumptions per structure, using meter readings and assigning each meter to nodes and land uses, then applying a global factor to account the UFW so that total usage corresponds to total consumption. For effective EPS, developing temporal patterns using the best available information from continuous meter reading or from literature, is required. To assign baseline demands spatially, information is acquired from water utilities billing records, but this assignment should include customer classes such as residential, industrial, commercial users and diurnal varying demands should be developed for each major customer class or for each geographic zones with in a service area (Wood, 1980).

Models require base line demands and information on how demands change over time for extended period simulation. Average-daily demand, maximum-daily demand and peak-hour demands are demand events which are frequently considered.

Determining the amount of water being used, where it is being used and its variation with time is key to modelling and it shows the overall success of the modeling; because water demand is the driving force behind the operation of water supply distribution systems.

Demand determination is not straight forward. Billing and production records can be directly collected from utilities, but these data are not in the form that can be directly entered in to the model. After collecting these data, consumption rates will be established by studying the past, present and future projected usages. Then the water use is spatially distributed as demands or loads, assigned to model nodes; it is called loading the model.

The steps to load a model are;

i. Allocate average day demands to nodes.
ii. Develop peaking factors for steady state runs, it is the ratio of maximum-daily demand to average-daily demand and peak-hour demand to maximum-daily demand.
iii. Estimate fire and other special demands, mostly added on the maximum-daily demand.
iv. Project demands under future conditions for planning and design.

The demands can be customer demand, UFW or fire flow demands. Customer demand and UFW together forms the base-line demand. Base-line demand is usually the average-daily demand in the current year from which other demand distributions are built. Simple unit loading method is the most common method for allocating base-line demands.

Peaking Factors: Peaking factors are multiplication factors which can be applied on some consumption conditions, especially for predicted consumption conditions, for example future maximum demand condition. The peaking factors from average-daily demand to maximum-daily demand and from maximum-daily demand to peak-hour demand can be determined from the ratios maximum-daily demand to average-daily demand and peak-hour demand to maximum-daily demand, respectively. Determining the system-wide peaking factor is so simple if good records of production and tank levels are available, but determining peaking factors for each individual node is so difficult; because each individual node do not necessarily follow the same demand pattern as the whole system. Peaking factors from average-daily demand to maximum-daily demand and from maximum-daily demand to peak-hour demand ranges from 1.2 to 3 and 3 to 6, respectively depending on the demand characteristics of the system at hand (Bowen, 1993).

2.9.2. Projecting future water demands

Even though the methods of projecting future water demands significantly differ for each system, delineating service areas and projecting future population based on published reports are common to all systems. By using the current actual population number and water demand, it is possible to project the population of the coming design years and hence the corresponding demand (EPD, 2007). Future demands can be projected by applying global or regional multipliers to the existing current demand, but for new developing areas, it is better to use population-based projection or land-use method than using the existing water use. Land-use method is based on mapping the land use and applying water use factor to each land use category (Johnson and Loux, 2004). Land use based projection is flexible and superior over the population based method; because it accounts for varying type of existing and future land uses. This method is derived by applying per-acre or per dwelling unit water demand factors to either the number of acres slated for development or the number of dwelling units. Both of these unit factor methods capture the unique water use characteristic of the land uses. The general step-by-step approaches for calculating residential and non-residential water demands are as follows (Tully and Young, 2007).

Residential demand projection:

i. Determine total acreage for each residential land use classification.

ii. Multiply gross acreage by an average density for the category to obtain an estimated number of dwelling units.

iii. Assign water demand factors to the estimated number of dwelling units in each land use category.

iv. Refine unit demand factors by considering average lot size. For residential land uses, a factor of .8-.85 is reasonable.

Non-Residential demand projection:

i. Determine a percentage of coverage assigned for each land use category indoor, hardscape and landscape use types.

ii. Multiply the total acreage for each land use category by the respective indoor, hardscape and landscape coverage

iii. To obtain an estimated water demand for each use type, multiply the acreage for each use type by the applicable unit demand factor

iv. Add demands for each use type to project a total water demand for the land use classification

Unaccounted For Water demands: The estimated demand should be multiplied by the unaccounted water demand factor and added to the projected demand to obtain an overall demand for the whole potable water distribution system. It is reasonable to assuming the unaccounted water factors less than 10 percent of the demand for newer, primary residential developments and 20 to 25 percent of the water demand in old community residents. It is also possible to estimate the unaccounted water demand by comparing end user water demand to the treatment plant production or to the storage tank release.

Customer water consumption and needed fire flow: Water demands needs to be provided during all periods of the day, week and month throughout the year for both consumers use and fire protection. But to answer the question 'how much water will the system requires to deliver and to where, for today and the future?', acquisition of basic information about the community including historical water usage, population trends, planned growth, topography and existing system capabilities, is required. Determination of the quantity of water that is available for current use and that will be required for the future is the first consideration of water distribution systems. This demand is usually estimated on the per capita basis in terms of total quantity for domestic consumption in a community. The amount of water for controlling and extinguishing fires in structures differs throughout a community due to different buildings and occupant conditions. Therefore, the fire demand has to be determined at different locations throughout the distribution network (E.Hickey, 2008). Fire flow analysis is necessary to determine whether the capacity of a system meets the fire requirement (Edwards *et al.*, 2009).

2.9.3. Water supply distribution systems design constraints

Even though the values of maximum and minimum constraints regarding the pressure and velocity of water in pipes are somehow differ manual to manual, the following values are most commonly used for designing water supply distribution systems.

2.9.3.1. Pressure and velocity

In hydraulics, we measure pressure in terms of head loss or head pressure. 1 psi pressure drop in the system measures 2.31 feet height (www.taco-hvac.com). The residual pressure at ferrule points (customer premises) should be 7 meters for single storey, 12 meters for double storey, 17 meters for triple storey and do not exceed 22 meters. In any water supply distribution system, the minimum velocity of the flowing water in the pipes should be 0.6 l/s to prevent sedimentation and the maximum velocity should not exceed 2.3 m/s in order to avoid high pressure in the pipes and the resulting side effects on the pipes (Prof. B.S.Murty, 2005). The required pressure in water supply distribution systems ranges from 150 kpa to 300 kpa. The minimum allowable pressure head is 15 meters and maximum of 90 meters manometric head, but under exceptional conditions and rural areas, a minimum pressure head of up to 5 meters are permitted. Water velocities in pipes should be maintained a maximum of 2.2 m/s and a minimum of 0.6 m/s, but in some loop systems, there may be some pipe sections with zero velocity (AWRDB, 2014).

2.9.3.2. Hazen-William friction factor/C/

Most of the time Hazen-Williams formula is used for its less complexity. The formula is;

$$hL = \frac{10.675LQ^{1.852}}{C^{1.852}D^{4.87}} \quad \text{...} \quad (2\text{-}2)$$

Where hL=head loss (m), Q= pipe (AWRDB, 2012)discharge (m^3/s), L=pipe length, D= pipe diameter, C=Hazen-William friction factor. The ‘C’ factor value for new DI pipes=120 to 110, for new PVC pipes=150 and for old PVC pipes=130 (AWRDB, 2014).

2.9.3.3. Fire demand

It is possible to meet fire demand either directly from the distribution network with minimum allowable pressure of 50 meters or by installing fire hydrants at lower elevation nodes so that the fire trucks can fill in by the available head (AWRDB, 2012). The fire flow in the distribution system should be within the range of 1890 L/min. and 32400 L/min..

3. Materials and Methods

3.1. Description of the study area

The study area, Jimma Town, is the capital of Jimma Zone in Oromia region, Ethiopia. It is located about $7°37'0''$ to $7°43'25''$ North latitude and $36°47'20''$to $36°53'45''$east longitude with a total area of about 106 square kilometers. The current total population of Jimma Town is about 199,567 with an average growth rate of 4% and an average population density of 1883 people per square kilometer. Jimma Town collectively clasp a heterogeneous people from almost all over the country in the same way as our universities do, and more than eighteen languages are spoken in the town according to a report by Oromia Urban Planning Institute. Frankly speaking, it is not an exaggeration to call Jimma Town 'The Little Ethiopia! The immigration from the rural areas of Jimma zone and other places, is making the town expanding rapidly. As a result, it is demanding a high level of effort for better services by all sectors. Amongst these issues of levels of services in the town, the one which is becoming serious is water supply, in which this research is dealt with. The town included around sixteen kebeles in the current town boundary. According to JWSSE, out of the sixteen kebeles found in the town, fourteen are being legally registered as water customer areas and supplied with potable water by JWSSE. According to Oromia urban Planning Institute report, out of the total population of Jimma Town, 49% had access to piped water in their compounds, 23% used from their neighbors piped water and 19% used public stand pipes (Development Partners, 2008).

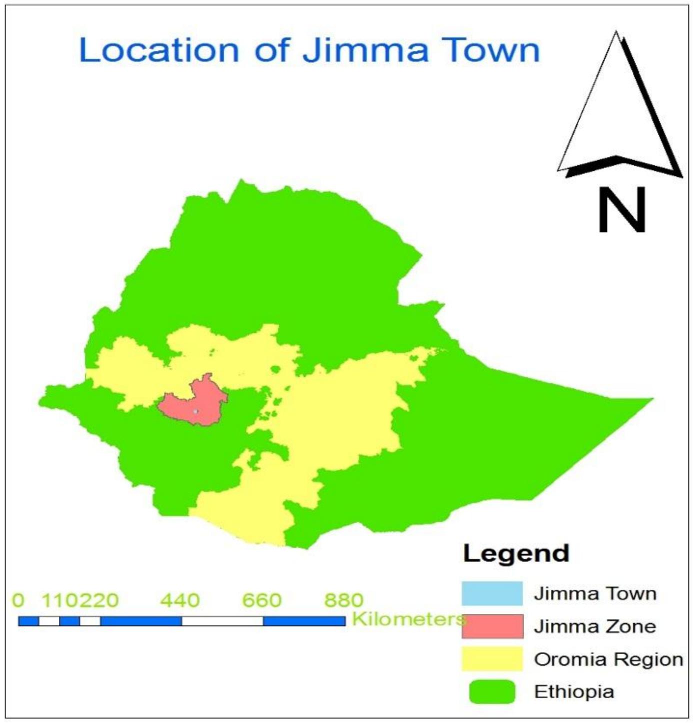


Figure 3-1: Location of the study area

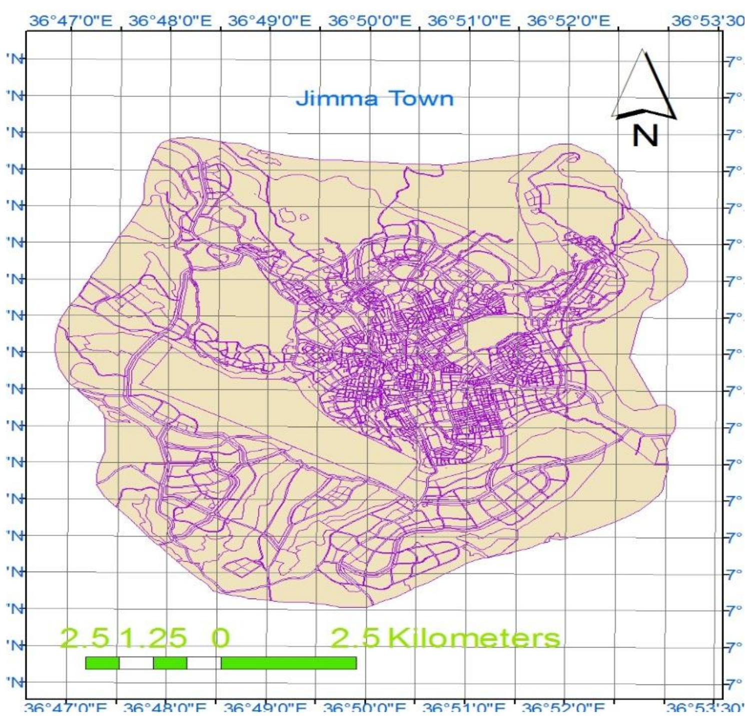


Figure 3-2: Map of the study area

3.2. General about the distribution system

Jimma Town is getting its potable water from Boye Treatment Plant. Boye Treatment Plant has two stations; the old treatment plant station which is being used since 1987 E.C. and the new treatment plant station which was implemented since 2005 E.C. The treatment plant is getting its raw water from Gibe River and after many treatment processes, the treated water enters in to the clear water wells. The clear water tanks, now assigned as reservoirs R1 and R2 in this research give their clear water to their back wash tanks for washing the treatment plant filters and gives water to be pumped to Jimma Town community.

Jimma Town Water Supply Distribution System has four pressure zones; Aba Jifar pressure zone, Ginjo pressure zone, Hospital pressure zone and Jiren kela pressure zone. Among these four pressure zones, Jiren Kela pressure zone is the widest and has two service reservoirs (which now and after wards named “storage tanks”) and one Pressure Break Tank (PBT). The other three pressure zones have one storage tank for each.

The old treatment plant pumping station supplies clear water to Jiren Kela pressure zone through direct pumping from Boye to the distribution network without storage using three centrifugal pumps with capacities 166 cubic meter of water per one hour through a 400mm PVC main. The pumps are being operated for sixteen hours per day; eight hour at day time and eight hours at night time. The new treatment plant pumping station supplies water for the two Jren Kela storage tanks 24 hours a day using three centrifugal surface pumps with maximum capacity of 465 cubic meter of water per hour each through 600mm ductile iron main. The two interconnected tanks have 2000 cubic meter volume and fills at the same time when water pumped from Boye and drain their water at the same time to Ginjo and Hospital tanks through a 500mm DI gravity main. Then Ginjo Booster Station pumps water to Aba Jifar Storage Tank. The distribution system is working in this way for the time being, but the 600mm DI gravity main which was laid during the expansion project from Jiren kela Tank 2 to Jiren Kela pressure zone, is out of the Active Network Topology and waiting for solution for integrating it with the existing network topology in a better way so as to improve the current service of the utility.

Figure 3-3: Photo showing the current water Supply distribution network of Jimma Town

Figure 3-4: The new treatment plan

Figure 3-5: The old treatment plan

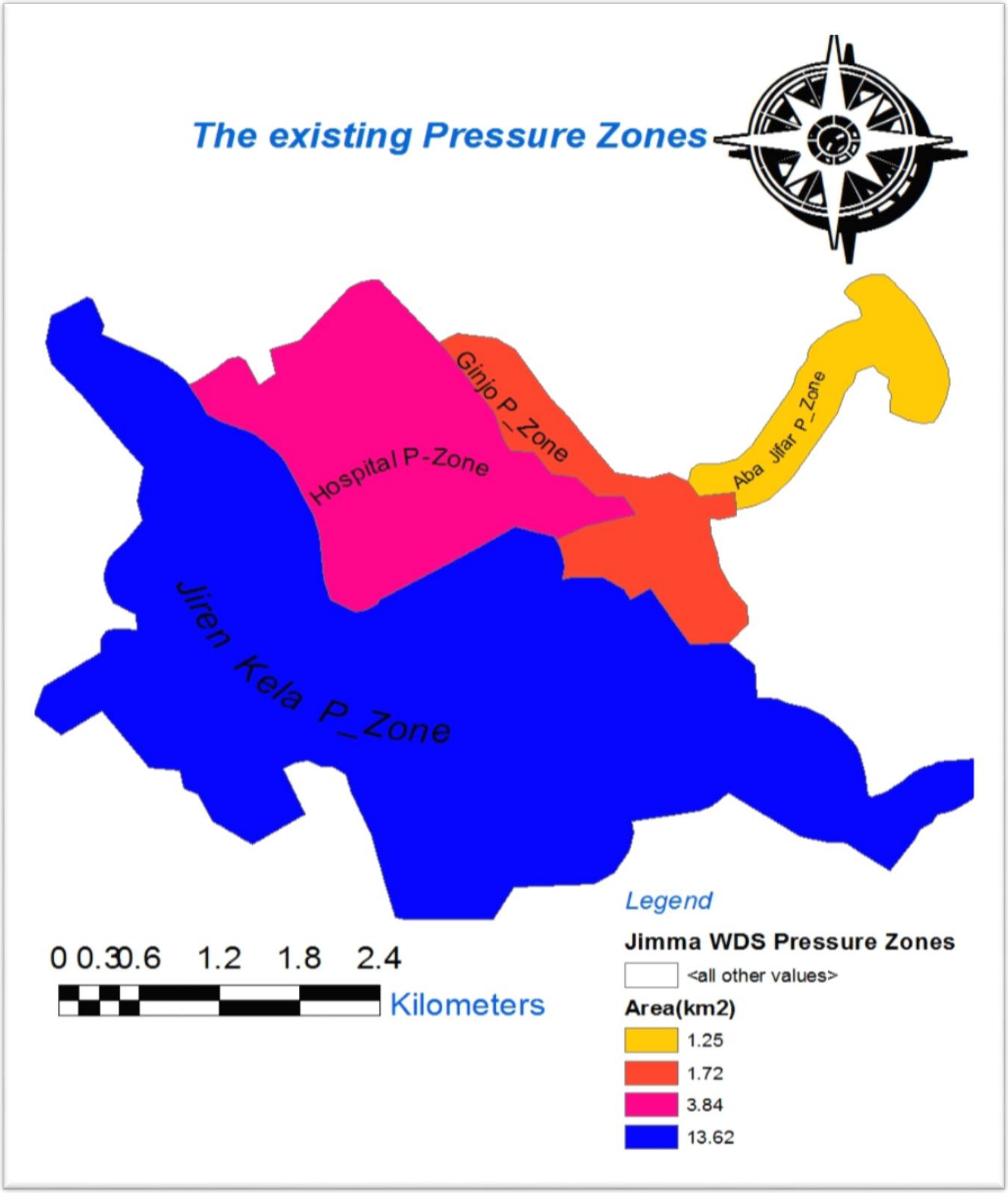


Figure 3-6: The current four pressure zones of Jimma Town WSS

3.3. Materials

To collect field data at any point where field measurements seem to be most relevant for better calibration of models and to collect the required quantity of flow and pressure measurement, different flow gauges and pressure gauges are very important, but these materials were unavailable for this study. As a result, GPS was used to take coordinates and elevation data for cross-checking with the coordinates of the boundary nodes obtained from the Auto Cad source and elevations generated by TRex. It was also used to take coordinates of some components of the distribution system which have no spatial data on the Auto Cad network. A combination of water CAD, auto CAD, waterGEMS and Arc GIS softwares were used for the model development in this study.

WaterCAD software: Used to analyze potable water networks, fire protection, allows calibration of large distribution networks, performing cost analysis and operational studies and many more functions. It also has AutoCAD interface and GIS integration features. Creating the network within AutoCAD by adding the figure directly to the drawing is possible. For this study, Heastad standalone Water CAD software played the major role to import the AutoCAD drawing to waterGEMS software in the form of .mdb sub model file extension.

GIS Software: GIS is becoming an important tool for both as a modeling data source and decision support tool. Although only 15% of water utilities are using GIS in their modeling of water distribution networks, there is a plan to use GIS by 80% of utilities (Anderson *et al.*, 2001).

GIS can perform system analysis by answering different questions in addition to map-making. The evolution of model/GIS has a three step process (Shamsi, 2001).

Interchange: data are exchanged through an intermediary file and the data is reformatted here for the model and, the model and GIS run independently.

Interface: links are built between the model and GIS which are used to synchronize the model and GIS, use of shape files which can pass data between the model and GIS.

Integration: the model can be run from the GIS and vice versa.

Arc GIS, specifically Arc map was intensively used in this research to prepare the shape files of the major components of Jimma Town Water Supply Distribution system, to prepare different types of maps you are looking on this paper and to extract and analyze the attributes of these shape files for better analysis of the water supply distribution system and hence for better modelling.

3.4. Methods and procedures

3.4.1. Data Collection

The detailed Auto CAD drawings of Jimma Town water supply distribution system, structural and land use maps of Jimma Town and some other excel data were obtained from MS Consultancy, a consulting company which prepared the new expansion Project of Jimma Town Water supply distribution system. To effectively model the distribution network and to have a reliable model, reliable input data were collected by surveying the location of some components of the distribution system such as the location and elevation of the water storage tanks, pressure reducing valves and isolation valves of the network using GPS. All the collected spatial data were used to convert the water distribution system in to shape files using Arc Map. A hard copy map of the distribution system from JWSSE was used for cross checking with the AutoCAD drawing with additional explanation by the JWSSE personnel about some missing components. Data regarding the operation such as manual controlling systems and pump head-discharge relationship were also obtained from the operational staff. Internet sources were used in this study, especially the elevation of all demand and boundary nodes were extracted from the topographic map of jimma Town after downloading its DEM from USGS website.

The as-built drawings showing the alignment, connectivity, materials, diameter, location of other system components, pressure zone boundaries, elevations and other notes and back ground information, played the key role to effectively prepare this model and analyze the distribution system. Moreover, the 2006 Jimma Town revised developmental master plan of the 1994 masterplan was used as source of data regarding the extent of future expansion of Jimma town. Ground elevations at junction nodes and other location throughout the distribution system were interpolated by preparing the topographical map of the area from DEM data and superimposing on the map of the network model.

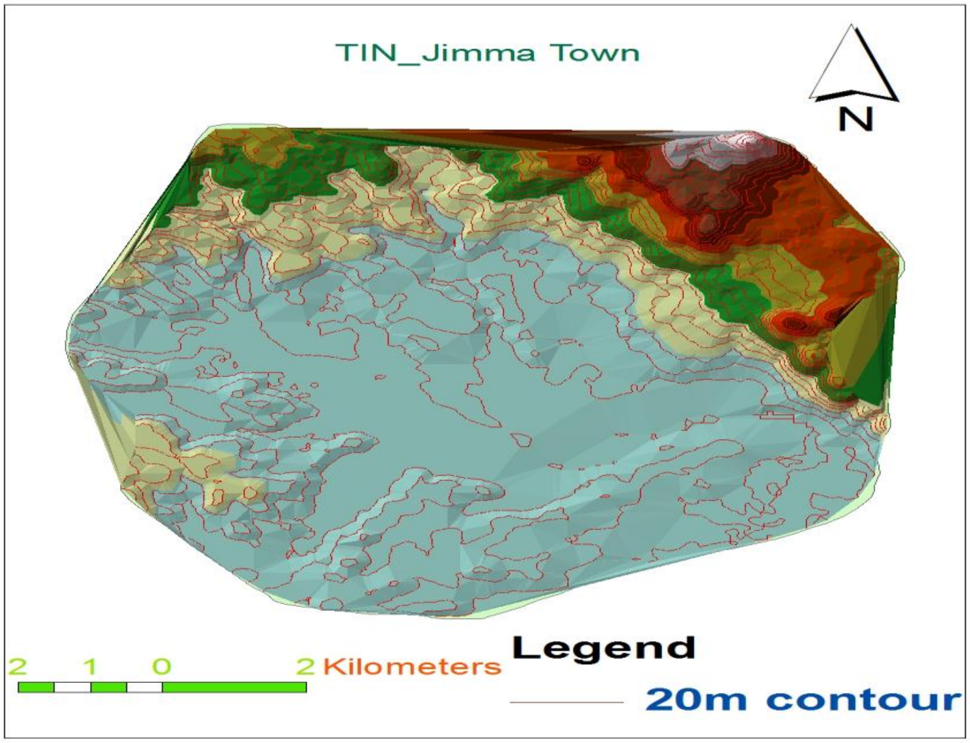


Figure 3-7: Topographic Map of the study area

3.4.1.1. Calibration Data Measurement

Field data collection is the first and key step to provide insight in to the performance of the system and model calibration (Walski *et al.*, 2001). Therefore, samples are taken at key and representative points throughout the distribution system. Pipe flow at the three pumping station discharge pipes (the main pipes which the pumps are discharging to their Storage Tanks) and pipe statuses for some pipes are observed on field for the model calibration.

Pressure Measurements: Pressure measurement devices must be located near high demand points far from sources (Walski *et al.*, 2001). But in this study, it was very difficult to get pressure measurement gages and almost all the fire hydrants at which these pressure measurement devices would equip with to measure the calibration data, were non-functional. Therefore, pressure data for model calibration were not used for this study.

Flow Measurements: Flow measurements are usually taken at some key points throughout the distribution network, such as at treatment plants and pump stations. It is also possible to measure the flow in the pipes at key and representative points throughout the distribution system by undertaking fire hydrant flow test. In this study, flow measurements were taken at all the pumping stations where there are flow measuring gages; because there were no other ways of measuring the flow through pipes of the distribution system other than the mains. To obtain data for a wide range of operating conditions, to get test data for simulation of high flow conditions and for analyzing the system behavior under extreme conditions, it is must to undertake fire hydrant flow test (Walski *et al.*, 2001). Unfortunately, it was not possible to undertake fire hydrant flow test in this study due to absence of flow measurement gages, and all the hydrants are also non-functional.

3.4.2. Data completeness and Accuracy

The data obtained from the AutoCAD source were closely reviewed and some systematic errors on the AutoCAD drawing were corrected after observing all the components of the water supply distribution system on field. Moreover, discussions were undertaken with the JWSSE personnel about the real and current condition of the distribution system and missing information were made complete. Then the data was updated to ensure the correctness of the values used as data and to ensure that all the relevant and specified data are all available

3.4.3. Data Processing and Analysis

From the available data, baseline demands/average consumption conditions/, current maximum day consumption conditions, minimum demand conditions, peak hour demands, future developments and the resulting increase in water consumption conditions were determined. Locations of larger customers were identified using ArcMap Selection tool from the prepared land use shape files and their consumptions were allocated to the corresponding nodes.

3.4.3.1. Baseline Demand Determination

Spatially allocating the existing and future demands, which are subsequently used in conjunction with peaking factors or diurnal patterns to simulate time varying water use is an initial step to develop hydraulic models (Edwards *et al.*, 2009).

Determining the area of influence is the first step for nodal demand allocation. Consumption of water can be estimated based on the amount supplied rather than the actual demand (Amdewerk, 2012). There are many approaches to allocate baseline demands for each node. It is possible to work the demand for each node using top-down or bottom-up approaches. Top-down approach was used for this study; because top-down approach with data on meter route-basis is better to achieve intermediate level of detail (AWWA, 1998(b)). The hourly water productions of each pump station were used to formulate the base line demand for each demand node by applying a global factor on the base line demand of each node to account the UFW.

Proportional Flow Distribution method was used to allocate the base line demands for each node by distributing the average-daily water consumption, which is obtained from the difference of treatment plant average daily production data and UFW/24% of the average-daily production/. This total average-daily consumption is divided for the 13 water customer kebeles of JWSSE in proportion of their population number. Then the lump-sum demand which is assigned to each current water customer kebele is equally divided for the service polygons of each node. Then the Unaccounted For Water (UFW), the water which is lost due to leakage or water taped by illegal users (theft) and which is not metered, was taken 24% of the production; this is the trend what JWSSE is using to estimate the UFW in the distribution system. The nodal demands then corrected by assigning the UFW for each node in proportion to their demands using the following formula.

$$\text{Corrected demand} = \text{Node consumption}\left(\frac{\text{Production}}{\text{Metered sales}}\right) \qquad (3\text{-}1)$$

The per capita consumption was determined for the residential users from the corrected average daily consumption. After knowing the total corrected water usage, the per capita water consumption was obtained by dividing the average-daily demand for the population number of the town.

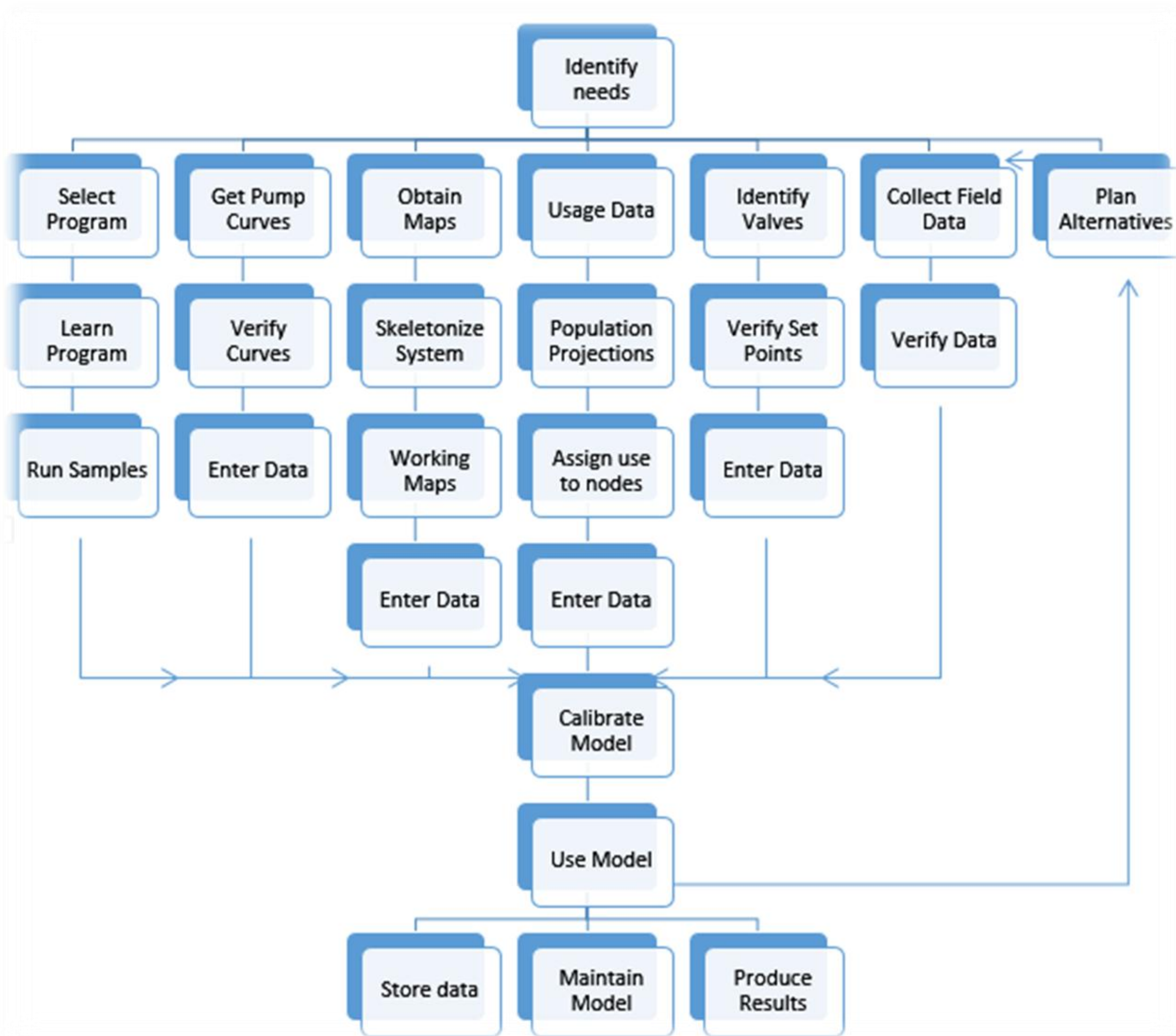


Figure 3-8: Flow Chart of the modeling process (Walski, 2003)

3.4.4. Model Building and data entry

3.4.4.1. Importing the network

To import the AutoCAD drawing in to the waterGEMS software, the AutoCAD drawing was first converted to .dxf file extension after correcting all types of errors on the AutoCAD drawing. Then the dxf file network was imported in to Heastade standalone waterCAD software using the shape file link wizard. However, since the Heastade standalone waterCAD software has many limitations as compared to the water GEMS software, re-importing the drawing from the standalone waterCAD in to the waterGEMS software was used for this paper even though there may be different methods of importing network data.

3.4.4.2. Model Skeletonization

Skeletonization is the process of selecting parts of the distribution system, which have significant impact on the behavior of the whole distribution system when included in the model for the model preparation. Even though preparing an all-pipes model requires less skilled labor to collect the data, it was not financially feasible and since it is time consuming, a moderately skeletonized network model was prepared by taking pipes with nominal diameter above 80mm, as exactly situated on the Auto CAD drawing. But the demand nodes were created using Darwin Skelebrator wizard of waterGEMS software by merging series pipes with the same diameter in to an equivalent pipe. The nodes were created at diameter changes, at end of pipes and at intersection of more than two pipes.

The level of skeletonization depends on the purpose of the study. This study is intended to be used for general purpose, especially for improving the operation and management of Jimma Town water supply distribution system. So the skeletonization technique will not affect the purpose of the study as long as components with significant impacts on the whole system are included in the model. It is possible to identify segments with significant impact on the performance of the network by undertaking criticality analysis using waterGEMS software, but with great professional decision. So as a fresh researcher, to take care of those errors due to wrong professional decision, the whole autoCAD network pipes were imported as they are on the autoCAD drawing with slight addition for missing pipes and deletion of some mis-placed pipes. But by obeying the skeletenization rules, significant changes were made on the autoCAD nodes to create the model nodes for modelling the distribution network. The level of skeletonization is also still within the moderate range.

To perform the model building process, data for modeling the system which were missed during the data collection, especially the elevations of demand nodes were generated using TRex wizard of waterGEMS software. Then grouping of pipes with similar characteristics (diameter), merging of series pipes and replacing them with equivalent pipes and other modifications on the network were made.

After building the distribution layout using the combination of standalone waterCAD, autoCAD and waterGEMS softwares, all the collected data and generated input data were entered in to the waterGEMS model and running the model was performed to test the reasonableness of the simulated parameters and to check topological errors with in the network.

3.4.4.3.Data entry and data Verification

To detect and correct data errors related to network data, demand data and operational data, which occur during data gathering process, data preparation and data analysis processes were undertaken. Then the processed data were entered in to the model using Flex Tables. The data sorting and color coding capability of waterGEMS software was used to identify very small and very large values and to focus on these values when testing and calibrating the hydraulic model.

3.4.5. Model Testing

Before going to the time consuming and tedious model calibration process, model testing was undertaken using the standard input data to check if the model perform correctly without any mathematical instabilities. Significant differences between the run results and expected system performance were investigated before going to further works. During the model testing process, there were many errors associated with the network topology and the allocated demands. Therefore, some further manual adjustments on physical and hydraulic parameters were made to make the model simulated parameter values reasonable. The demands of some nodes was transferred to another nodes and some slight adjustments on pump operating conditions were made to eliminate model error messages and to go for the next process. During the model testing, the model showed large values of pressure and flows in areas where there is no flow in the real situation and vice-versa. This condition suggested to undertake the calibration process.

3.4.6. Model Calibration

After all the error messages made corrected during the model testing process, all of the samples which were taken at some key points of the distribution network, such as flow measurement at the pumping stations and pipe statuses, were used for the model calibration. Regarding the calibration process, everything was made using Darwin Calibrator with the combination of manual and Genetic Algorithm (GA) optimized calibration runs. After comparing the model flow and the measured flow, the observed pipe statuses with the model adjusted status of the pipes, the model was just made ready for use after the observed and simulated values were agreed.

3.4.6.1. Macro Calibration

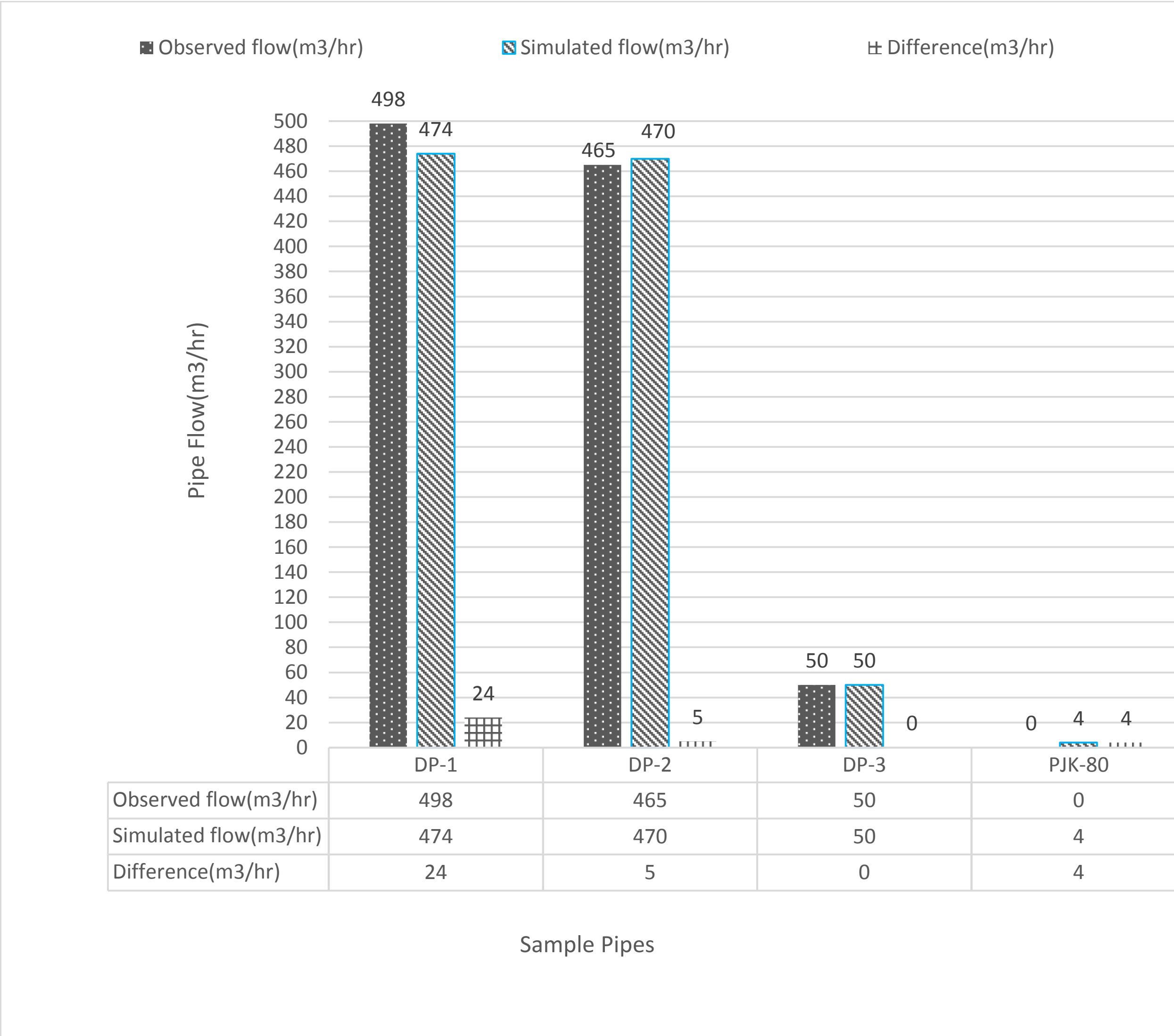
Discrepancies between modeled and observed values of nodal demands, initial valve settings, in accurate pump curves, reservoir data, pressure zone boundary data and operational data was analyzed.

3.4.6.2. Sensitivity Analysis

Since the calibration parameters are few in number, undertaking sensitivity analysis was not that much necessary; the water GEMS software itself can manage the available parameters to identify potential problems and parameters to be adjusted for micro calibration. Sources of model errors and parameters with most significant impact on the model results was identified to focus on them during the micro calibration.

3.4.6.3. Micro Calibration

At this stage, the two primary parameters, pipe roughness and nodal demand were adjusted and other model parameters were also adjusted to match pipe statuses and flow rates associated with steady state and extended period observations. There is no calibration standard to limit where to stop the calibration process in water distribution modelling, but according to the calibration standard table 2.1 in the literature review part, flow readings were taken at four pipes, which are exactly 2% of the whole pipes of the distribution network and the maximum discrepancy between the observed and simulated values, that is 24 m3/hour is +4% error tolerance, which is in the range of the specified error tolerance for models prepared for operational use and future planning, like this one.



	DP-1	DP-2	DP-3	PJK-80
Observed flow(m3/hr)	498	465	50	0
Simulated flow(m3/hr)	474	470	50	4
Difference(m3/hr)	24	5	0	4

Figure 3-9: Chart showing the calibration result

Table 3-1: Flow model calibration results

Sample Pipes	Observed flow(m3/hr)	Simulated flow(m3/hr)	Difference(m3/hr)
DP-1	498	474	24
DP-2	465	470	5
DP-3	50	50	0
PJK-80	0	4	4

Table 3-2: Pipe Status model calibration results

Sample Pipes	Observed original status	Adjusted status
PJK-1	Closed	Closed
PJK-2	Closed	Closed
PJK-3	Closed	Closed
clear water rising main	Open	Open
PJK-124	Open	Open
Aba Jifar Pressure Line	Open	Open
Tank Jiren Kela 2 inlet	Open	Open
PG-5	Open	Open
Gravity Main-2	Open	Open
PJK-80	Open	Open

3.5. System Analysis

For analyzing the distribution system capacity, the average-daily demand, maximum-daily plus fire flow demand and peak-hour demand were determined for both the existing and future conditions. The whole system was analyzed for both existing and future conditions using the procedure given below;

i. Demand determination

ii. Steady State model run with the imported calibration scenario for average-daily, maximum-daily plus fire flow and peak-hour demand conditions

iii. Model simulated result check against design criteria

iv. Identifying Short comings of the system in terms of pressure, velocity and flow

v. Model adjustment and re-run to establish the required work

vi. 24 hours EPS model run to confirm the system's ability to refill tanks,

vii. Investigation of possible upgrading options and identification of options to provide water supply and fire flow for new residents and future development areas using different scenarios.

3.5.1. Existing Demand Determination

The total residential demand was distributed to each water customer kebele in proportion to their population size by multiplying the per capita water demand with the population number of the kebele. The lump-sum non-residential demand was divided to each kebele based on the areal coverage of non-residential sites of the kebele. Then nodal demands for each kebele were distributed equally to each node with in the kebele.

3.5.1.1. Per Capita demand determination

The average per capita water demand was determined for the residential areas of the thirteen water customer areas, which are currently supplied potable water by JWSSE. The per capita water demand was determined based on daily water production records taken from the two treatment plants' pumping stations, major customers' annual consumption data obtained from JWSSE and current population number of the thirteen water customer areas. Information on housing and average family size for each house hold was obtained from a report paper by Oromia Urban Planning Institute. The ratio of total average-daily water consumption/the difference of total average daily production and the UFW/, to the population number of the water customer areas gives the per capita water consumption for the current condition of the distribution system. The current population number in the water customer areas of JWSSE is about 170000, but the total population of Jimma Town in the current year, 2008 E.C. is 199567. The people living in these water customer areas have an access to get 56 Liters of water per capita per day, but the distribution system is actually supplying all the community with 47 liters of water for each individual daily.

Table 3-3: Access per capita water demand for the current water customer kebeles

Year(E.C)	Daily average water production (m3/day)	Daily average UFW (m3/day) 24% of Production	Daily average water consumption /Residential &Non-residential /(m3/day)	Major customers'/non-residential/ daily average consumption (m3/day)	Average Daily residential consumption (m3/day)	Population	Average day demand (L/C/day)
2008	15144	3635	11509	2051	9459	170000	56

Table 3-4: Actual per capita water demand for the whole people of Jimma Town

Year(E.C)	Daily average water production (m3/day)	Daily average UFW (m3/day) 24% of Production	Daily average water consumption /Residential &Non-residential /(m3/day)	Major customers'/non-residential/ daily average consumption (m3/day)	Average Daily residential consumption (m3/day)	Population	Average day demand (L/C/day)
2008	15144	3635	11509	2051	9459	199567	47

3.5.1.2. Residential water demand determination

The water consumption for each water customer area was determined by multiplying the current population of the area by the per capita water demand as expressed earlier. See Table 3.4 below

3.5.1.3. Non-residential water demand determination

The non-residential sites like industrial, commercial, mixed uses, recreations and services were extracted using ArcMap from Jimma Town structural map developed by Development Partners Spatial Study consultancy team, for Oromia Urban Planning Institute. Then the area of non-residential sites of each water customer kebele was calculated to multiply the system wide average daily non-residential water consumption by the percentage areal coverage of the non-residential sites and hence to get the non-residential water consumption of the kebele.

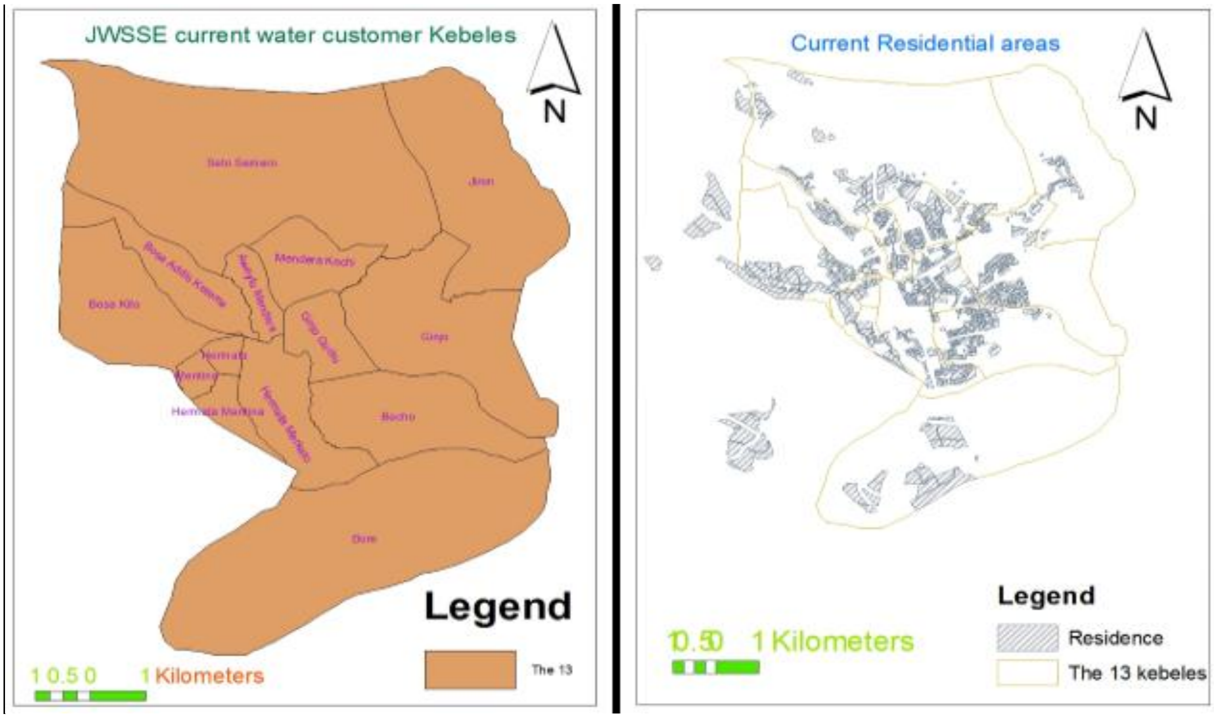


Figure 3-10: Map showing current residential areas

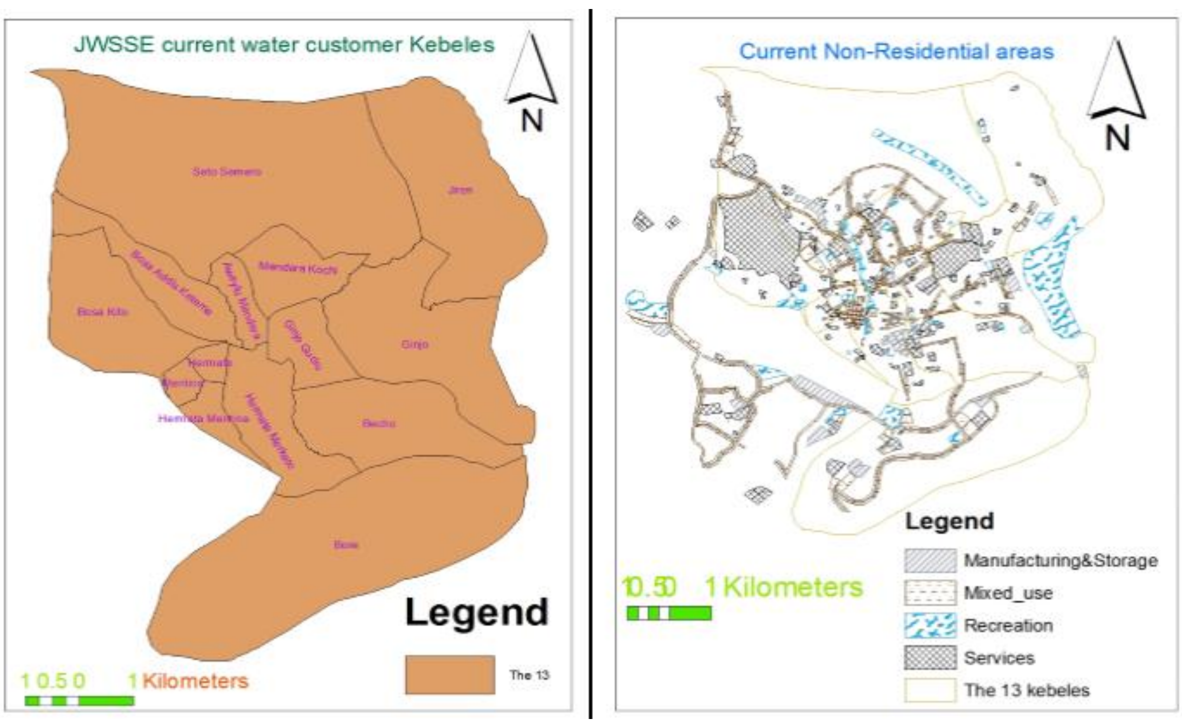


Figure 3-11: Map showing Non-residential areas

Table 3-5: Average daily non-residential water consumption of each water customer kebele

S.No	Kebele	Land Use Area(m2)						Areal coverage (%)	Lump-sum average daily water use(m3/day)	Non-residential average daily water demand (m3/day)
		Mixed	Manufacturing & Storage	Reacreation	Services	Commerce	Total			
1	Hermata	90682	1152	36244	41466	9350	178894	1.5	2051	30.8
2	Hermata Mentina	31553		6456	70776	34875	143660	1.2	2051	24.7
3	Hermata Merkato	337879	211682	79847	211349	244222	1084979	9.1	2051	186.8
4	Bosa Kito		5697	33077	198972	30661	268407	2.3	2051	46.2
5	Bosa Addis Ketema	543512	3954	44318	265568	92605	949957	8.0	2051	163.6
6	Mentina	19638			14709		34347	0.3	2051	5.9
7	Aweytu Mendera	151290	8379	22242	118744		300655	2.5	2051	51.8
8	Mendera Kochie	323222	30438	60415	224687	69181	707943	5.9	2051	121.9
9	Ginjo Guduru	259683	77981		269638	89440	696742	5.8	2051	120.0
10	Ginjo	248733	110222	28958	1247553	178375	1813841	15.2	2051	312.3
11	Becho Bore	1499335	315267	98996	676224	350653	2940475	24.7	2051	506.3
12	Seto Semero	667050	191289	634615	410386	178033	2081373	17.5	2051	358.3
13	Jiren	86994	23736	129947	134848	336068	711593	6.0	2051	122.5
Total		4259571	979797	1175115	3884920	1613463	11912866	100		2051

3.5.1.4. Nodal demand determination

After determining the residential and non-residential demands for each kebele, the total demand of the kebele was divided for the number of nodes of the kebele. Now every node with in a kebele assigned equal amount of water demand as a daily base demand from which the maximum-daily and peak-hour demands are derived by applying peaking factors.

Table 3-6: Categories of nodal demands by kebele

S.No	Kebele	Population	Per Capita Water consumption(m3/C/day	Residential Demand(m3/day)	Non-residential Demand(m3/day)	Total Demand (m3/day)	No. of Nodes	Nodal Demand(m3/node/day)		
								Residential	Non-residential	Total
1	Hermata	10923	0.056	611.7	30.8	642.5	8	76	4	80
2	Hermata Mentina	8828	0.056	494.4	24.7	519.1	3	165	8	173
3	Hermata Merkato	9808	0.056	549.2	186.8	736.0	13	42	14	56
4	Bosa Kito	13708	0.056	767.6	46.2	813.8	14	55	3	58
5	Bosa Addis Ketema	7663	0.056	429.1	163.6	592.7	13	33	13	46
6	Mentina	7838	0.056	438.9	5.9	444.8	5	88	1	89
7	Aweytu Mendera	9813	0.056	549.5	51.8	601.3	2	275	26	301
8	Mendera Kochie	10813	0.056	605.5	121.9	727.4	14	43	9	52
9	Ginjo Guduru	6443	0.056	360.8	120.0	480.7	9	40	13	53
10	Ginjo	7813	0.056	437.5	312.3	749.8	16	27	20	47
11	Becho Bore	56813	0.056	3181.5	506.3	3687.8	10	318	51	369
12	Seto Semero	15283	0.056	855.8	358.3	1214.2	6	143	60	203
13	Jiren	4258	0.056	238.4	122.5	360.9	4	60	31	91
Total		170000		9520.0	2051.0	11571.0	117			

Table 3-7: Corrected nodal demands

S.No	Kebele	Allocated nodal demand(m3/day/node)		Correction Factor (production/Consumption)	Corrected nodal demand(m3/day/node)	
		Residential	Non-residential		Residential	Non-residential
1	Hermata	76	4	1.3	101	5
2	Hermata Mentina	165	8	1.3	217	11
3	Hermata Merkato	42	14	1.3	56	19
4	Bosa Kito	55	3	1.3	72	4
5	Bosa Addis Ketema	33	13	1.3	43	17
6	Mentina	88	1	1.3	116	2
7	Aweytu Mendera	275	26	1.3	362	34
8	Mendera Kochie	43	9	1.3	57	11
9	Ginjo Guduru	40	13	1.3	53	18
10	Ginjo	27	20	1.3	36	26
11	Becho Bore	318	51	1.3	418	67
12	Seto Semero	143	60	1.3	188	79
13	Jiren	60	31	1.3	78	40

3.5.2. Demand Allocation

The corrected nodal demands of each kebele are equally distributed to their corresponding nodes for the current condition with the assumption that each service area with in the kebele have equal population numbers irrespective of their areal extent; because larger service areas located at far from the center of the town which are created by low density demand nodes have relatively low population density than smaller service areas which are created by high density demand nodes. Therefore, for this study, larger areas with low population densities are assumed to have the same population numbers with small areas with high population density. The label of demand nodes with their assigned demands are presented in *Appendix I*.

3.5.3. Future Demand Estimation

3.5.3.1. Population Forecasting

The 2007 E.C population was obtained from Jimma Town Administration and it was about 191781. CSA established urban growth rates at the national level to forecast the population using equation (3-2) AWRDB (2014).

$$P_n = P_0(1 + 0.01r)^n \quad \text{(3-2)}$$

Where P_n =future population, P_0 =Present population, r =growth rate, n =design period in years.

Table 3-8: Urban growth rate for towns in Ethiopia

Year(E.C)	Urban Growth rate/r/
1995-2000	4.3
2001-2005	4.1
2006-2010	4.06
2011-2015	3.88
2016-2020	3.69
2021-2025	3.51
2026-2030	3.35

Table 3-9: Forecasted Population for the design years

Year(E.C)	2009	2010	2011	2012	2013
Population	207670	216101	224486	233196	242244

3.5.3.2.Future non-residential water demand estimation

The non-residential future water demand was determined based on the gross non-residential area of the town including non-residential areas which have not been registered as a water customer area.

Table 3-10: Average daily non-residential future water demand for the whole town

Non-residential areas(m2)						Lump-sum average daily non-residential water use(m3/day)
Mixed	Manufacturing	Recreation	Services	Commerce	Total	
6480151.719	1766942.398	4344663.611	7794510.283	2065190.34	22451458.4	3865

3.5.3.3. Future per capita water demand determination

If the current water source is assumed to continue for the future as it is, the per capita water demands for the design years 2009, 2010, 2011, 2012 and 2013 will be as presented in table 3-9 below.

Table 3-11: Per capita water consumption for years 2009 to 2013

Year(E.C)	2009	2010	2011	2012	2013
Population	207670	216101	224486	233196	242244
Total daily water consumption(m3/day)	11509	11509	11509	11509	11509
Non-residential water consumption(m3/day)	3865	3865	3865	3865	3865
average daily residential water consumption(m3/day)	7644	7644	7644	7644	7644
Per Capita demand(l/c/day)	37	35	34	33	32

For this study, the non-residential water demand is assumed constant and the development of the town regarding these non-residential infrastructures is assumed to have insignificant effect on the water use within the next five consecutive years; because five years design period is relatively short.

3.5.3.4. Future residential average water demands

Usually the current residential per capita water demand is used as the starting point for future water demand forecasting. If JWSSE was being supplied all the community of Jimma Town including those without customers' account, the per capita water demand would have been 47 l/c/day for the year 2008. Therefore, with the assumption that JWSSE will supply all the community starting from 2009, the 47 l/c/day per capita water demand is taken as the starting point to estimate the future water demands instead of using 56 l/c/day. Starting from the current actual per capita water demand, the future water demands for the design years are calculated to be the product of the current per capita demand and the forecasted population numbers of the design years. The estimated residential water demands for the design years are presented in the table below.

Table 3-12: Future residential water demands

Year(E.C)	2009	2010	2011	2012	2013
Population	207670	216101	224486	233196	242244
current per capita water demand(m3/c/day)	0.047	0.047	0.047	0.047	0.047
average daily residential water consumption(m3/day)	9760	10157	10551	10960	11385

3.5.3.5. System wide future demand

The total average future water demand in the town is calculated as the sum of residential and non-residential future water demands. Peaking factors 1.15 and 1.6 are applied on this average water demand to get maximum-daily and peak-hour future water demands, respectively as presented in table 3-13 below.

Table 3-13: Forecasted future water demands for different consumption conditions

Year(E.C)	2009	2010	2011	2012	2013
Non-residential water consumption(m3/day)	3865	3865	3865	3865	3865
average daily residential water consumption(m3/day)	9760.49	10156.747	10550.842	10960.212	11385.468
Total average daily demand(m3/day)	13625	14022	14416	14825	15250
Maximum-day demand(m3/day)	15669	16125	16578	17049	17538
Peak-hour demand(m3/day)	21801	22435	23065	23720	24401

3.5.3.6.Delineating service polygons

To estimate the future water demands of the demand nodes based on the future land use, service polygons were prepared by adjusting the Thiesen polygons which were created for each demand node using ArcMap. Then the corresponding areas were calculated to allocate the demand in proportion of the service areas.

After delineating the service areas in the town and forecasting the population for design years 2009 to 2013, future demands were forecasted for average-daily, maximum-daily and peak-hour conditions. Then the results of the future and the present demands are compared for Extended Period Hydraulic Simulation.

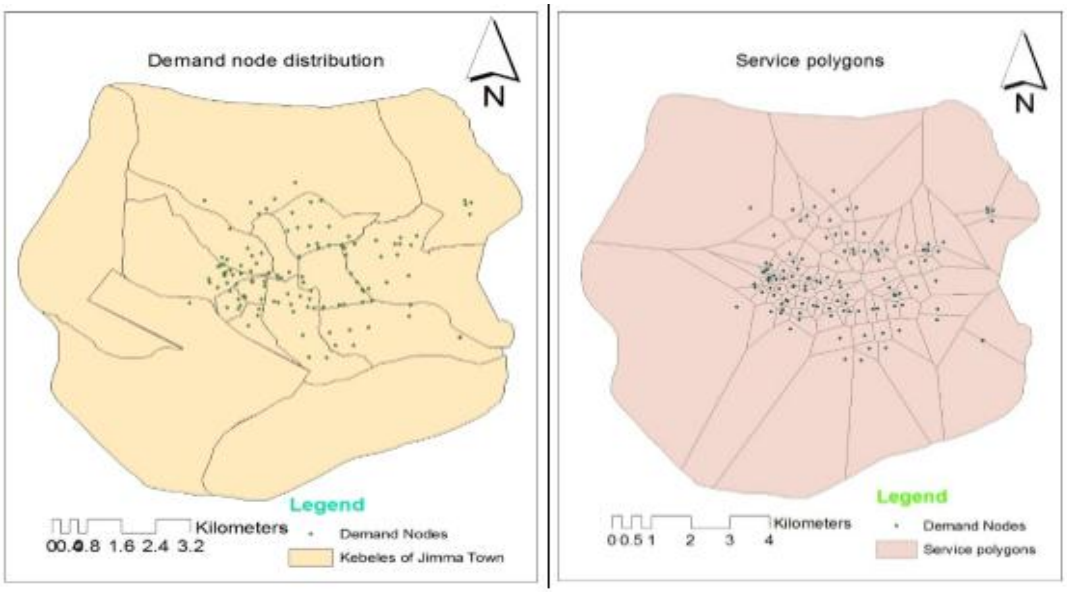


Figure 3-12: Prepared service polygons

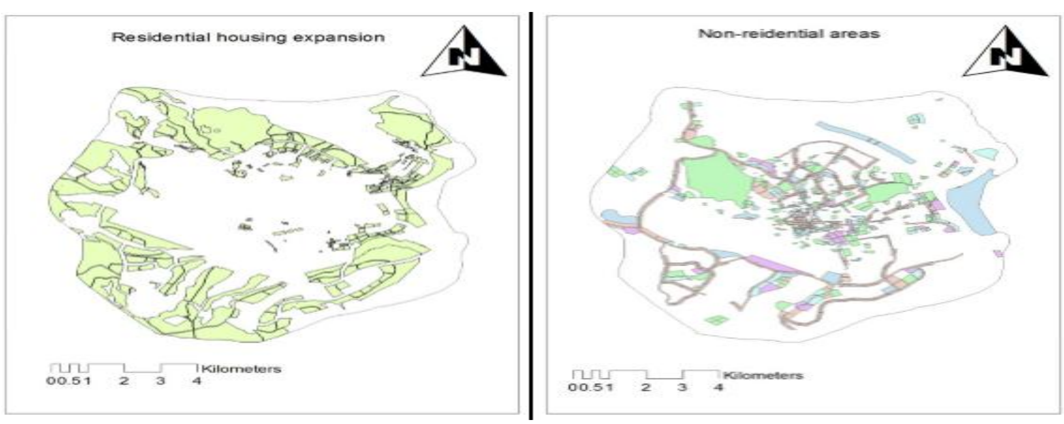


Figure 3-13: Future residential and Non-residential areas

3.5.3.7. Future demand allocation

The estimated future demands are allocated for each node in proportion of the areas of the corresponding service polygons of each demand node using the Load Builder Wizard of the waterGEMS software with the assumption that the residents are evenly distributed throughout the town. But non-residential areas are assigned for service areas where they are actually found. See *Appendix III* for detail about the allocated future demands for each node at different design periods

3.5.4. Peaking Factors

System wide peaking factors are applied on the average-daily demand which was taken as a base. Practically, the maximum-daily and peak-hour demands should be modeled by multiplying each node base demand by the ratios maximum-daily consumption to average-daily consumption and peak-hour consumption to average-daily consumption records, respectively. But for this research, these peaking factors was taken from different literatures. Because JWSSE had no production and consumption records on hourly basis and also records on the tank water level were not available to calculate the peaking factors. Therefore the peaking factors were applied based on the recommendations on some literatures for all types of water supply distribution systems. Keeping records of variations of demands for different users on hourly, daily and yearly basis helps to develop consumption patterns and peaking factors, but in the absence of such data, it is reasonable to use maximum-daily peaking factor of 1.2 and peak-hour factor less than 1.7 for towns with population greater than 80,000 (World Bank, 2005). On the other hand, (MoWR, 2006) had put a standard as maximum-daily demand peaking factor has to fall in the range 1 and 1.3, and the peak-hour factor should be 1.6 for towns with population greater than 100,000. Taking the average values, the peaking factors from average-daily to maximum-daily and from average-daily to peak-hour demands are taken as 1.15 and 1.6, respectively for this research.

3.5.5. Needed fire flow

According to (AWWA, 1998(C)), minimum needed fire flow demand should not be less than 32 l/s and the maximum needed fire flow should not exceed 757 l/s. As a developing town, taking the minimum, the fire flow needed for Jimma Town is taken as 32 l/s or 2765 m^3 /day for some nodes at the vicinity of some selected low elevation and high pressure nodes. A 2 hours duration is sufficient for fire requiring 158 l/s or less, 3 hours duration is needed for fires requiring 190 l/s to

221 l/s and for fires requiring more than 221 l/s flow, 4 hours duration is used (ISO, 1998). Therefore, a 2 hours duration of 2765 m^3/day fire flow was applied on the maximum-daily demand in different alternatives as a scenario.

3.6. Model Use

After passing all these processes starting from data collection to the micro calibration and validation of the model and after gaining a confidence about the model whether it is the real representation of Jimma Town Water Supply Distribution system, different parameters were calculated and different problems were identified for the existing condition using steady State and EPS and solutions were proposed for the identified problems. Future values of some parameters are predicted and the likely problems that may occur as a result of using the predicted values are identified and the remedial actions to be taken are suggested. These and other details are discussed on the next chapters.

Now, after all these processes, the model is just made ready to be used by JWSSE to train its personnel and assess the problems which was identified by the model. Enabling the utility to solve all the problems of the distribution system so as to improve the performance of the system and plan for better operation and hence for better community service in the future after reviewing proposed solutions, is the endeavor of this research, but updating and using the model and do accordingly is up to JWSSE!

4. Results and Discussions

Both Steady State and Extended Period hydraulic simulations were performed using WaterGEMS software based on mass and energy principles, which enables to identify the current problems and future problems that will likely to occur in the distribution system.

4.1. Current Condition/2008 E.C. /

4.1.1. Steady State Simulation

4.1.1.1. Pressures of water at the nodes

Pressures at nodes on the mains, which indicate expected terminal pressure at customer premises, are modeled and low pressure values at these points which show the presence of poor pressure condition at customer premises are identified using the color coding ability of waterGEMS software. The model prediction results showed that node JK-51 which is located around Gebrel Tank is receiving a low, but positive pressure and marked red as a low pressure node in the model Static Snapshot. To show the pressure condition at Gebrel Tank, a test node was used at Gebrel Tank and the model marked this test node as a very low pressure node with pressure very far below the minimum required pressure in all the three water use conditions; because the model assumes a fixed unchangeable demand in its steady state calculation. On the other hand, G-4 in Ginjo Pressure Zone, JK-78 in Jiren Kela pressure zone are receiving slightly low pressure under the design standard of minimum required pressure at a node/150kpa or 15m/ in all the three consumption conditions. See ***Appendix II***, columns 3, 11 and 19 for the detailed snapshot model results.

4.1.1.2. Velocity of water in the pipes

The model showed the velocities of water in most of the pipes are below the minimum range. The transmission main from the old treatment plant to Jiren kela Pressure Zone, Aba Jifar pressure line and some pipes in all the pressure zones have velocities in the acceptable range, but the velocity of water in the gravity main from Jiren Kela Tanks to Hospital and Ginjo Storage Tanks and pipe PG-5 in Ginjo pressure zone, have velocities above the acceptable range.

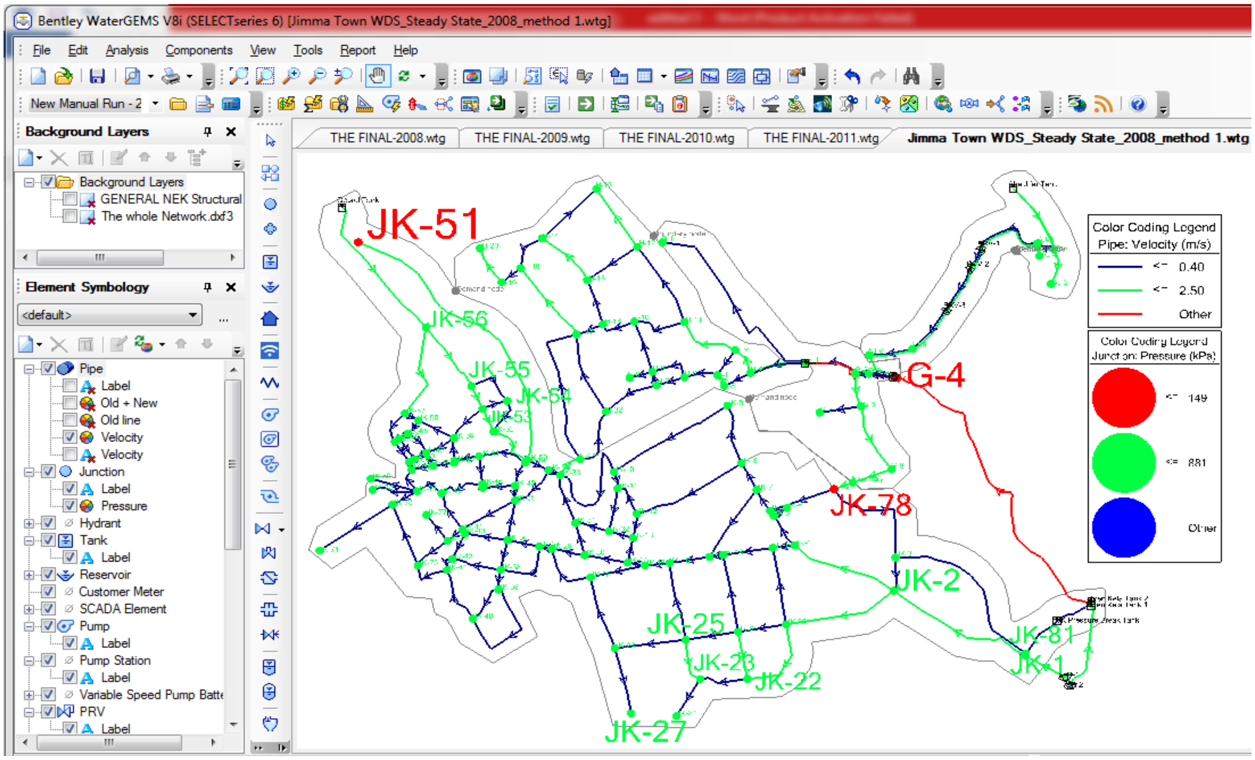


Figure 4-1: Steady State Simulated pressures and velocities

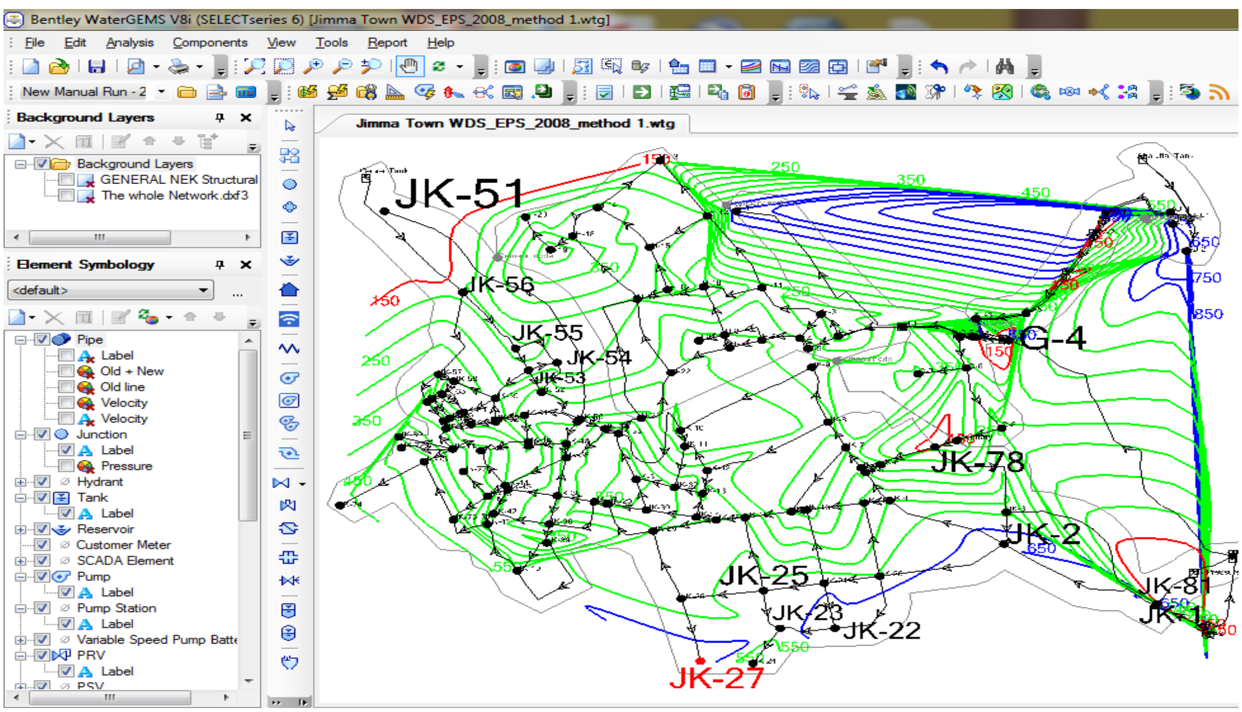


Figure 4-2: Pressure Contours for the year 2008 E.C.

4.1.1.3. Head losses in the pipes

The modeled head losses enable to judge whether booster stations are needed or not to boost the water pressure and add energy to let the flow continue. The model simulated as head loss values in gravity main 1, gravity main 2, Old TP CWRM, New TP CWRM and PG-10 are very high. Relatively high head losses in pipes PG-9, PJK-122 and Aba Jifar pressure line are shown by the model.

4.1.1.4. Discharge/flow of water in the network

Since discharge is a function of velocity and velocity is a function of pipe size, the results of discharge and velocity will be used for the judgment for solving the distribution network problems related to pipe size.

Quantities of water flow, water velocity and head lose in various pipe lines and resulting residual pressures at various demand nodes in the network are modeled. The distribution system problems related to pipe size, pumping and operation are identified using the model so as to formulate solutions. See ***Appendix III*** for the model simulated pipe velocities and pipe flows tabular results.

Water normally flows from high pressure point to low pressure point in the direction of the hydraulic gradient. Figures 4-3, 4-4 and 4-5 show flow and pressure profiles from the two treatment plants' clear wells to the corresponding storage tanks in the current condition. As shown on the figures, the slope of the HGL of water in the main from node JK-50, in the vicinity of Jimma Degitu Hotel to Gebrel Tank seems increasing in the Steady State snapshot. On the other hand, from the new treatment plant Clear Well to Ginjo, Hospital, Aba Jifar Storage tanks and from the old treatment plant Clear Well to Menafesha, The Four Lions and the vicinity in the mains have decreasing Hydraulic Gradient in the direction of flow and hence implies satisfactory flows. But the general decreasing pressure profile from the old treatment plant to Gebrel Tank shows the opposite, and poor performance of the old treatment plant pumps.

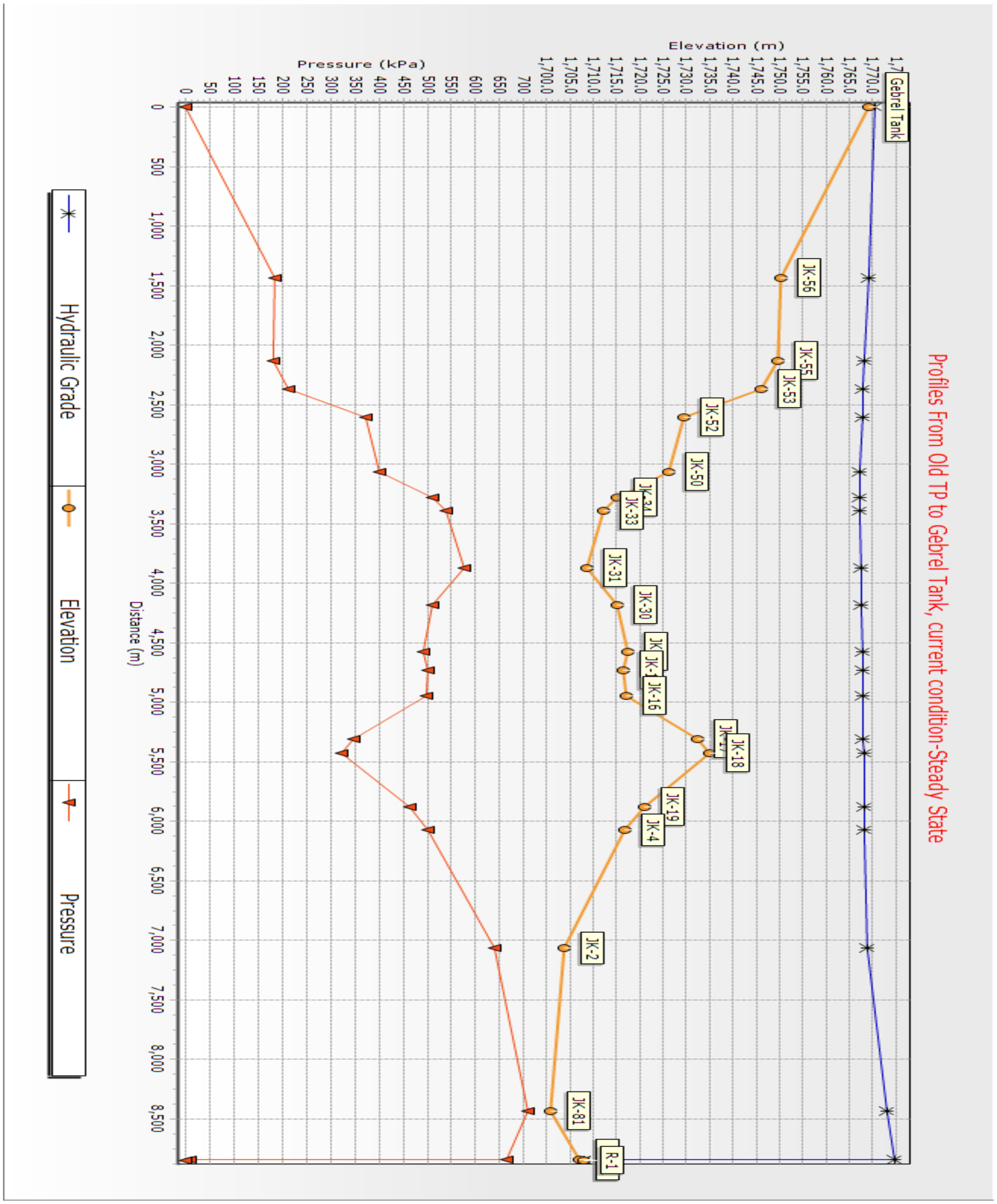


Figure 4-3: Profiles, from the old treatment plant to Gebrel Tank

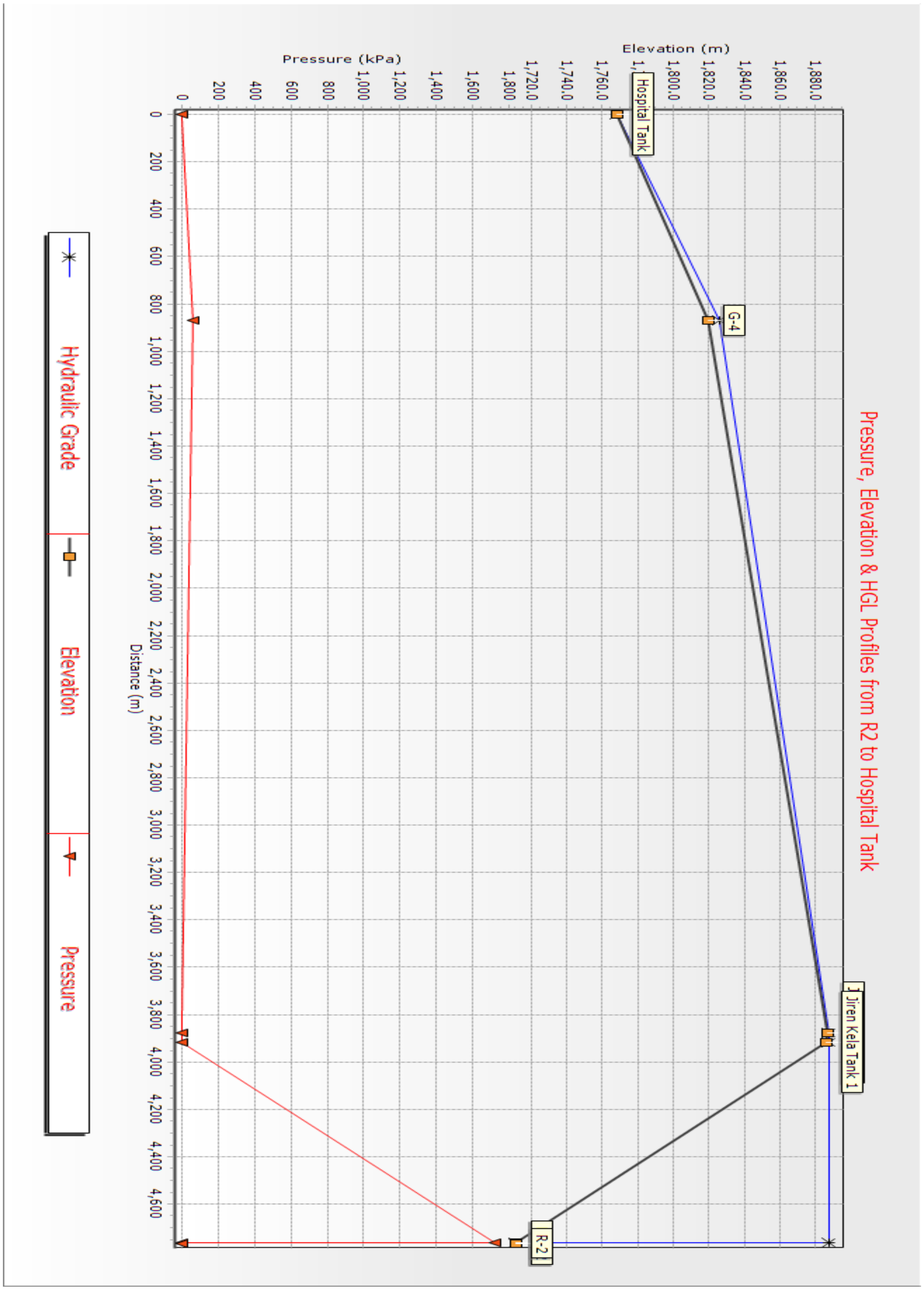


Figure 4-4: Profiles, from the New Treatment Plant to Hospital Tank

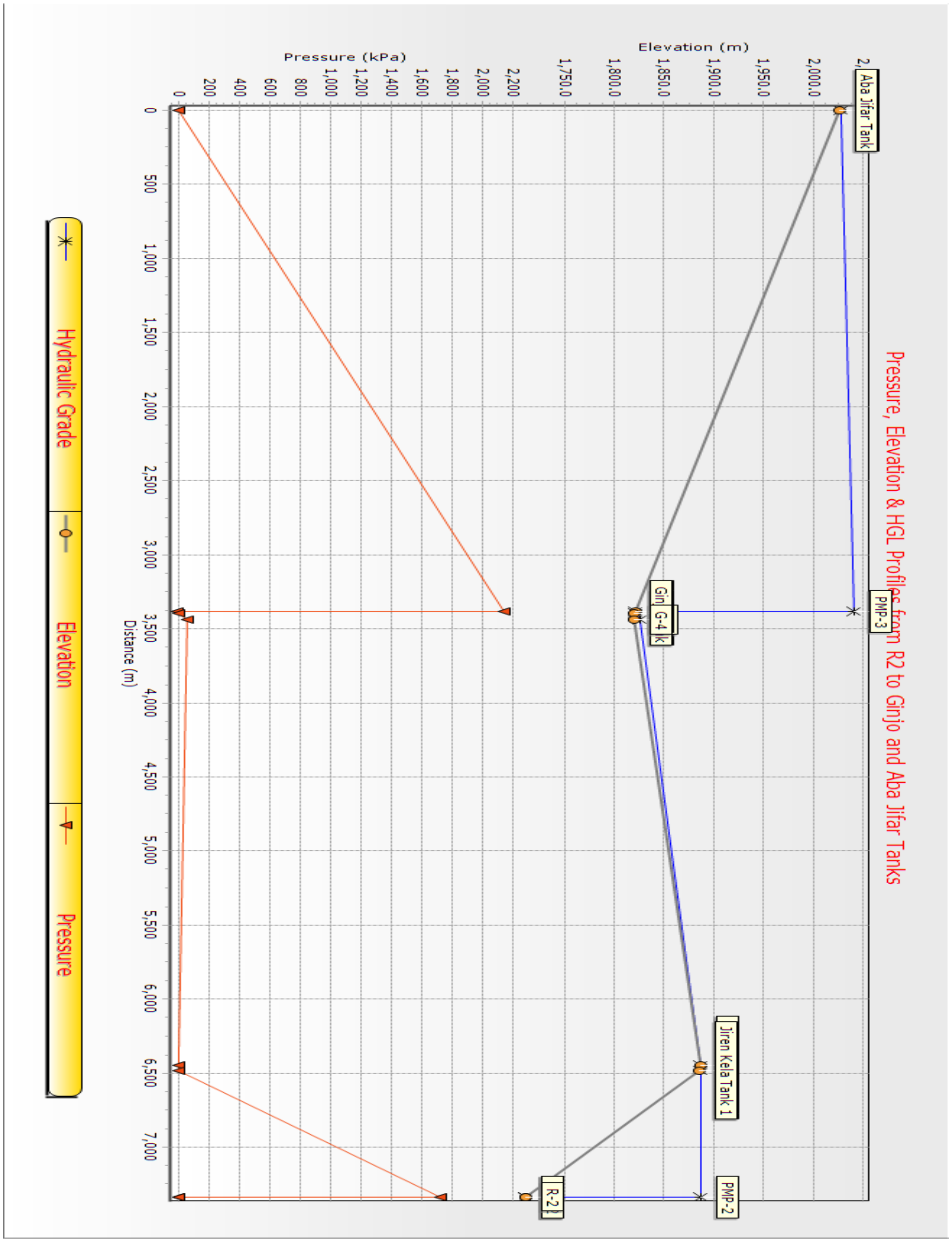


Figure 4-5: Profiles from the New Treatment Plant to Ginjo and Aba Jifar Tanks

4.1.2. Extended Period Simulation

The performance of the distribution system regarding the available pressure and pipe flow over time was analyzed for 24 hours EPS for average-daily, maximum-daily plus fire flow conditions and peak-hour condition. The observed flow data used for the model calibration was taken over the course of the day and hence used for the calibration of the EPS model.

4.1.2.1. Diurnal Curves of the residential and non-residential water users

In all water supply distribution systems, the water use patterns are changing over the course of a day, weekly and seasonally. The diurnal curves are constructed by applying demand pattern multipliers on the average water demand. Demand pattern multipliers could be determined using equation (4-1).

$$PF = \frac{Q_x}{Q_{ave}} \qquad (4\text{-}1)$$

Where PF=Peaking factor from the average condition to the required peak condition, $Q_x =$ peak demand condition/maximum day demand or peak hour demand/, $Q_{ave} =$ average demand condition.

But to determine the average-daily water demand, it is must to use the mass-balance technique by recording the tank water fluctuations over the course of the day during day and night in a fixed time interval for all the pressure zones, but some of the storage tanks of Jimma Town Water Supply Distribution System were not equipped with tank water level measuring device and the existing level metering devices were also non-functional.

In general, almost all water supply distribution systems have similar demand patterns. For this study, the demand patterns for residential and non-residential water users of jimma Town are approximated as below in table 4-1 in a 6 hours interval.

Table 4-1: Water use pattern multipliers

Residential Pattern		Non-Residential Pattern		Total Average Pattern	
Time from Start(hr)/local time/	Multiplier	Time from Start(hr)/local time/	Multiplier	Time from Start(hr)/local time/	Multiplier
12:00:00 AM	1	12:00:00 AM	1.1	12:00:00 AM	1.05
6:00:00 AM	0.6	6:00:00 AM	0.8	6:00:00 AM	0.7
12:00:00 PM	1	12:00:00 PM	0.6	12:00:00 PM	0.8
6:00:00 PM	0.4	6:00:00 PM	0.4	6:00:00 PM	0.4
12:00:00 AM	1	12:00:00 AM	1.1	12:00:00 AM	1.05

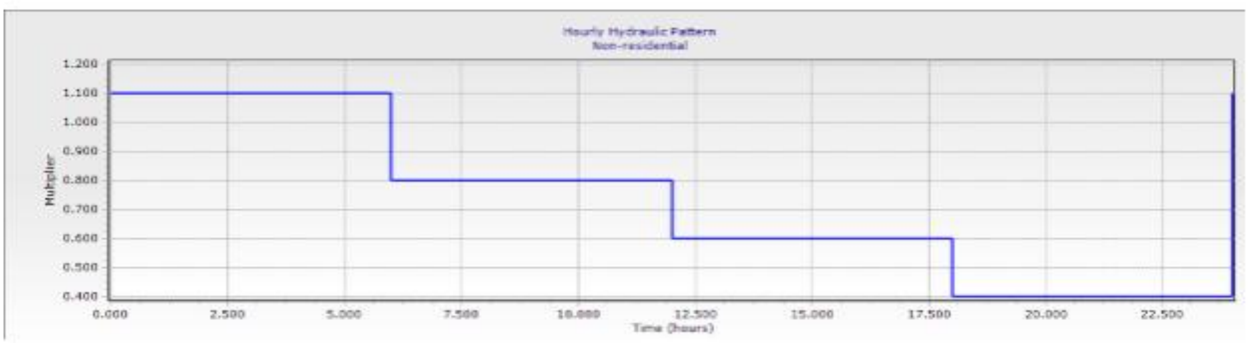


Figure 4-6: Residential and Non-Residential hourly water use pattern

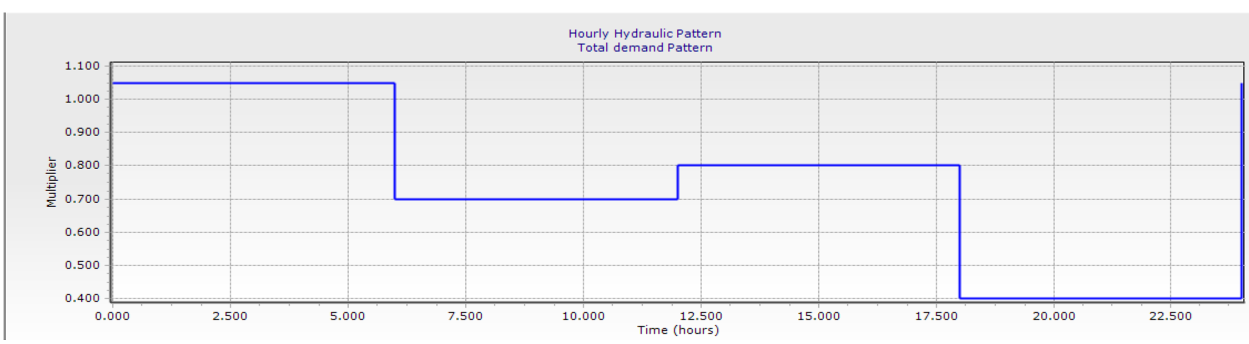


Figure 4-7: Total Average Water use Pattern

4.1.2.2. Analysis of average-day, maximum-daily and peak-hour consumption conditions

The available pressure at the demand nodes, pipe velocities, pipe flows and head losses in the pipes are simulated over the period of 24 hours with the assumption that the pattern repeats itself every 24 hour cycle. For the sake of reducing the bulk model simulation results for the 24 hours condition, only extremely high water use hours (12:00 AM to 1:00 AM local time) and some low consumption hours (6:00 PM to 11 PM local time) are used to display the result graphically as shown below, in figures 4-8, 4-9, 4-10, 4-11.

Average-daily water consumption condition:

In the average water consumption condition, all nodes except nodes around Gebrel and node JK-78, are receiving normal pressure in periods from 12:00 AM to 6:00 Am local time. All the nodes including nodes at the vicinity of Gebrel Storage Tank are receiving normal pressure at periods 6:00 PM to 11:00 PM, but nodes JK-1, JK-2, JK-22, Jk-23 JK-25, JK-27 and JK-81 would become over pressurized during this time interval if the pump is allowed to run for 24 hours. But the pump is operating for 8 hours on day time and 8 hours at night. So the maximum pressure period is between 6:00 PM to 8:00 PM local time with maximum pressure at nodes JK-1, JK-2, JK-22, JK-27 and JK-81.

Maximum-daily consumption condition:

Maximum-daily consumption is the average water consumption rate at the maximum water-use day. The maximum water consumption occurs at the weekend (Saturday and Sunday) in almost all Water Supply Distribution Systems all over the world. It is already mentioned as the maximum-daily water use peaking factor is 1.15 times the average-daily water use. The EPS result showed as Gebrel Storage Tank is receiving almost zero pressure in this water consumption condition.

Peak-Hour Consumption Condition:

Is the average rate of use during the maximum hour of usage and is assumed to be 1.6 times the average-daily water use. Since all water distribution systems are designed to meet the peak-hour demand condition, it was must to analyze the performance of the distribution system for two extreme periods, relatively high water use period and relatively low water use period. For the first case, all nodes in Jiren Kela and Hospital pressure zones recieve negative pressures, except nodes JK-1 and JK-81. On the other hand all nodes in Ginjo and Aba Jifar pressure zones recieve normal pressures except G-8. In the second case, all nodes receive normal pressure while JK-1 and JK-81 become over pressurized. The model simulated nodal pressure and pipe water velocity at the peak-hour water use are displayed in figures 4-10 and 4-11 below. The model simulated tabular results for all the three water use conditions are presented in *Appendix-II*.

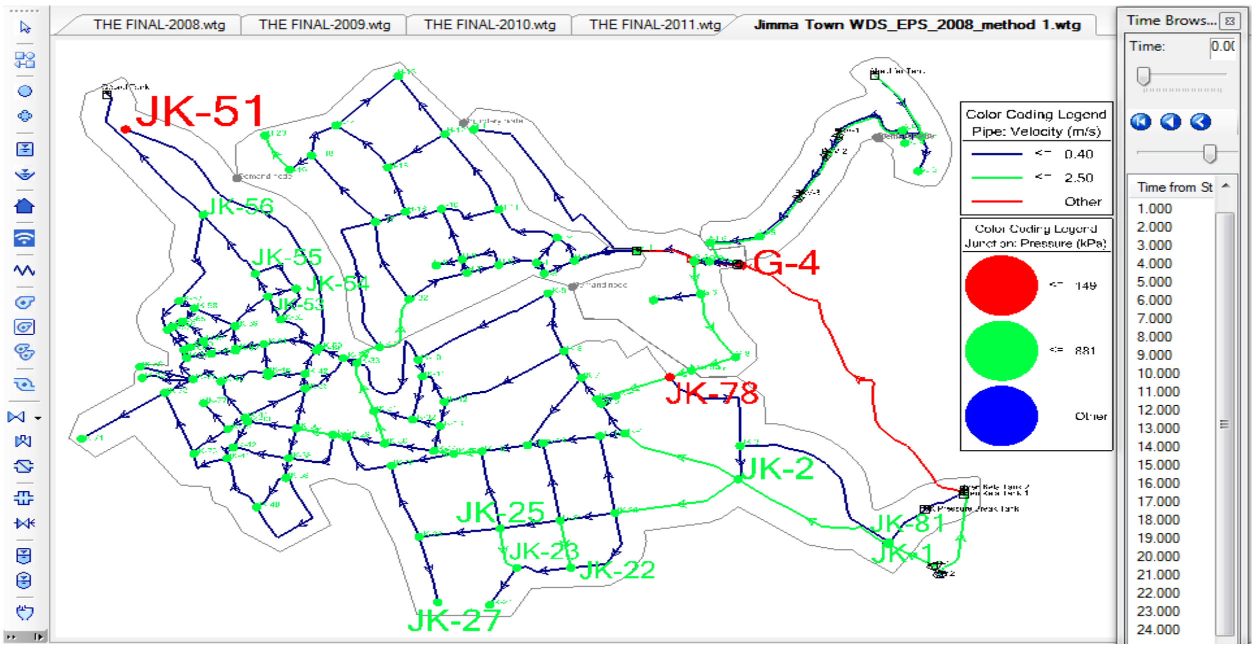


Figure 4-8: Pressures and velocities at 12:00 AM to 1:00 AM in the average consumption

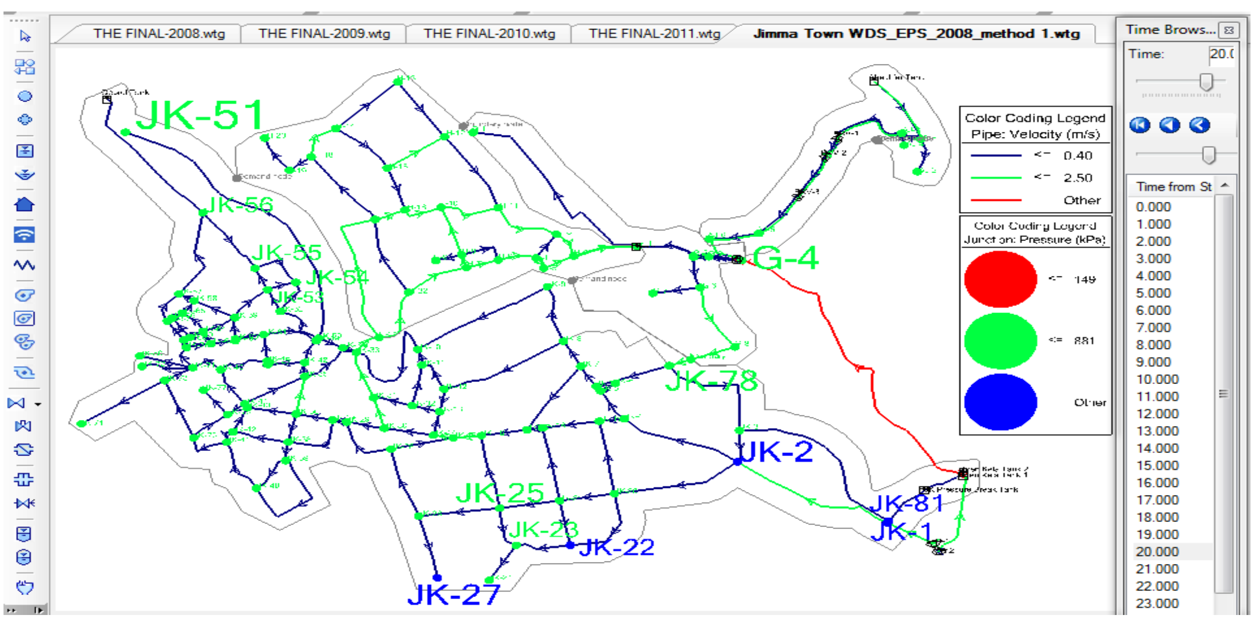


Figure 4-9: Pressures and velocities at 6:00 PM to 8:00 PM in the average consumption

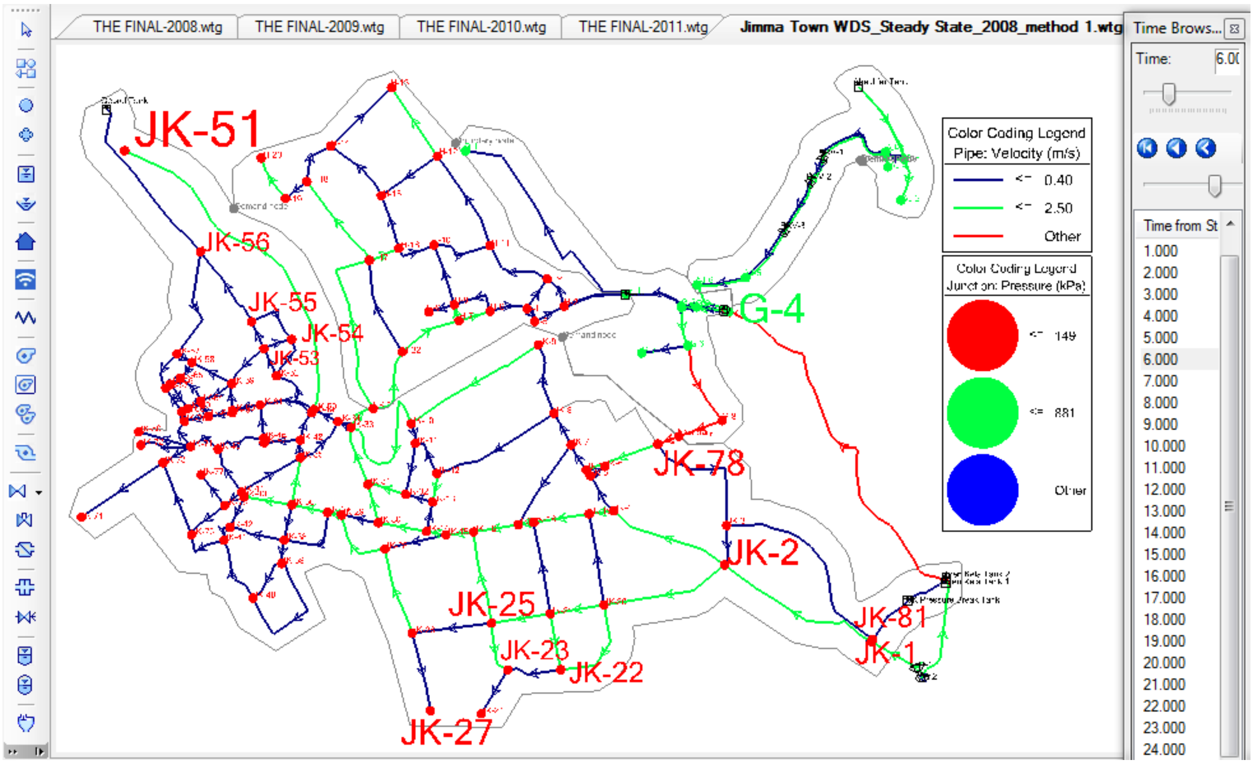


Figure 4-10: Pressures and velocities at 12:00 AM to 1:00 AM in the peak-hour consumption

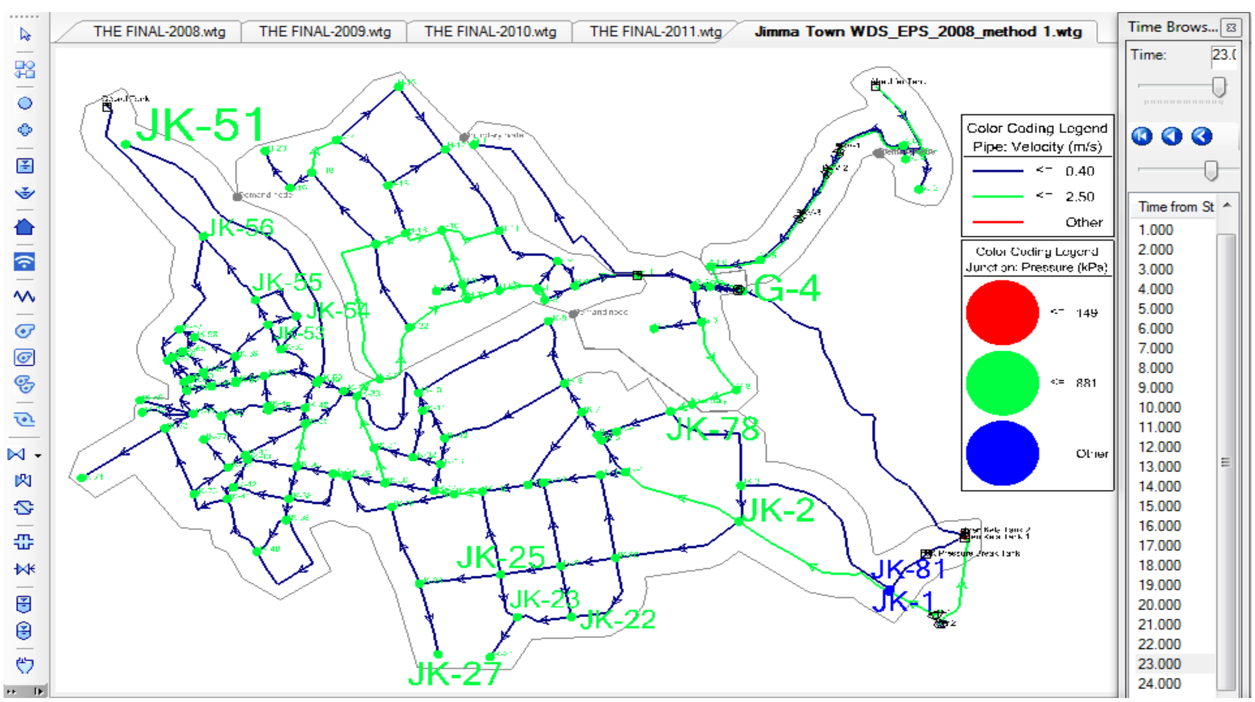


Figure 4-11: Pressures and velocities at 7:00 PM to 11:00 PM in the peak-hour consumption

Flow Balance

The flow fluctuation and tank refilling pattern graph over the period of 24 hours extended period simulation is prepared for average-daily and peak-hour consumption conditions for the current year, 2008 E.C. as shown on figure 4-12 and Figure 4-13 below. The two figures imply as there is much water storage in the system during average water use condition than during peak-hour water use condition.

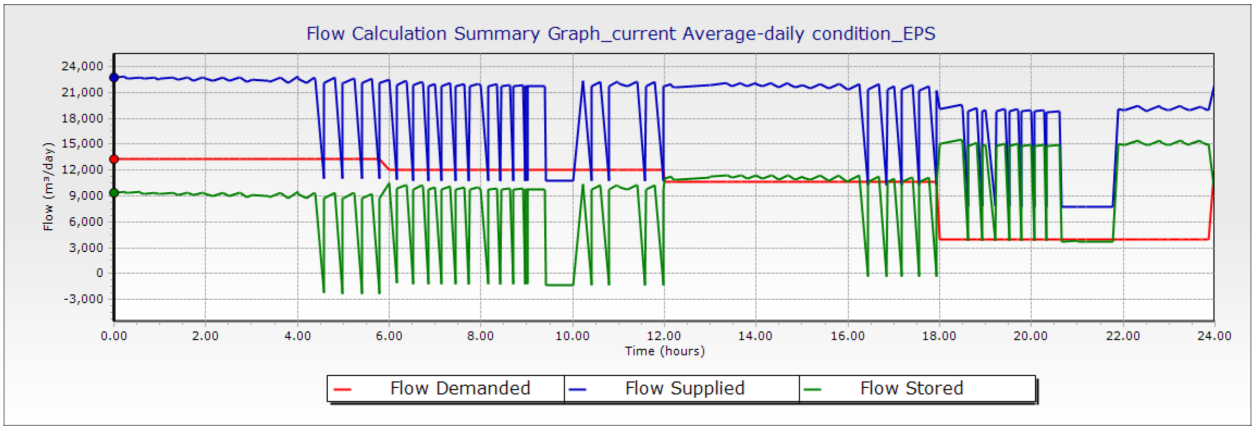


Figure 4-12: Flow Calculation Summary Graph for the current average-daily water use

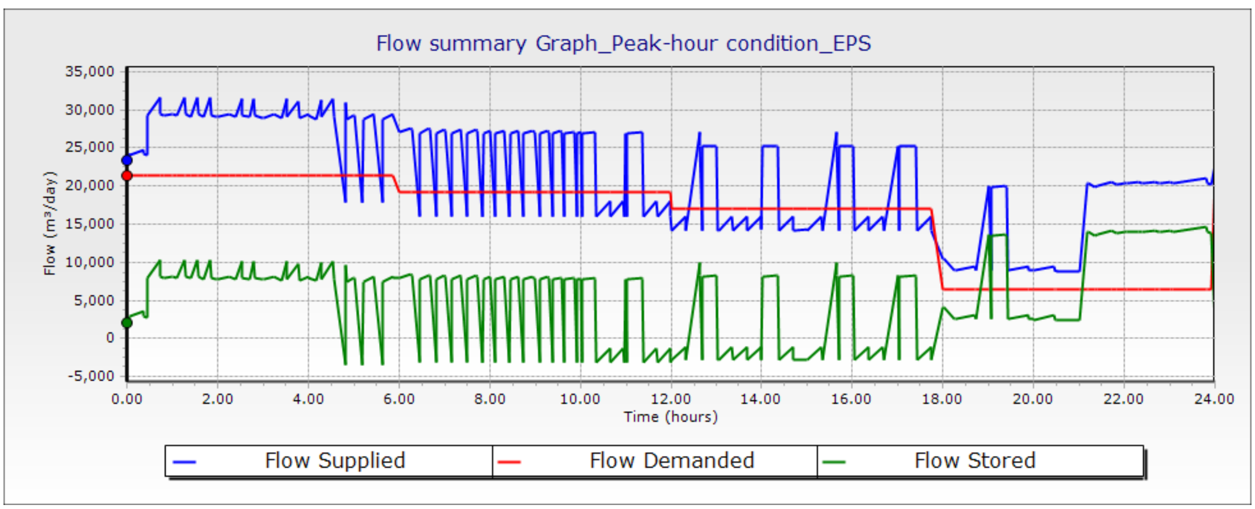


Figure 4-13: Flow Calculation Summary Graph for the current peak-hour water use

4.2. Future Scenarios

4.2.1. Network Topology Scenario

4.2.1.1. Alternative-I: Using the current network Topology

The future nodal demands were estimated for years 2009, 2010, 2011, 2012 and 2013 based on the extent of the area to where each individual demand node will likely serve the surrounding community for the specified years. This demand estimation technique is somehow different from the one done for the current year (2008 E.C) even though the 2008 E.C. network topology was used to allocate demands and analyze the distribution system in this alternative. The model simulated results showed a large negative pressure values for areas above The Four Lions to the vicinity of Gebrel Storage Tank including the whole Bosa Addis Ketema and Bosa Kito kebeles, as result of allocating high future demands for node JK-51 based on its service area. But the pressure and pipe flow conditions at other parts of the distribution system are somehow normal relative to the current year (2008 E.C). Since the rate of increase in population is not that much large, the resulting demand change between the specified periods are low. So the model simulated demand results for the design years 2009 to 2013 are not that much different. The model predicted as nodes in Aba Jifar pressure zone will receive low pressure at some periods between 12:00 AM and 6:00 AM and some nodes in Jiren Kela pressure zone near to the treatment plant will receive slightly high pressure at periods between 6:00 PM and 11:00 PM throughout the design periods (2009 to 2013 E.C). But Node JK-51 and the surrounding areas show negative pressure values throughout the day and throughout the design periods. Generally, there is high water consumption in periods between 12:00 AM to 1:00 AM and low consumption in periods 6:00 PM to 11:00 PM for all the design years. Nodes which receive abnormal pressure are presented in table 4-2 below.

Table 4-2: Future nodal pressure conditions in the Current Active Topology Alternative.

Network Topology Scenario: Alternative-I						
Year(E.C.)	Low pressure nodes at relatively peak water use hours			High pressure nodes at relatively low water use hours		
	Average-daily consumption	Maximum-daily consumption	Peak-hour consumption	Average-daily consumption	Maximum-daily consumption	Peak-hour consumption
2009	JK-51, G-4	JK-51, JK-53, JK-54, JK-55, JK-56, JK-78, H-2, H-3, H-10,H-13, AJ-1, AJ-2, AJ-3, AJ-4, AJ-5, AJ-6	All nodes except JK-1, JK-81, H-1, G-1, G-2, G-3, G-4, G-5, G-6, G-7	JK-1, JK-2, JK-22, JK-23, JK-25, JK-27, JK-81	JK-1, JK-2, JK-22, JK-27, JK-81	JK-1,JK-81, JK-22
2010	JK-51, AJ-1, AJ-2, AJ-3, AJ-4, AJ-5, AJ-6	JK-51, JK-53, JK-54, JK-55, JK-56, JK-74, JK-78, H-2, H-3, H-10, H-12, H-13, H-17 AJ-1, AJ-2, AJ-3, AJ-4, AJ-5, AJ-6	All nodes except H-1, G 1, G-2, G-3, G-4, G-5, G-6, G-7	JK-1, JK-2, JK-22, JK-23, JK-25, JK-27, JK-81	JK-1, JK-2, JK-22, JK-27, JK-81	JK-1, JK-81
2011	JK-51, JK-78, AJ-1, AJ-2, AJ-3, AJ-4, AJ-5, AJ-6	JK-51, JK-53, JK-54, JK-55, JK-56, JK-60, JK-62, JK-64, JK-74, JK-78, H-2, H-3, H-10, H-11, H-12, H-13, H-15, H-17 AJ-1, AJ-2, AJ-3, AJ-4, AJ-5, AJ-6	All nodes except H-1, G 1, G-2, G-3, G-4, G-5, G-6, G-7	JK-1, JK-2, JK-22, JK-27, JK-81	JK-1, JK-2, JK-22, JK-27, JK-81	JK-1, JK-81
2012	JK-51, JK-78, AJ-1, AJ-2, AJ-3, AJ-4, AJ-5, AJ-6	JK-51, JK-53, JK-54, JK-55, JK-56, JK-60, JK-62, JK-64, JK-74, JK-78, H-2, H-3, H-10, H-11, H-12, H-13, H-15, H-17 AJ-1, AJ-2, AJ-3, AJ-4, AJ-5, AJ-6	All nodes except H-1, G 1, G-2, G-3, G-4, G-5, G-6, G-7	JK-1, JK-2, JK-22, JK-27, JK-81	JK-1, JK-2, JK-22, JK-27, JK-81	JK-1, JK-81
2013	JK-51,JK-55, JK-56, JK-78, H-2, H-3, H-10, H-13, AJ-1, AJ-2, AJ-3, AJ-4, AJ-5, AJ-6	JK-6, JK-10, JK-11, JK-18, JK-39, JK-42, JK-43, JK-44, JK-46, JK-47, JK-51, JK-53, JK-54, JK-55, JK-56, JK-57, JK-58, JK-59, JK-60, JK-62, JK-63, JK-64, JK-65, JK-66, JK-74, JK-78, All Hospital pressure zone nodes except H-1, H-9, H-19, All Aba Jifar nodes	All nodes except H-1, G 1, G-2, G-3, G-4, G-5, G-6, G-7	JK-1, JK-2, JK-22, JK-27, JK-81	JK-1, JK-2, JK-22, JK-27, JK-81	JK-1, JK-81

The detail tabular model simulated nodal pressure and pipe water flow velocity results at peak hour condition are presented in *Appendix-IV*.

4.2.1.2.Alternative-II: Set pipes PJK-1, PJK-2 and PJK-3 open

JWSSE was not being used the newly installed main which is assigned as the combination of pipes PJK-1 and PJK-2 with diameters 600 mm and PJK-3 with diameter 500 mm, in this model. The general network topology would have an impact on the network hydraulics if these pipes were included in the analysis as opened. So in this alternative and the current operational control, JK-51 is receiving low pressure at relative-peak water use hours in all the three water use conditions. On the contrary, JK-1 and JK-81, which are located at the intersection of the old treatment plan main and the newly included gravity main, are receiving very high pressure at the relative-low water use hours. The detail is presented in table 4-3 below.

Table 4-3: Future nodal pressure conditions in the new Initial Pipe Setting Alternative.

Network Topology Scenario: Alternative-II						
Year(E.C.)	Low pressure nodes at relatively peak water use hours			High pressure nodes at relatively low water use hours		
	Average-daily consumption	Maximum-daily consumption	Peak-hour consumption	Average-daily consumption	Maximum-daily consumption	Peak-hour consumption
2009	JK-1, All Aba Jifar Pressure zone nodes	JK-51, All Aba Jifar Pressure zone nodes	JK-51, JK-74, H-13, H-1, All Ginjo and Aba Jifar pressure zone nodes	56% of the Jiren Kela Pressure zone nodes	53% of the Jiren Kela Pressure zone nodes	40% of the Jiren Kela Pressure zone nodes
2010	JK-1, All Aba Jifar Pressure zone nodes	JK-51, All Aba Jifar Pressure zone nodes	JK-51, JK-74, H-13, H-1, All Ginjo and Aba Jifar pressure zone nodes	53% of the Jiren Kela Pressure zone nodes and H-19	53% of the Jiren Kela Pressure zone nodes and H-19	36% of the Jiren Kela Pressure zone nodes
2011	JK-1, All Aba Jifar Pressure zone nodes	JK-51, All Aba Jifar and Ginjo Pressure zone nodes except G-7 and G-8	JK-51, JK-74, H-13, H-1, All Ginjo and Aba Jifar pressure zone nodes except G-8	51% of the Jiren Kela Pressure zone nodes and H-19	50% of the Jiren Kela Pressure zone nodes and H-19	34% of the Jiren Kela Pressure zone nodes
2012	JK-1, G-4, All Aba Jifar Pressure zone nodes	JK-51, H-1, All Aba Jifar and Ginjo Pressure zone nodes except G-8	JK-51, JK-74, H-13, H-1, All Ginjo and Aba Jifar pressure zone nodes except G-8	53% of the Jiren Kela Pressure zone nodes and H-19	52% of the Jiren Kela Pressure zone nodes and H-19	35% of the Jiren Kela Pressure zone nodes
2013	JK-1, All Aba Jifar Pressure zone nodes	JK-51, H-13, G-4, All Aba Jifar and Ginjo Pressure zone nodes except G-8	JK-51, JK-74, H-13, H-1, All Ginjo and Aba Jifar pressure zone nodes except G-8	53% of the Jiren Kela Pressure zone nodes and H-19	48% of the Jiren Kela Pressure zone nodes and H-19	36% of the Jiren Kela Pressure zone nodes

4.2.2. Fire Flow Scenario

The capacity of the system to supply adequate amount of water for the estimated fire demand was analyzed using two alternatives by applying the estimated 2-Hour 2765 m3/day fire flow on the maximum-daily demand at periods between 9:00 PM to 11:00 PM local time.

4.2.2.1. Alternative-I: Maximum-daily demand plus fire demand at 'ALL' nodes

In this case, the capacity of the distribution system for firefighting was analyzed by applying the maximum-day demand plus the fire flow for all the nodes and the model simulated results showed as all of the nodes will receive a very large negative pressure in this fire demand assignment alternative.

4.2.2.2. Alternative-II: Maximum-daily demand plus fire demand at 'SELECTED' nodes

In this alternative, by applying the fire demand to some selected low elevation and representative nodes, the firefighting capacity of the distribution system was analyzed. Nodes JK-1, JK-4, JK-81 and G-1 was selected as nodes where fire hydrants are to be installed for tapping fire flow since these nodes showed slightly high pressure at the maximum-daily water use condition. After analyzing the system by applying 2765 m3/day fire demand plus maximum-daily demand at these nodes, the batch run result of the model showed normal pressure values at all the nodes except JK-51, after taping the estimated fire demand for the required duration.

4.2.3. Solution Scenario

4.2.3.1. Alternative-I: Physical Alternative-Adjusting the Diameter of pipe PJK-72

After the allocation of the forecasted future demands for all the design periods, the velocity in PJK-72 is shown large. Adjusting its diameter is determined to be the solution to improve the velocity through it.

4.2.3.2. Alternative-II: Scenario Combination:

Analyzing the distribution system with a combination of different scenarios and their alternatives gives different pressure and pipe velocity results.

Scenario combination-I: The distribution system under Network Topology Scenario-Alternative-I and Fire Flow Scenario-Alternative-II gives a negative pressure values for all the nodes and large velocity through pipe PJK-72. After some trials, modifying the diameter of PJK-72 to 250mm was determined to solve the pressure deficit problems of all the nodes except JK-51, JK-78, H-13, G-2, G-3 and G-4. But replacing The Fire Flow Scenario-Alternative-II by alternative-I gives a normal pressure value result at none of the nodes.

Scenario combination-II: The distribution system under Network Topology Scenario-Alternative-II and Fire Flow Scenario-Alternative-II gives a normal pressure values for all the nodes except JK-51, G-2, G-3 and G-4 even before the adjustment of the diameter of PJK-72, but with a large velocity value through pipe PJK-72. After setting the diameter of PJK-72 to 250mm, both the velocity through PJK-72 and pressure at JK-51 are modelled having normal values. On the contrast, using Fire Flow Scenario-Alternative-I gives negative values for all the nodes except JK-1 and JK-81 even after modifying the diameter of PJK-72 even though the velocity through PJK-72 becomes normal.

5. Conclusions and Recommendations

5.1. Conclusions

The absence of water in Gebrel tank might be closed main; because the model showed as Gebrel Tank and the vicinity is receiving normal pressure at a relative-low water use hours both in the current condition and in the future scenarios under the current Active network Topology.

Node JK-51 and the vicinity will never receive an adequate pressure during day time under the maximum-daily water use condition and will never get water 12:00 AM to 7:00 PM local time during peak-hour consumption condition throughout the design years under the current network topology due to the allocation of large demand at node JK-51.

On contrast to Network Topology Scenario-Alternative-I, all nodes in Aba Jifar Pressure Zone will receive low pressure from 12:00 AM to 7:00 PM local time whilst most of the nodes in Jiren Kela Pressure Zone becomes over pressurized, under Network Topology-Alternative-II.

The model simulated a decreasing pressure profile from the old treatment plant to Gebrel Storage Tank in all the water use conditions and Network Topology Scenario-Alternative-I. It implies that the Old Treatment Plant pumps alone are unable to impart the required energy as a result of very high elevation and long distance of this service area from the pumping station. On the contrary, the reason to very high pressure at nodes JK-1, JK-81and the vicinity at a relative-low water use hours is being low elevation nodes and being nearest to the pumping stations.

The current trend to control the flow in all the pressure zones is to manually operate gate valves at the tanks till the tank operator at the opposite end call back to tell the filling of his tank. Often the water is released from Jiren kela Storage Tanks to Ginjo and Hospital Tanks without informing the operators of these Tanks. Large volume of water will continue to over flow if the operation control techniques continue in this way. In the analysis of the distribution system for the design years 2009 E.C. to 2013 E.C., the model showed as the pressure deficit is due to operational control problem; because the water pumped from the new treatment plant is allowed to fill both of the tanks; Jiren Kela Tank 1 and Jiren Kela tank 2 at the same time. As a result, if PJK-1, PJK-2 and PJK-3 are set to open, since the tanks have a slight elevation difference, the water tends to flow in to Jeren Kela Tank 1 and then to Jiren Kela pressure zone when Ginjo and Hospital Tanks remained empty. Therefore, it is reasonable to conclude that future water shortage in Hospital, Ginjo and Aba Jifar pressure zones will likely to occur not because of the supply, but the operation. Moreover, during this study, it was observed that Hospital Tank is flowing over while Ginjo Pressure zone is facing water shotage. This implies that the water shortage problems at Hospital and Ginjo pressure zones are lack of proper management of the distribution system.

5.2. Recommendations

If the current network topology has to be used, the long last solution to solve the pressure deficit problems in Saris/Sar Sefer/ district is to establish a new pressure zone which includes service areas above The Four Lions with a booster pump station at somewhere around 'Variety'. But it is preferable to check the status of pipe PJK-80 for the time being.

Moreover, the gravity main from Jeren kela Tank 2 to these pressure zones show a large velocity, large head loss and increasing pressure profile, so a Pressure Break Tank has to be installed and re-boosted so as to have normal pressure at the downstream ends.

If the second network topology is implemented, using optimized operational controls can solve all the problems without a need to boost the water to Saris district. For areas facing high pressure even at average water use condition, it is better to either install a pressure reducing valve (PRV) on the new gravity main from Jiren Kela Tank 2 to Jiren Kela pressure zone or zoning the high pressure area so as to manage the pressure of the area properly. To solve low pressure problem in Ginjo and Aba Jifar pressure zones, it is must to schedule and control the water in Jiren Kela Tank 1 and 2. Using the combination of Solution Scenario-Alternative-I, Network Topology Scenario-Alternative-II and Fire Flow Scenario-Alternative-II gives a better way for a healthy operation of Jimma Town Water Distribution System. But undertaking optimized pump scheduling will be the best measure to enhance the operation and management works of JWSSE to have a reliable system so as to serve the community efficiently and effectively.

Concerning the firefighting capacity of the distribution system, the current trend is that, the town Municipality is using non-functional wells of JWSSE free of charge. JWSSE has to include the gravity main from Jiren Kela 1 to Jiren Kela Pressure zone (combination of PJK-1, PJK-2 and PJK-3) in the Active Network Topology if it is must to have a system capable of supplying water to extinguish fire hazards and other emergency conditions arising in the town. So JWSSE and the Municipality or the Fire Department(if any) have to cooperate either to install new fire hydrants at low elevation and relatively high-pressure nodes located at accessible locations for fire trucks, or repairing the existing fire hydrants to assure the firefighting capacity of the distribution system. Nodes JK-1, JK-2, JK-31 and G-1 are identified as nodes which are suitable location for taping the estimated 2-hour fire demand without affecting the pressure and flow conditions at other parts of the distribution system.

A detailed modelling is required on the distribution system for better analysis of the real problems of the distribution system including the water quality aspect, so as to formulate the corresponding real solutions. To do that, JWSSE has to improve its data storage and data management system. This research could have been done in a better way if the SCADA system installed for JWSSE was functional. So the utility has to train its personnel about the data collection, storage and management using the SCADA System.

JWSSE has to take a care for disputes not to arise as a result of water distribution and allocation for the newly expanding districts, by assuring a reliable source of supply for the future beyond the design periods specified on this study. Moreover, the utility should have a habit to cooperate with those researchers who want to undertake a research on the water distribution system through whatever it can; otherwise it will face a big challenge to administrate the distribution system under the increasing water-demand future!

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7. Glossary

Alternatives	Are categorized field sets which create a scenario when placed together
Clear Well	Storage tank at raw water treatment plants which is used to store clean water from where the potable water is pumped to distribution systems
Fire Flow/Fire demand	Water required to distinguish fire hazards arising in an area
Network Topology	It is the structural connectivity of the network elements
Pressure Zone	Region or Sub-part of a water distribution system where different service areas in it are managed with a similar pressure condition
SCADA System	It is a water distribution network satellite technology used to record and manage data in a distribution system and make an integrated communication between the service storage tanks and the treatment plant clear well and other components
Scenario	Is a collection of Alternatives and other calculation options
Skeletonization	Is a technique of simplifying the complexity of the water supply network by excluding less relevant or non-critical nodes and links for the modelling
WDNs resilience	A way of quickly recovering after some topological changes or structural deformation

8. Appendix

Appendix-I: Nodal demand allocation for the current average-daily, maximum-daily and peak-hour condition

S.No	Kebele	No. of Nodes	Node Label	Nodal Demand (m3/day/node)					Total dd(m3/day		
				Average Condition			Maximum day Condition	Peak-Hour Condition	Average	max-day	Peak-hr
				Residential	Non-residential	Total					
1	Hermata	8	JK-35, JK-36, JK-43, JK-44, JK-45, JK-46, JK-47, JK-48	101	5	106	122	170	848	975	1357
2	Hermata Mentina	3	JK-38, JK-39, JK-40	217	11	228	262	365	684	787	1094
3	Hermata Merkato	13	JK-12, JK-13, JK-14, JK-15, JK-24, JK-26, JK-27, JK-28, JK-29, JK-30, JK-31, JK-32, JK-37	56	19	75	86	87	975	1121	1560
4	Bosa Kito	14	JK-60, JK-62, JK-63, JK-64, JK-66, JK-67, JK-68, JK-69, JK-70, JK-71, JK-72, JK-73, JK-74, JK-80	72	4	76	87	122	1064	1224	1702

5	Bosa Addis Ketema	13	JK-54 JK-57 JK-34 JK-59 JK-50 JK-55 JK-65 JK-58 JK-53 JK-56 JK-49 JK-52 JK-61	43	17	60	69	96	780	897	1248
6	Mentina	5	JK-41 JK-42 JK-75 JK-76 JK-77	116	2	118	136	189	590	679	944
7	Aweytu Mendera	2	JK-33 H-21	362	34	396	455	634	792	911	1267
8	Mendera Kochie	14	G-1 H-10 H-11 H-12 H-15 H-16 H-17 H-22 H-3 H-4 H-6 H-7 H-8 H-9	57	11	68	78	109	952	1095	1523
9	Ginjo Guduru	9	JK-10 JK-11 JK-16 JK-17 JK-18 JK-19 JK-5 JK-7 JK-79	53	18	71	82	114	639	735	1022

10	Ginjo	16	AJ-5 AJ-6 G-2 G-3 G-4 G-5 G-6 G-7 G-8 H-1 H-21 H-5 JK-6 JK-78 JK-8 JK-9	36	26	62	71	99	992	1141	1587
11	Becho Bore	10	JK-2 JK-4 JK-21 JK-20 JK-23 JK-25 JK-33 JK-22 JK-1 JK-81	418	67	485	558	776	4850	5578	7760
12	Seto Semero	6	H-13 H-14 H-18 H-19 H-20 JK-51	188	79	267	307	427	1602	1842	2563
13	Jiren	4	AJ-1 AJ-2 AJ-3 AJ-4	78	40	118	136	189	472	543	755
Total		117				2130	2449.5	3375	15240	17526	24384

Appendix-II: Simulated pressures at the demand nodes in different water use conditions

FlexTable: Junction																								
	Average Day Condition								Maximum Day Condition								Peak-Hour Condition							
	Current Time								Current Time								Current Time							
	12:00 AM		6:00 AM		12:00 PM		6:00 PM		12:00 AM		6:00 AM		12:00 PM		6:00 PM		12:00 AM		6:00 AM		12:00 PM		6:00 PM	
Label	dd (m^3/h)	P (kPa)	dd (m^3/h)	P (kPa)	dd (m^3/h)	P (kPa)	dd (m^3/h)	P (kPa)	dd (m^3/h)	P (kPa)	dd (m^3/h)	P (kPa)	dd (m^3/h)	P (kPa)	dd (m^3/h)	P (kPa)	dd (m^3/h)	P (kPa)	dd (m^3/h)	P (kPa)	dd (m^3/h)	P (kPa)	dd (m^3/h)	P (kPa)
AJ-1	5	582	4	613	4	636	1	612	6	580	5	610	5	633	2	619	8	572	7	587	6	603	2	616
AJ-2	5	717	4	750	4	773	1	751	6	714	5	746	5	770	2	758	8	703	7	720	6	737	2	754
AJ-3	5	580	4	611	4	634	1	610	6	577	5	608	5	632	2	617	8	569	7	585	6	601	2	614
AJ-4	5	667	4	699	4	722	1	699	6	665	5	696	5	719	2	706	8	655	7	671	6	688	2	703
AJ-5	3	374	2	374	2	374	1	375	3	373	3	374	2	374	1	375	4	371	4	372	3	373	1	375
AJ-6	3	639	2	639	2	640	1	641	3	638	3	638	2	639	1	641	4	634	4	635	3	637	1	641
G-1	3	668	3	683	2	710	1	709	3	668	3	712	3	708	1	703	5	667	4	687	4	713	1	670
G-2	3	160	2	174	2	202	1	200	3	160	3	203	2	199	1	194	4	159	4	179	3	205	1	161
G-3	3	159	2	174	2	201	1	199	3	159	3	203	2	199	1	193	4	159	4	179	3	204	1	161
G-4	0	59	0	191	0	201	0	205	0	59	0	204	0	204	0	202	0	59	0	186	0	213	0	180
G-5	5	166	5	180	4	208	2	207	6	166	5	209	5	205	2	200	8	165	7	184	7	210	2	167
G-6	3	219	2	234	2	261	1	261	3	219	3	262	2	258	1	254	4	218	4	234	3	261	1	221
G-7	3	421	2	436	2	463	1	464	3	420	3	464	2	460	1	457	4	418	4	435	3	462	1	424
G-8	3	363	2	379	2	407	1	466	3	359	3	384	2	390	1	421	4	342	4	219	3	302	1	384
H-1	3	318	2	332	2	360	1	358	3	318	3	361	2	357	1	352	4	317	4	337	3	362	1	319
H-2	3	182	2	182	2	187	1	204	3	182	3	138	2	169	1	186	4	179	4	-381	3	-153	1	182
H-3	3	205	3	205	2	210	1	230	3	204	3	161	3	191	1	210	5	199	4	-358	4	-130	1	205
H-4	3	310	3	310	2	316	1	343	3	309	3	265	3	296	1	318	5	303	4	-252	4	-25	1	311
H-5	3	342	2	342	2	347	1	366	3	341	3	297	2	328	1	347	4	337	4	-221	3	7	1	342
H-6	3	365	3	366	2	374	1	423	3	364	3	321	3	352	1	382	5	354	4	-195	4	31	1	370
H-7	3	377	3	380	2	389	1	455	3	376	3	335	3	365	1	401	5	363	4	-181	4	46	1	387
H-8	3	364	3	366	2	375	1	431	3	363	3	321	3	352	1	385	5	351	4	-196	4	31	1	372
H-9	3	394	3	396	2	404	1	461	3	393	3	351	3	382	1	415	5	380	4	-167	4	61	1	402
H-10	3	175	3	176	2	182	1	217	3	174	3	131	3	162	1	187	5	163	4	-387	4	-160	1	178
H-11	3	285	3	285	2	290	1	317	3	284	3	241	3	271	1	293	5	275	4	-278	4	-50	1	286
H-12	3	265	3	266	2	272	1	300	3	264	3	221	3	252	1	274	5	254	4	-298	4	-70	1	267
H-13	11	184	10	187	9	193	3	225	13	181	12	140	10	172	4	199	18	162	16	-384	14	-154	5	191
H-14	11	339	10	341	9	348	3	390	13	336	12	296	10	327	4	355	18	317	16	-225	14	4	5	345
H-15	3	297	3	298	2	305	1	344	3	295	3	253	3	284	1	311	5	280	4	-266	4	-38	1	301
H-16	3	346	3	347	2	353	1	392	3	344	3	302	3	333	1	359	5	331	4	-217	4	11	1	349
H-17	3	268	3	274	2	288	1	401	3	265	3	228	3	257	1	313	5	247	4	-284	4	-59	1	288
H-18	11	353	10	359	9	373	3	486	13	349	12	312	10	343	4	400	18	326	16	-207	14	21	5	376
H-19	11	464	10	470	9	484	3	597	13	460	12	422	10	454	4	512	18	436	16	-97	14	131	5	487
H-20	11	315	10	324	9	342	3	465	13	306	12	273	10	308	4	379	18	262	16	-263	14	-28	5	352
H-21	25	440	22	450	20	472	7	632	28	436	26	406	23	432	9	504	40	413	36	-93	32	126	12	470
H-22	3	347	3	353	2	367	1	479	3	345	3	307	3	336	1	391	5	328	4	-203	4	21	1	366
JK-1	16	754	15	768	13	793	5	961	19	746	17	728	15	752	6	838	26	710	23	301	21	489	8	800
JK-2	16	684	15	700	13	726	5	909	19	677	17	656	15	681	6	773	26	640	23	192	21	397	8	732
JK-3	16	585	15	601	13	627	5	810	19	578	17	557	15	582	6	674	26	541	23	93	21	298	8	633
JK-4	16	547	15	562	13	588	5	774	19	539	17	518	15	543	6	635	26	503	23	47	21	254	8	594
JK-5	2	445	2	461	2	487	1	673	3	438	2	417	2	442	1	534	4	402	3	-55	3	153	1	492
JK-6	2	363	2	379	2	405	1	591	2	356	2	335	2	360	1	452	3	320	3	-137	3	71	1	411
JK-7	2	385	2	400	2	426	1	613	3	378	2	356	2	381	1	473	4	341	3	-116	3	91	1	431
JK-8	2	400	2	415	2	442	1	628	2	393	2	371	2	396	1	488	3	357	3	-102	3	106	1	447
JK-9	2	379	2	394	2	421	1	607	2	372	2	350	2	375	1	467	3	336	3	-124	3	85	1	425
JK-10	2	314	2	329	2	355	1	542	3	308	2	285	2	310	1	398	4	274	3	-195	3	16	1	357
JK-11	2	357	2	372	2	398	1	585	3	351	2	328	2	352	1	441	4	317	3	-152	3	59	1	400
JK-12	3	468	2	483	2	510	1	696	3	461	3	439	2	464	1	555	4	425	4	-36	3	173	1	514
JK-13	3	476	2	491	2	517	1	705	3	470	3	447	2	472	1	561	4	436	4	-32	3	179	1	520
JK-14	3	532	2	547	2	573	1	761	3	526	3	503	2	528	1	617	4	492	4	25	3	235	1	576
JK-15	3	543	2	558	2	585	1	772	3	537	3	514	2	539	1	629	4	502	4	37	3	247	1	588
JK-16	2	540	2	555	2	582	1	769	3	534	2	511	2	536	1	627	4	499	3	36	3	245	1	586
JK-17	2	391	2	406	2	433	1	620	3	385	2	362	2	388	1	479	4	349	3	-111	3	97	1	437
JK-18	2	366	2	381	2	408	1	594	3	359	2	337	2	362	1	454	4	323	3	-136	3	72	1	412
JK-19	2	506	2	521	2	548	1	734	3	499	2	477	2	503	1	595	4	463	3	6	3	214	1	553
JK-20	16	599	15	614	13	641	5	826	19	591	17	570	15	595	6	689	26	554	23	101	21	307	8	647

JK-21	16	633	15	648	13	675	5	861	19	625	17	604	15	630	6	723	26	588	23	133	21	341	8	681
JK-22	16	702	15	719	13	748	5	940	19	691	17	672	15	700	6	801	26	642	23	192	21	403	8	758
JK-23	16	635	15	653	13	682	5	875	19	624	17	606	15	634	6	736	26	573	23	123	21	335	8	693
JK-24	3	567	2	585	2	614	1	807	3	556	3	537	2	565	1	668	4	504	4	54	3	267	1	625
JK-25	16	644	15	659	13	686	5	873	19	636	17	615	15	640	6	734	26	599	23	143	21	351	8	692
JK-26	3	563	2	579	2	605	1	792	3	556	3	534	2	560	1	653	4	519	4	61	3	270	1	611
JK-27	3	685	2	700	2	727	1	914	3	678	3	656	2	682	1	774	4	641	4	183	3	391	1	733
JK-28	3	543	2	558	2	585	1	772	3	537	3	514	2	539	1	629	4	502	4	37	3	247	1	588
JK-29	3	627	2	641	2	668	1	856	3	621	3	597	2	622	1	711	4	588	4	116	3	328	1	669
JK-30	3	552	2	566	2	593	1	780	3	546	3	522	2	547	1	636	4	512	4	42	3	253	1	594
JK-31	3	614	2	628	2	654	1	841	3	609	3	584	2	609	1	695	4	577	4	101	3	313	1	654
JK-32	3	540	2	554	2	581	1	768	3	534	3	510	2	535	1	624	4	500	4	31	3	242	1	583
JK-33	20	571	18	584	16	610	6	796	23	567	21	541	18	565	7	645	32	538	29	52	25	267	10	605
JK-34	2	542	2	556	2	581	1	769	2	539	2	512	2	536	1	616	3	510	3	24	3	238	1	575
JK-35	4	504	3	518	3	544	1	733	4	501	4	475	3	498	1	580	6	471	5	-14	5	201	2	539
JK-36	4	476	3	491	3	517	1	707	4	471	4	447	3	471	1	559	6	439	5	-38	5	175	2	517
JK-37	3	588	2	603	2	629	1	818	3	583	3	559	2	584	1	672	4	550	4	77	3	289	1	630
JK-38	8	506	7	520	6	547	2	737	9	501	8	476	7	501	3	590	12	467	11	-10	10	204	4	548
JK-39	8	376	7	391	6	418	2	608	9	371	8	347	7	371	3	460	12	337	11	-140	10	74	4	418
JK-40	8	613	7	627	6	654	2	845	9	607	8	583	7	607	3	697	12	573	11	95	10	309	4	654
JK-41	4	406	4	420	3	447	1	638	5	401	4	376	4	400	1	489	6	367	6	-113	5	102	2	447
JK-42	4	380	4	394	3	421	1	612	5	375	4	350	4	374	1	463	6	341	6	-138	5	76	2	421
JK-43	4	388	3	402	3	428	1	620	4	383	4	358	3	382	1	471	6	350	5	-130	5	84	2	428
JK-44	4	386	3	401	3	427	1	619	4	382	4	357	3	381	1	469	6	349	5	-132	5	83	2	427
JK-45	4	465	3	479	3	506	1	698	4	461	4	435	3	459	1	548	6	427	5	-54	5	161	2	505
JK-46	4	319	3	333	3	359	1	548	4	315	4	289	3	313	1	394	6	285	5	-200	5	15	2	353
JK-47	4	324	3	337	3	363	1	553	4	320	4	294	3	317	1	399	6	290	5	-195	5	20	2	358
JK-48	4	493	3	506	3	532	1	721	4	489	4	463	3	486	1	567	6	460	5	-26	5	189	2	526
JK-49	2	421	2	434	2	460	1	648	2	418	2	391	2	414	1	493	3	389	3	-98	3	117	1	452
JK-50	2	434	2	447	2	473	1	661	2	431	2	404	2	427	1	506	3	402	3	-85	3	130	1	465
JK-51	9	80	8	101	7	133	3	343	10	65	9	48	8	79	3	187	14	-7	13	-477	12	-247	4	141
JK-52	2	401	2	414	2	440	1	629	2	399	2	372	2	394	1	466	3	374	3	-117	3	98	1	426
JK-53	2	239	2	252	2	278	1	467	2	237	2	210	2	232	1	301	3	214	3	-279	3	-64	1	261
JK-54	2	240	2	253	2	279	1	468	2	238	2	211	2	232	1	302	3	214	3	-278	3	-63	1	261
JK-55	2	205	2	218	2	243	1	433	2	203	2	176	2	197	1	263	3	183	3	-313	3	-98	1	222
JK-56	2	197	2	210	2	235	1	426	2	196	2	169	2	188	1	244	3	184	3	-321	3	-106	1	203
JK-57	2	390	2	404	2	430	1	620	2	387	2	361	2	383	1	461	3	356	3	-130	3	85	1	419
JK-58	2	320	2	334	2	360	1	551	2	317	2	291	2	313	1	392	3	286	3	-200	3	16	1	350
JK-59	2	314	2	327	2	353	1	543	2	310	2	284	2	307	1	385	3	280	3	-207	3	9	1	344
JK-60	3	292	2	306	2	332	1	521	3	289	3	263	2	286	1	365	4	259	4	-228	3	-12	1	324
JK-61	2	407	2	421	2	447	1	636	2	404	2	378	2	401	1	480	3	374	3	-112	3	103	1	439
JK-62	3	297	2	311	2	337	1	526	3	294	3	268	2	291	1	370	4	264	4	-223	3	-7	1	329
JK-63	3	326	2	339	2	366	1	556	3	322	3	296	2	319	1	399	4	290	4	-195	3	21	1	357
JK-64	3	313	2	327	2	353	1	544	3	309	3	284	2	306	1	386	4	278	4	-208	3	8	1	344
JK-65	2	316	2	330	2	356	1	547	2	313	2	287	2	310	1	389	3	281	3	-205	3	11	1	347
JK-66	3	391	2	404	2	431	1	621	3	387	3	361	2	384	1	463	4	355	4	-130	3	86	1	421
JK-67	3	436	2	450	2	476	1	667	3	432	3	407	2	429	1	509	4	401	4	-85	3	131	1	467
JK-68	3	463	2	477	2	503	1	694	3	459	3	433	2	456	1	537	4	427	4	-58	3	158	1	495
JK-69	3	410	2	424	2	450	1	641	3	406	3	381	2	403	1	483	4	375	4	-111	3	105	1	441
JK-70	3	468	2	481	2	508	1	698	3	464	3	438	2	461	1	541	4	432	4	-54	3	162	1	499
JK-71	3	509	2	523	2	550	1	742	3	504	3	479	2	503	1	592	4	471	4	-11	3	205	1	549
JK-72	3	615	2	630	2	657	1	850	3	610	3	585	2	610	1	700	4	574	4	93	3	309	1	657
JK-73	3	615	2	629	2	656	1	848	3	610	3	585	2	609	1	698	4	577	4	95	3	311	1	655
JK-74	3	522	2	536	2	563	1	755	3	517	3	492	2	516	1	605	4	483	4	2	3	217	1	562
JK-75	4	621	4	636	3	662	1	854	5	616	4	591	4	616	1	705	6	582	6	103	5	318	2	662
JK-76	4	476	4	490	3	517	1	709	5	471	4	446	4	470	1	559	6	437	6	-43	5	172	2	517
JK-77	4	498	4	513	3	540	1	734	5	492	4	468	4	493	1	585	6	454	6	-24	5	192	2	542
JK-78	2	145	2	160	2	187	1	370	2	138	2	117	2	142	1	234	3	101	3	-345	3	-141	1	193
JK-79	2	420	2	435	2	461	1	647	3	412	2	391	2	416	1	508	4	376	3	-81	3	127	1	466
JK-80	3	589	2	603	2	630	1	822	3	584	3	559	2	583	1	671	4	551	4	69	3	284	1	629
JK-81	16	752	15	767	13	791	5	960	19	745	17	726	15	750	6	836	26	708	23	299	21	487	8	798

Appendix-III: Simulated pipe flows and velocities at different water use conditions

FlexTable: Pipe																								
	Average Condition								Maximum-Day Condition								Peak-Hour Condition							
	Current Time								Current Time								Current Time							
	12:00 AM		6:00 AM		12:00 PM		6:00 PM		12:00 AM		6:00 AM		12:00 PM		6:00 PM		12:00 AM		6:00 AM		12:00 PM		6:00 PM	
Label	Q(m³/h)	V(m/s)	Q(m³/h)	V(m/s)	Q(m³/h)	V(m/s)	Q(m³/h)	V(m/s)	Q(m³/h)	V(m/s)	Q(m³/h)	V(m/s)	Q(m³/h)	V(m/s)	Q(m³/h)	V(m/s)	Q(m³/h)	V(m/s)	Q(m³/h)	V(m/s)	Q(m³/h)	V(m/s)	Q(m³/h)	V(m/s)
Aba Jifar Pr	45	0.70	42	0.67	43	0.68	0	0.00	45	0.70	46	0.72	43	0.68	0	0.00	45	0.70	45	0.71	46	0.73	40	0.64
Gravity Ma	3,171	4.49	2,963	4.19	2,787	3.94	2,843	4.02	3,171	4.49	2,796	3.95	2,839	4.02	2,872	4.06	3,171	4.49	2,857	4.04	2,870	4.06	2,977	4.21
Gravity Ma	1,681	4.85	0	0.00	0	0.00	0	0.00	1,681	4.85	0	0.00	0	0.00	0	0.00	1,681	4.85	0	0.00	0	0.00	0	0.00
JK_transitio	-1,409	1.99	-8,406	11.89	6,079	8.60	762	1.08	-1,409	1.99	5,870	8.30	-6,418	9.08	-5,482	7.76	-1,409	1.99	4,712	6.67	0	0.00	0	0.00
New TP CW	484	0.48	479	0.47	462	0.45	466	0.46	484	0.48	461	0.45	482	0.47	475	0.47	484	0.48	464	0.46	0	0.00	0	0.00
Old TP CW	465	1.03	457	1.01	442	0.98	327	0.72	469	1.04	479	1.06	466	1.03	415	0.92	488	1.08	667	1.47	592	1.31	438	0.97
PAJ-1	25	0.39	22	0.35	20	0.31	7	0.12	29	0.45	26	0.40	23	0.36	9	0.13	40	0.62	36	0.56	32	0.50	12	0.19
PAJ-2	5	0.27	4	0.24	4	0.22	1	0.08	6	0.31	5	0.28	5	0.25	2	0.09	8	0.43	7	0.39	6	0.35	2	0.13
PAJ-3	15	0.24	13	0.21	12	0.19	5	0.07	17	0.27	16	0.24	14	0.22	5	0.08	24	0.38	22	0.34	19	0.30	7	0.11
PAJ-4	5	0.27	4	0.24	4	0.22	1	0.08	6	0.31	5	0.28	5	0.25	2	0.09	8	0.43	7	0.39	6	0.35	2	0.13
PAJ-5	5	0.18	5	0.16	4	0.15	2	0.05	6	0.21	5	0.19	5	0.17	2	0.06	8	0.29	7	0.26	7	0.23	2	0.09
PAJ-6	5	0.18	5	0.16	4	0.15	2	0.05	6	0.21	5	0.19	5	0.17	2	0.06	8	0.29	7	0.26	7	0.23	2	0.09
PAJ-7	5	0.18	5	0.16	4	0.15	2	0.05	6	0.21	5	0.19	5	0.17	2	0.06	8	0.29	7	0.26	7	0.23	2	0.09
PAJ-8	5	0.18	5	0.16	4	0.15	2	0.05	6	0.21	5	0.19	5	0.17	2	0.06	8	0.29	7	0.26	7	0.23	2	0.09
PAJ-9	3	0.14	2	0.13	2	0.11	1	0.04	3	0.16	3	0.15	2	0.13	1	0.05	4	0.23	4	0.21	3	0.18	1	0.07
PG-1	3	0.04	3	0.04	2	0.04	1	0.01	3	0.05	3	0.05	3	0.04	1	0.02	5	0.07	4	0.06	4	0.06	1	0.02
PG-2	5	0.05	5	0.04	4	0.04	2	0.01	6	0.06	6	0.05	5	0.04	2	0.02	9	0.08	8	0.07	7	0.06	3	0.02
PG-3	8	0.07	7	0.06	6	0.06	2	0.02	9	0.08	8	0.07	7	0.07	3	0.02	13	0.11	12	0.10	10	0.09	4	0.03
PG-4	11	0.09	10	0.08	8	0.07	3	0.03	12	0.11	11	0.10	10	0.09	4	0.03	17	0.15	15	0.13	14	0.12	5	0.04
PG-5	1,490	5.86	2,963	11.64	2,787	10.95	2,843	11.17	1,490	5.86	2,796	10.99	2,839	11.16	2,872	11.29	1,490	5.86	2,857	11.23	2,870	11.28	2,977	11.70
PG-6	56	0.31	54	0.31	53	0.30	37	0.21	58	0.33	59	0.34	57	0.32	45	0.25	65	0.37	82	0.46	74	0.42	47	0.26
PG-7	50	0.45	50	0.44	49	0.43	35	0.31	52	0.46	54	0.48	52	0.46	43	0.38	57	0.50	75	0.66	67	0.59	44	0.39
PG-8	3	0.14	2	0.13	2	0.11	1	0.04	3	0.16	3	0.15	2	0.13	1	0.05	4	0.23	4	0.21	3	0.18	1	0.07
PG-9	45	1.60	45	1.59	45	1.58	34	1.19	46	1.62	49	1.72	47	1.67	41	1.46	48	1.71	67	2.38	60	2.13	42	1.48
PG-10	43	2.35	43	2.35	43	2.36	33	1.81	43	2.37	46	2.54	45	2.47	40	2.23	44	2.45	64	3.51	57	3.15	41	2.24
PH-1	3	0.05	-2	0.03	-7	0.11	-32	0.51	6	0.10	0	0.00	0	0.00	-18	0.28	21	0.33	0	0.00	0	0.00	-11	0.17
PH-2	24	0.14	9	0.05	-10	0.06	-94	0.53	35	0.20	16	0.09	14	0.08	-50	0.28	78	0.44	22	0.13	20	0.11	-28	0.16
PH-3	1	0.07	2	0.09	2	0.14	6	0.35	1	0.08	2	0.08	1	0.08	4	0.21	-1	0.03	2	0.12	2	0.10	3	0.15
PH-4	-10	0.09	-24	0.21	-39	0.34	-115	1.02	-1	0.01	-21	0.19	-19	0.17	-67	0.59	49	0.43	-30	0.26	-26	0.23	-47	0.41
PH-5	-8	0.03	-21	0.08	-36	0.14	-114	0.45	2	0.01	-19	0.07	-17	0.06	-66	0.26	53	0.21	-26	0.10	-23	0.09	-45	0.18
PH-6	16	0.06	-9	0.03	-37	0.15	-175	0.69	33	0.13	0	0.00	0	0.00	-97	0.38	114	0.45	0	0.00	0	0.00	-60	0.24
PH-7	-14	0.13	-28	0.25	-43	0.38	-122	1.08	-6	0.05	-26	0.23	-23	0.20	-72	0.63	45	0.40	-36	0.32	-32	0.28	-51	0.45
PH-8	-19	0.16	-31	0.28	-45	0.40	-118	1.05	-11	0.10	-30	0.26	-27	0.23	-70	0.62	37	0.33	-42	0.37	-37	0.33	-51	0.45
PH-9	6	0.23	8	0.28	10	0.37	22	0.76	7	0.24	8	0.29	7	0.26	13	0.48	6	0.22	11	0.40	10	0.36	11	0.38
PH-10	3	0.10	3	0.09	2	0.08	1	0.03	3	0.12	3	0.10	3	0.09	1	0.03	5	0.16	4	0.14	4	0.13	1	0.05
PH-11	1	0.08	1	0.05	0	0.00	-5	0.27	2	0.11	1	0.07	1	0.06	-3	0.14	3	0.18	2	0.09	2	0.08	-1	0.07
PH-12	2	0.08	4	0.13	6	0.21	15	0.53	2	0.08	3	0.12	3	0.11	9	0.32	0	0.01	5	0.17	4	0.15	7	0.23
PH-13	6	0.05	-6	0.05	-17	0.15	-73	0.65	12	0.11	-2	0.01	-1	0.01	-41	0.36	41	0.36	-2	0.02	-2	0.02	-26	0.23
PH-15	23	0.13	8	0.04	-10	0.05	-88	0.50	33	0.19	15	0.08	13	0.07	-47	0.27	73	0.41	20	0.11	18	0.10	-26	0.15
PH-16	14	0.12	11	0.10	6	0.05	-16	0.14	17	0.15	13	0.12	12	0.10	-7	0.06	28	0.24	18	0.16	16	0.14	-1	0.01
PH-17	3	0.11	1	0.05	-2	0.08	-13	0.47	4	0.15	2	0.08	2	0.07	-8	0.27	9	0.32	3	0.11	3	0.10	-5	0.17
PH-18	8	0.28	7	0.24	6	0.20	-4	0.13	9	0.33	8	0.28	7	0.25	0	0.01	14	0.50	11	0.39	10	0.35	2	0.09
PH-19	-3	0.18	-3	0.18	-3	0.18	-7	0.38	-3	0.18	-4	0.20	-3	0.17	-4	0.22	-4	0.20	-5	0.27	-4	0.24	-3	0.16
PH-20	13	0.21	9	0.14	4	0.06	-15	0.23	17	0.27	11	0.18	10	0.16	-7	0.11	27	0.42	16	0.25	14	0.22	-2	0.04
PH-21	13	0.21	10	0.15	8	0.13	0	0.01	16	0.25	12	0.19	11	0.17	2	0.03	22	0.35	17	0.26	15	0.23	4	0.06
PH-22	6	0.05	-4	0.04	-14	0.12	-59	0.52	11	0.10	-1	0.01	-1	0.01	-33	0.29	36	0.32	-1	0.01	-1	0.01	-21	0.19
PH-23	10	0.36	17	0.59	24	0.86	59	2.10	8	0.28	16	0.56	14	0.50	36	1.27	-9	0.34	22	0.78	20	0.69	27	0.94
PH-24	34	0.30	35	0.31	35	0.31	35	0.31	37	0.33	38	0.34	34	0.30	26	0.23	48	0.42	53	0.47	47	0.42	27	0.23
PH-25	-1	0.06	-5	0.26	-9	0.47	-25	1.38	1	0.06	-4	0.21	-3	0.19	-15	0.82	5	0.30	-5	0.29	-5	0.26	-11	0.58
PH-26	22	0.20	20	0.18	18	0.16	7	0.06	26	0.23	23	0.20	20	0.18	8	0.07	36	0.31	32	0.28	28	0.25	11	0.09
PH-27	11	0.61	10	0.55	9	0.49	3	0.18	13	0.71	12	0.64	10	0.57	4	0.21	18	0.98	16	0.89	14	0.79	5	0.30
PH-28	32	0.28	39	0.34	47	0.42	90	0.80	30	0.27	40	0.35	36	0.31	57	0.50	18	0.16	56	0.49	49	0.44	45	0.40
PH-29	47	0.41	60	0.53	75	0.66	147	1.30	43	0.38	61	0.54	54	0.48	92	0.81	3	0.03	85	0.75	75	0.67	73	0.65
PH-30	16	0.14	15	0.13	14	0.13	5	0.04	18	0.16	17	0.15	15	0.13	6	0.06	25	0.22	24	0.21	21	0.19	9	0.08
PH-31	-28	0.25	-42	0.37	-58	0.51	-141	1.24	-21	0.19	-41	0.36	-36	0.32	-85	0.75	26	0.23	-57	0.50	-51	0.45	-63	0.55
PJK-1	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

PJK-2	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
PJK-3	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
PJK-4	-29	0.16	-29	0.17	-30	0.17	-23	0.13	-29	0.17	-32	0.18	-31	0.18	-28	0.16	-30	0.17	-44	0.25	-39	0.22	-28	0.16
PJK-5	13	0.03	15	0.03	17	0.04	18	0.04	11	0.02	15	0.03	16	0.04	22	0.05	4	0.01	21	0.05	19	0.04	20	0.04
PJK-6	212	0.47	213	0.47	211	0.47	172	0.38	207	0.46	219	0.49	218	0.48	219	0.48	197	0.43	305	0.67	271	0.60	224	0.50
PJK-7	54	0.21	55	0.21	54	0.21	45	0.18	53	0.21	56	0.22	56	0.22	57	0.22	49	0.19	78	0.31	69	0.27	58	0.23
PJK-8	2	0.07	2	0.07	2	0.06	1	0.02	2	0.08	2	0.08	2	0.07	1	0.03	3	0.12	3	0.11	3	0.09	1	0.04
PJK-10	54	0.21	55	0.22	55	0.22	49	0.19	51	0.20	56	0.22	56	0.22	62	0.24	43	0.17	77	0.30	69	0.27	62	0.24
PJK-11	432	0.96	427	0.94	416	0.92	317	0.70	432	0.95	445	0.98	436	0.96	404	0.89	437	0.97	620	1.37	551	1.22	423	0.93
PJK-12	-40	0.16	-41	0.16	-42	0.16	-38	0.15	-37	0.15	-42	0.16	-42	0.17	-48	0.19	-30	0.12	-58	0.23	-51	0.20	-48	0.19
PJK-13	-38	0.34	-39	0.35	-40	0.36	-37	0.33	-35	0.31	-39	0.35	-40	0.36	-48	0.42	-27	0.24	-55	0.48	-49	0.43	-47	0.42
PJK-14	0	0.00	0	0.00	1	0.01	4	0.04	-1	0.01	0	0.00	0	0.00	4	0.04	-4	0.04	0	0.00	0	0.00	3	0.03
PJK-15	4	0.24	4	0.25	5	0.25	4	0.24	4	0.21	4	0.24	5	0.25	6	0.31	3	0.15	6	0.34	5	0.30	6	0.31
PJK-16	12	0.18	12	0.18	12	0.18	10	0.16	11	0.17	12	0.19	12	0.19	13	0.20	10	0.15	17	0.26	15	0.23	13	0.20
PJK-17	217	0.48	215	0.47	209	0.46	159	0.35	217	0.48	224	0.50	220	0.49	201	0.44	219	0.48	312	0.69	277	0.61	211	0.47
PJK-18	-27	0.24	-29	0.25	-29	0.26	-28	0.25	-25	0.22	-28	0.25	-29	0.26	-36	0.32	-17	0.15	-39	0.35	-35	0.31	-35	0.31
PJK-19	142	0.31	144	0.32	144	0.32	122	0.27	136	0.30	147	0.32	147	0.33	157	0.35	122	0.27	204	0.45	181	0.40	159	0.35
PJK-20	167	0.37	170	0.38	171	0.38	149	0.33	158	0.35	172	0.38	174	0.39	192	0.42	135	0.30	240	0.53	213	0.47	193	0.43
PJK-21	-15	0.23	-16	0.24	-16	0.25	-16	0.25	-13	0.20	-15	0.24	-16	0.25	-20	0.32	-8	0.12	-21	0.33	-19	0.30	-20	0.31
PJK-22	167	0.37	166	0.37	162	0.36	124	0.27	167	0.37	173	0.38	170	0.38	157	0.35	166	0.37	241	0.53	214	0.47	164	0.36
PJK-23	6	0.33	5	0.30	5	0.27	2	0.13	7	0.38	6	0.34	6	0.31	3	0.15	9	0.51	9	0.48	8	0.43	3	0.19
PJK-24	14	0.48	12	0.43	11	0.39	4	0.15	16	0.56	14	0.50	13	0.44	5	0.17	22	0.77	20	0.70	17	0.62	7	0.23
PJK-25	4	0.19	3	0.18	3	0.16	2	0.09	4	0.22	4	0.20	3	0.18	2	0.11	5	0.29	5	0.28	5	0.25	2	0.12
PJK-26	3	0.09	2	0.08	2	0.07	1	0.03	3	0.10	3	0.09	2	0.08	1	0.03	4	0.14	4	0.13	3	0.11	1	0.04
PJK-27	15	0.54	14	0.48	12	0.42	4	0.14	18	0.62	16	0.55	14	0.49	4	0.16	25	0.87	22	0.77	19	0.69	7	0.24
PJK-28	123	0.27	124	0.27	122	0.27	99	0.22	120	0.26	127	0.28	126	0.28	127	0.28	111	0.25	177	0.39	157	0.35	130	0.29
PJK-29	-30	0.26	-32	0.28	-32	0.29	-31	0.27	-27	0.24	-31	0.27	-32	0.29	-40	0.35	-17	0.15	-43	0.38	-38	0.34	-39	0.35
PJK-30	180	0.40	185	0.41	186	0.41	166	0.37	168	0.37	186	0.41	189	0.42	214	0.47	137	0.30	258	0.57	230	0.51	214	0.47
PJK-31	179	0.40	184	0.41	185	0.41	164	0.36	168	0.37	185	0.41	188	0.42	211	0.47	139	0.31	258	0.57	229	0.51	211	0.47
PJK-32	3	0.10	3	0.11	3	0.11	3	0.10	3	0.10	3	0.11	3	0.11	3	0.12	2	0.08	4	0.15	4	0.13	3	0.12
PJK-33	207	0.46	214	0.47	217	0.48	196	0.43	192	0.42	214	0.47	219	0.48	253	0.56	151	0.33	298	0.66	265	0.59	252	0.56
PJK-34	6	0.04	5	0.03	4	0.02	-1	0.00	7	0.04	6	0.04	6	0.03	0	0.00	11	0.06	9	0.05	8	0.04	2	0.01
PJK-35	-57	0.32	-59	0.34	-61	0.35	-58	0.33	-51	0.29	-59	0.33	-61	0.34	-75	0.42	-35	0.20	-82	0.46	-72	0.41	-74	0.42
PJK-36	62	0.24	64	0.25	65	0.26	59	0.23	57	0.22	64	0.25	65	0.26	76	0.30	43	0.17	89	0.35	79	0.31	76	0.30
PJK-37	3	0.02	2	0.02	2	0.02	1	0.01	3	0.03	3	0.02	2	0.02	1	0.01	4	0.04	4	0.03	3	0.03	1	0.01
PJK-38	60	0.34	63	0.35	63	0.36	56	0.32	55	0.31	62	0.35	64	0.36	74	0.42	43	0.24	87	0.49	77	0.44	74	0.42
PJK-39	-63	0.25	-63	0.25	-61	0.24	-43	0.17	-60	0.23	-64	0.25	-65	0.26	-62	0.24	-57	0.22	-88	0.35	-79	0.31	-67	0.26
PJK-40	-177	0.39	-185	0.41	-188	0.42	-175	0.39	-161	0.36	-183	0.40	-189	0.42	-227	0.50	-118	0.26	-255	0.56	-226	0.50	-224	0.50
PJK-41	-198	0.44	-206	0.46	-211	0.47	-196	0.43	-181	0.40	-205	0.45	-211	0.47	-252	0.56	-135	0.30	-286	0.63	-254	0.56	-249	0.55
PJK-42	-19	0.17	-20	0.17	-20	0.18	-20	0.18	-18	0.16	-20	0.17	-20	0.18	-24	0.21	-13	0.12	-28	0.24	-24	0.22	-23	0.21
PJK-43	5	0.26	5	0.27	5	0.28	5	0.26	4	0.24	5	0.27	5	0.28	6	0.34	3	0.17	7	0.38	6	0.33	6	0.34
PJK-44	-21	0.19	-22	0.20	-23	0.21	-24	0.21	-19	0.17	-22	0.20	-23	0.20	-30	0.26	-12	0.11	-31	0.27	-27	0.24	-28	0.25
PJK-45	2	0.02	2	0.02	2	0.01	0	0.00	2	0.02	2	0.02	2	0.02	0	0.00	3	0.03	3	0.03	3	0.02	1	0.01
PJK-46	21	0.33	22	0.35	23	0.36	23	0.36	18	0.29	22	0.34	22	0.35	29	0.46	12	0.18	30	0.47	27	0.42	28	0.44
PJK-47	112	0.44	120	0.47	126	0.49	132	0.52	98	0.39	117	0.46	122	0.48	164	0.64	57	0.22	163	0.64	144	0.57	157	0.62
PJK-48	130	0.51	139	0.55	146	0.58	154	0.60	114	0.45	136	0.53	142	0.56	192	0.76	65	0.25	189	0.74	168	0.66	184	0.72
PJK-49	103	0.91	120	1.07	142	1.26	244	2.16	102	0.90	127	1.12	113	1.00	157	1.39	61	0.54	176	1.56	157	1.38	130	1.15
PJK-50	35	0.31	38	0.33	40	0.35	41	0.36	31	0.28	37	0.33	39	0.34	51	0.45	19	0.16	51	0.45	46	0.40	49	0.44
PJK-51	-42	0.24	-39	0.22	-28	0.16	55	0.31	-21	0.12	-25	0.14	-50	0.28	-79	0.45	9	0.05	-35	0.20	-31	0.18	-93	0.53
PJK-52	-4	0.07	-7	0.10	-8	0.13	-13	0.21	-2	0.03	-5	0.09	-6	0.10	-14	0.22	7	0.12	-8	0.12	-7	0.11	-12	0.19
PJK-53	-42	0.37	-45	0.40	-48	0.42	-50	0.44	-33	0.29	-42	0.37	-47	0.41	-71	0.62	0	0.00	-59	0.52	-52	0.46	-68	0.60
PJK-54	-113	0.44	-115	0.45	-115	0.45	-94	0.37	-104	0.41	-115	0.45	-119	0.47	-129	0.51	-86	0.34	-160	0.63	-142	0.56	-133	0.52
PJK-55	-121	0.47	-123	0.48	-122	0.48	-98	0.39	-112	0.44	-123	0.48	-127	0.50	-135	0.53	-95	0.37	-172	0.67	-152	0.60	-140	0.55
PJK-56	6	0.19	6	0.19	5	0.19	4	0.14	5	0.19	6	0.20	6	0.20	5	0.19	6	0.20	8	0.28	7	0.25	6	0.20
PJK-57	28	0.25	27	0.23	25	0.22	14	0.12	29	0.26	29	0.25	27	0.24	18	0.16	38	0.34	40	0.35	35	0.31	21	0.18
PJK-58	21	0.19	20	0.18	19	0.17	12	0.10	22	0.19	22	0.19	21	0.19	16	0.14	27	0.23	30	0.26	27	0.24	18	0.16
PJK-59	9	0.15	9	0.15	9	0.14	7	0.10	9	0.14	9	0.15	10	0.15	9	0.14	10	0.16	13	0.21	12	0.18	10	0.15
PJK-60	4	0.15	4	0.15	4	0.14	3	0.10	4	0.14	4	0.15	4	0.15	4	0.14	4	0.16	6	0.21	5	0.18	4	0.15
PJK-61	6	0.09	7	0.11	7	0.11	7	0.11	4	0.06	6	0.09	7	0.11	10	0.16	2	0.03	8	0.13	7	0.11	10	0.16
PJK-62	-5	0.08	-4	0.07	-4	0.06	0	0.00	-7	0.11	-6	0.09	-5	0.07	0	0.00	-10	0.15	-8	0.12	-7	0.11	0	0.01
PJK-63	5	0.17	5	0.17	5	0.17	4	0.13	4	0.16	5	0.17	5	0.18	5	0.18	5	0.17	7	0.24	6	0.21	5	0.19
PJK-64	-5	0.07	-3	0.05	-2	0.03	3	0.04	-7	0.11	-5	0.08	-3	0.05	4	0.06	-11	0.18	-7	0.10	-6	0.09	3	0.05

PJK-65	-40	0.35	-40	0.36	-40	0.35	-29	0.25	-37	0.33	-41	0.36	-42	0.37	-39	0.35	-42	0.37	-56	0.50	-50	0.44	-42	0.37
PJK-66	-32	0.28	-34	0.30	-35	0.31	-30	0.27	-27	0.23	-32	0.28	-35	0.31	-42	0.37	-25	0.22	-45	0.39	-40	0.35	-43	0.38
PJK-67	-1	0.01	-5	0.08	-8	0.13	-15	0.23	7	0.11	-1	0.01	-6	0.09	-21	0.33	17	0.26	-1	0.01	-1	0.01	-19	0.30
PJK-68	-35	0.20	-41	0.23	-44	0.25	-51	0.29	-20	0.11	-34	0.19	-43	0.24	-76	0.43	15	0.08	-47	0.27	-42	0.24	-74	0.42
PJK-69	-23	0.13	-30	0.17	-35	0.20	-47	0.27	-6	0.03	-21	0.12	-31	0.18	-71	0.40	34	0.19	-30	0.17	-26	0.15	-66	0.38
PJK-70	-2	0.01	-11	0.06	-18	0.10	-48	0.27	18	0.10	-1	0.01	-11	0.06	-56	0.32	66	0.37	-2	0.01	-2	0.01	-47	0.27
PJK-71	-45	0.18	-44	0.17	-35	0.14	43	0.17	-20	0.08	-29	0.11	-54	0.21	-93	0.37	20	0.08	-40	0.16	-36	0.14	-104	0.41
PJK-72	-9	0.32	-8	0.29	-7	0.26	-3	0.10	-10	0.37	-9	0.33	-8	0.29	-3	0.11	-14	0.51	-13	0.46	-12	0.41	-4	0.15
PJK-73	-36	0.14	-45	0.18	-44	0.17	-1	0.01	10	0.04	-19	0.07	-55	0.22	-145	0.57	103	0.41	-26	0.10	-23	0.09	-146	0.57
PJK-74	-33	0.13	-42	0.16	-42	0.16	-1	0.00	13	0.05	-16	0.06	-51	0.20	-141	0.55	105	0.41	-22	0.09	-20	0.08	-141	0.56
PJK-75	-1	0.05	-1	0.05	-1	0.05	0	0.01	-1	0.05	-1	0.04	-1	0.05	0	0.02	-2	0.12	-1	0.06	-1	0.05	-1	0.03
PJK-76	-1	0.06	-1	0.07	-1	0.07	0	0.01	-1	0.03	-1	0.04	-2	0.09	-4	0.20	2	0.11	-1	0.06	-1	0.05	-4	0.20
PJK-77	-27	0.10	-37	0.14	-37	0.15	-1	0.00	21	0.08	-9	0.03	-46	0.18	-149	0.59	120	0.47	-12	0.05	-11	0.04	-149	0.58
PJK-78	0	0.00	0	0.02	-1	0.03	0	0.01	1	0.04	1	0.03	-1	0.04	-3	0.18	3	0.17	1	0.04	1	0.03	-3	0.17
PJK-79	-25	0.10	-35	0.14	-36	0.14	0	0.00	25	0.10	-6	0.02	-45	0.18	-152	0.60	127	0.50	-9	0.03	-8	0.03	-151	0.59
PJK-80	19	0.08	32	0.13	35	0.14	0	0.00	-32	0.13	0	0.00	44	0.17	165	0.65	-144	0.57	0	0.00	0	0.00	164	0.64
PJK-81	3	0.11	1	0.04	-1	0.03	-1	0.02	6	0.19	4	0.15	-1	0.04	-14	0.50	14	0.49	6	0.20	5	0.18	-14	0.49
PJK-82	0	0.00	1	0.02	3	0.04	1	0.02	-2	0.03	-1	0.02	3	0.05	13	0.20	-8	0.13	-2	0.03	-1	0.02	13	0.20
PJK-83	7	0.11	7	0.10	6	0.10	0	0.01	8	0.12	7	0.11	8	0.12	6	0.10	10	0.16	10	0.15	9	0.13	7	0.12
PJK-84	4	0.13	3	0.09	2	0.07	-1	0.03	5	0.19	4	0.15	3	0.09	-9	0.33	11	0.38	6	0.21	5	0.18	-9	0.31
PJK-85	-8	0.13	-9	0.14	-8	0.13	-1	0.02	-9	0.14	-8	0.12	-10	0.16	-15	0.24	-9	0.13	-11	0.17	-10	0.15	-17	0.26
PJK-86	-18	0.16	-18	0.16	-16	0.14	-2	0.02	-20	0.18	-18	0.16	-20	0.17	-20	0.18	-25	0.22	-25	0.22	-22	0.20	-24	0.21
PJK-87	-18	0.16	-17	0.15	-15	0.13	1	0.01	-21	0.19	-18	0.16	-18	0.16	-14	0.13	-29	0.26	-25	0.22	-22	0.20	-18	0.16
PJK-88	-2	0.08	-3	0.10	-3	0.11	-4	0.13	-1	0.04	-2	0.07	-3	0.11	-7	0.23	1	0.05	-3	0.10	-3	0.09	-6	0.23
PJK-89	-5	0.18	-5	0.16	-4	0.14	-2	0.05	-6	0.22	-5	0.18	-5	0.17	-3	0.11	-8	0.27	-7	0.25	-6	0.22	-4	0.14
PJK-90	-9	0.13	-8	0.12	-7	0.11	-3	0.04	-10	0.16	-9	0.14	-8	0.13	-4	0.07	-13	0.21	-12	0.19	-11	0.17	-6	0.09
PJK-91	1	0.04	1	0.08	2	0.11	3	0.18	-1	0.06	1	0.04	1	0.08	5	0.26	-3	0.18	1	0.06	1	0.05	4	0.24
PJK-92	-19	0.17	-19	0.17	-18	0.16	-14	0.12	-19	0.17	-19	0.17	-20	0.17	-20	0.18	-20	0.18	-27	0.24	-24	0.21	-21	0.19
PJK-93	8	0.13	7	0.10	5	0.08	0	0.01	11	0.17	8	0.13	7	0.11	0	0.01	16	0.25	12	0.18	10	0.16	1	0.02
PJK-94	4	0.22	4	0.20	3	0.17	1	0.07	5	0.25	4	0.22	4	0.20	1	0.07	6	0.35	6	0.31	5	0.28	2	0.10
PJK-95	0	0.00	0	0.01	-1	0.01	-2	0.03	1	0.02	0	0.00	-1	0.01	-3	0.05	3	0.05	0	0.01	0	0.01	-2	0.04
PJK-96	-7	0.11	-8	0.12	-8	0.12	-6	0.10	-6	0.10	-7	0.11	-8	0.12	-9	0.14	-6	0.09	-10	0.16	-9	0.14	-9	0.14
PJK-97	-3	0.12	-4	0.13	-4	0.13	-3	0.10	-3	0.11	-4	0.12	-4	0.13	-4	0.15	-3	0.09	-5	0.17	-4	0.15	-4	0.16
PJK-98	3	0.04	2	0.04	2	0.03	1	0.01	3	0.05	3	0.04	2	0.04	1	0.01	4	0.06	4	0.06	3	0.05	1	0.02
PJK-99	2	0.02	1	0.02	0	0.01	-1	0.02	3	0.04	2	0.03	1	0.01	-2	0.04	6	0.09	2	0.04	2	0.03	-2	0.03
PJK-100	-15	0.13	-14	0.13	-14	0.12	-10	0.08	-16	0.14	-15	0.13	-15	0.13	-14	0.13	-18	0.16	-21	0.19	-19	0.16	-15	0.14
PJK-101	3	0.14	2	0.13	2	0.11	1	0.04	3	0.16	3	0.14	2	0.13	1	0.05	4	0.22	4	0.20	3	0.18	1	0.07
PJK-102	-6	0.20	-6	0.23	-7	0.25	-9	0.30	-5	0.16	-5	0.19	-7	0.25	-14	0.50	0	0.00	-8	0.27	-7	0.24	-14	0.49
PJK-103	1	0.04	1	0.02	0	0.01	-2	0.08	1	0.05	1	0.04	1	0.03	-2	0.08	3	0.12	1	0.05	1	0.05	-2	0.06
PJK-104	5	0.17	4	0.16	4	0.14	-1	0.03	6	0.20	5	0.17	5	0.18	3	0.11	8	0.28	7	0.24	6	0.21	4	0.16
PJK-105	7	0.12	7	0.11	6	0.09	0	0.00	8	0.13	7	0.12	7	0.12	4	0.06	12	0.19	10	0.16	9	0.14	6	0.09
PJK-106	1	0.05	2	0.05	2	0.06	1	0.03	1	0.04	1	0.04	2	0.07	5	0.16	1	0.02	2	0.06	1	0.05	5	0.17
PJK-107	3	0.11	3	0.10	2	0.08	0	0.02	4	0.13	3	0.11	3	0.10	-1	0.05	6	0.21	4	0.15	4	0.14	0	0.02
PJK-108	0	0.02	-1	0.03	-1	0.03	0	0.02	0	0.01	0	0.01	-1	0.04	-2	0.09	1	0.04	0	0.02	0	0.01	-3	0.09
PJK-109	-5	0.08	-4	0.06	-2	0.03	1	0.02	-8	0.12	-6	0.09	-3	0.04	7	0.11	-15	0.24	-8	0.13	-7	0.12	6	0.10
PJK-110	-4	0.06	-3	0.04	-2	0.02	1	0.02	-5	0.09	-4	0.07	-2	0.03	5	0.08	-11	0.17	-6	0.09	-5	0.08	5	0.08
PJK-111	-1	0.02	-1	0.02	-1	0.02	0	0.00	-2	0.03	-1	0.02	-1	0.02	0	0.01	-3	0.04	-2	0.03	-2	0.03	-1	0.01
PJK-112	0	0.00	-1	0.01	-2	0.03	-2	0.03	1	0.01	0	0.00	-2	0.03	-7	0.10	4	0.06	0	0.01	0	0.00	-7	0.11
PJK-113	1	0.05	1	0.04	1	0.04	-1	0.03	2	0.06	1	0.05	1	0.05	0	0.01	3	0.12	2	0.07	2	0.06	1	0.02
PJK-114	-1	0.05	-2	0.07	-3	0.09	-4	0.13	0	0.01	-1	0.04	-3	0.09	-8	0.27	4	0.12	-1	0.05	-1	0.04	-7	0.26
PJK-115	-4	0.07	-5	0.08	-5	0.08	-6	0.09	-3	0.05	-4	0.06	-6	0.09	-11	0.17	1	0.01	-5	0.09	-5	0.08	-11	0.17
PJK-116	0	0.02	-1	0.03	-1	0.04	-1	0.06	0	0.00	0	0.02	-1	0.04	-2	0.13	1	0.07	0	0.02	0	0.02	-2	0.13
PJK-117	1	0.04	1	0.03	0	0.01	0	0.01	1	0.07	1	0.05	0	0.01	-2	0.11	3	0.14	1	0.07	1	0.06	-2	0.10
PJK-118	50	0.20	51	0.20	51	0.20	43	0.17	48	0.19	51	0.20	52	0.20	55	0.22	42	0.16	72	0.28	64	0.25	56	0.22
PJK-119	59	0.23	60	0.24	60	0.24	52	0.20	56	0.22	61	0.24	61	0.24	66	0.26	49	0.19	85	0.33	75	0.30	67	0.26
PJK-120	3	0.02	2	0.02	2	0.02	1	0.01	3	0.03	3	0.02	2	0.02	1	0.01	4	0.04	4	0.03	3	0.03	1	0.01
PJK-121	11	0.41	12	0.41	11	0.41	9	0.33	11	0.40	12	0.42	12	0.42	12	0.42	11	0.38	17	0.59	15	0.53	12	0.42
PJK-122	-43	2.35	-43	2.35	-43	2.36	-33	1.81	-43	2.37	-46	2.54	-45	2.47	-40	2.23	-44	2.45	-64	3.51	-57	3.15	-41	2.24
PJK-123	-16	0.04	-15	0.03	-13	0.03	-5	0.01	-19	0.04	-17	0.04	-15	0.03	-6	0.01	-26	0.06	-23	0.05	-21	0.05	-8	0.02
SP-1	465	1.03	457	1.01	442	0.98	327	0.72	469	1.04	479	1.06	466	1.03	415	0.92	488	1.08	667	1.47	592	1.31	438	0.97
SP-2	484	0.17	479	0.17	462	0.16	466	0.16	484	0.17	461	0.16	482	0.17	475	0.17	484	0.17	464	0.16	0	0.00	0	0.00
SP-3	45	0.39	42	0.38	43	0.38	0	0.00	45	0.39	46	0.41	43	0.38	0	0.00	45	0.39	45	0.40	46	0.41	40	0.36

Appendix-IV: Allocation of forecasted future demands

Area Information						Demand Information									
						Total forecasted future demands(m3/day)					Allocated nodal demands(m3/day)				
S.No	Node Label	Service Area ID	Area of Service polygons (m2)	Total area of Jimma Town(m2)	Coverage of service areas(%)	2009	2010	2011	2012	2013	2009(2)	2010(2)	2011(2)	2012(2)	2013(2)
1	JK-69	400	16727.09	105670000	0.016	13625	14022	14416	14825	15250	2.16	2.22	2.28	2.35	2.41
2	JK-66	85	21188.8	105670000	0.020	13625	14022	14416	14825	15250	2.73	2.81	2.89	2.97	3.06
3	JK-60	252	24655.5	105670000	0.023	13625	14022	14416	14825	15250	3.18	3.27	3.36	3.46	3.56
4	JK-68	79	26612.3	105670000	0.025	13625	14022	14416	14825	15250	3.43	3.53	3.63	3.73	3.84
5	JK-65	320	28888.9	105670000	0.027	13625	14022	14416	14825	15250	3.72	3.83	3.94	4.05	4.17
6	JK-62	355	34896.6	105670000	0.033	13625	14022	14416	14825	15250	4.50	4.63	4.76	4.90	5.04
7	JK-63	402	37732.6	105670000	0.036	13625	14022	14416	14825	15250	4.87	5.01	5.15	5.29	5.45
8	JK-70	230	38822.89	105670000	0.037	13625	14022	14416	14825	15250	5.01	5.15	5.30	5.45	5.60
9	JK-64	81	39246	105670000	0.037	13625	14022	14416	14825	15250	5.06	5.21	5.35	5.51	5.66
10	JK-5	466	43725.6	105670000	0.041	13625	14022	14416	14825	15250	5.64	5.80	5.97	6.13	6.31
11	JK-49	459	44967.3	105670000	0.043	13625	14022	14416	14825	15250	5.80	5.97	6.13	6.31	6.49
12	G-5	1831	45714.19	105670000	0.043	13625	14022	14416	14825	15250	5.89	6.07	6.24	6.41	6.60
13	G-3	490	46199.3	105670000	0.044	13625	14022	14416	14825	15250	5.96	6.13	6.30	6.48	6.67
14	JK-46	261	47205.39	105670000	0.045	13625	14022	14416	14825	15250	6.09	6.26	6.44	6.62	6.81
15	H-5	337	49382.1	105670000	0.047	13625	14022	14416	14825	15250	6.37	6.55	6.74	6.93	7.13
16	G-2	511	52735.8	105670000	0.050	13625	14022	14416	14825	15250	6.80	7.00	7.19	7.40	7.61
17	JK-71	212	52920.6	105670000	0.050	13625	14022	14416	14825	15250	6.82	7.02	7.22	7.42	7.64
18	JK-43	344	57956.6	105670000	0.055	13625	14022	14416	14825	15250	7.47	7.69	7.91	8.13	8.36
19	JK-42	416	58334.89	105670000	0.055	13625	14022	14416	14825	15250	7.52	7.74	7.96	8.18	8.42
20	JK-76	191	59070.89	105670000	0.056	13625	14022	14416	14825	15250	7.62	7.84	8.06	8.29	8.52
21	JK-48	407	61147.39	105670000	0.058	13625	14022	14416	14825	15250	7.88	8.11	8.34	8.58	8.82
22	JK-79	1689	62429.1	105670000	0.059	13625	14022	14416	14825	15250	8.05	8.28	8.52	8.76	9.01
23	JK-44	211	62832.8	105670000	0.059	13625	14022	14416	14825	15250	8.10	8.34	8.57	8.82	9.07
24	JK-34	97	68211.79	105670000	0.065	13625	14022	14416	14825	15250	8.80	9.05	9.31	9.57	9.84
25	JK-47	143	68805.6	105670000	0.065	13625	14022	14416	14825	15250	8.87	9.13	9.39	9.65	9.93
26	H-4	120	72295.89	105670000	0.068	13625	14022	14416	14825	15250	9.32	9.59	9.86	10.14	10.43
27	JK-61	503	74370.5	105670000	0.070	13625	14022	14416	14825	15250	9.59	9.87	10.15	10.43	10.73
28	JK-13	139	75139.29	105670000	0.071	13625	14022	14416	14825	15250	9.69	9.97	10.25	10.54	10.84
29	JK-53	346	75703.7	105670000	0.072	13625	14022	14416	14825	15250	9.76	10.05	10.33	10.62	10.93
30	JK-45	422	78438.1	105670000	0.074	13625	14022	14416	14825	15250	10.11	10.41	10.70	11.00	11.32
31	JK-30	325	81518.79	105670000	0.077	13625	14022	14416	14825	15250	10.51	10.82	11.12	11.44	11.76
32	JK-32	395	87272.6	105670000	0.083	13625	14022	14416	14825	15250	11.25	11.58	11.91	12.24	12.59
33	JK-58	335	91133.7	105670000	0.086	13625	14022	14416	14825	15250	11.75	12.09	12.43	12.79	13.15
34	H-8	304	91694.39	105670000	0.087	13625	14022	14416	14825	15250	11.82	12.17	12.51	12.86	13.23
35	JK-33	475	93277.39	105670000	0.088	13625	14022	14416	14825	15250	12.03	12.38	12.73	13.09	13.46
36	JK-14	433	94128	105670000	0.089	13625	14022	14416	14825	15250	12.14	12.49	12.84	13.21	13.58
37	JK-59	257	94173.5	105670000	0.089	13625	14022	14416	14825	15250	12.14	12.50	12.85	13.21	13.59
38	JK-77	309	96844.2	105670000	0.092	13625	14022	14416	14825	15250	12.49	12.85	13.21	13.59	13.98
39	JK-52	496	98718.6	105670000	0.093	13625	14022	14416	14825	15250	12.73	13.10	13.47	13.85	14.25
40	JK-50	307	99513.29	105670000	0.094	13625	14022	14416	14825	15250	12.83	13.21	13.58	13.96	14.36
41	JK-37	315	99714.39	105670000	0.094	13625	14022	14416	14825	15250	12.86	13.23	13.60	13.99	14.39
42	JK-29	235	101568	105670000	0.096	13625	14022	14416	14825	15250	13.10	13.48	13.86	14.25	14.66
43	JK-38	168	108810	105670000	0.103	13625	14022	14416	14825	15250	14.03	14.44	14.84	15.27	15.70
44	JK-36	135	112257	105670000	0.106	13625	14022	14416	14825	15250	14.47	14.90	15.31	15.75	16.20
45	JK-35	317	114603	105670000	0.108	13625	14022	14416	14825	15250	14.78	15.21	15.63	16.08	16.54
46	JK-41	83	118843	105670000	0.112	13625	14022	14416	14825	15250	15.32	15.77	16.21	16.67	17.15
47	JK-11	275	127559	105670000	0.121	13625	14022	14416	14825	15250	16.45	16.93	17.40	17.90	18.41
48	JK-15	70	128203	105670000	0.121	13625	14022	14416	14825	15250	16.53	17.01	17.49	17.99	18.50
49	JK-6	179	129457	105670000	0.123	13625	14022	14416	14825	15250	16.69	17.18	17.66	18.16	18.68
50	H-16	314	130422	105670000	0.123	13625	14022	14416	14825	15250	16.82	17.31	17.79	18.30	18.82
51	H-6	196	142681	105670000	0.135	13625	14022	14416	14825	15250	18.40	18.93	19.47	20.02	20.59
52	JK-31	295	142961	105670000	0.135	13625	14022	14416	14825	15250	18.43	18.97	19.50	20.06	20.63
53	JK-72	354	147088	105670000	0.139	13625	14022	14416	14825	15250	18.97	19.52	20.07	20.64	21.23
54	H-9	67	155674	105670000	0.147	13625	14022	14416	14825	15250	20.07	20.66	21.24	21.84	22.47
55	JK-73	95	157883	105670000	0.149	13625	14022	14416	14825	15250	20.36	20.95	21.54	22.15	22.79
56	H-18	237	162784	105670000	0.154	13625	14022	14416	14825	15250	20.99	21.60	22.21	22.84	23.49
57	H-21	507	163758	105670000	0.155	13625	14022	14416	14825	15250	21.11	21.73	22.34	22.97	23.63
58	H-2	481	166178	105670000	0.157	13625	14022	14416	14825	15250	21.43	22.05	22.67	23.31	23.98

59	JK-19	234	169608	105670000	0.161	13625	14022	14416	14825	15250	21.87	22.51	23.14	23.80	24.48
60	H-7	228	182794	105670000	0.173	13625	14022	14416	14825	15250	23.57	24.26	24.94	25.65	26.38
61	JK-16	401	194873	105670000	0.184	13625	14022	14416	14825	15250	25.13	25.86	26.59	27.34	28.12
62	JK-7	285	196440	105670000	0.186	13625	14022	14416	14825	15250	25.33	26.07	26.80	27.56	28.35
63	JK-18	302	202424	105670000	0.192	13625	14022	14416	14825	15250	26.10	26.86	27.62	28.40	29.21
64	JK-17	458	205656	105670000	0.195	13625	14022	14416	14825	15250	26.52	27.29	28.06	28.85	29.68
65	H-10	408	210840	105670000	0.200	13625	14022	14416	14825	15250	27.19	27.98	28.76	29.58	30.43
66	JK-23	240	212995	105670000	0.202	13625	14022	14416	14825	15250	27.46	28.26	29.06	29.88	30.74
67	G-6	244	217262	105670000	0.206	13625	14022	14416	14825	15250	28.01	28.83	29.64	30.48	31.35
68	JK-10	274	234903	105670000	0.222	13625	14022	14416	14825	15250	30.29	31.17	32.05	32.96	33.90
69	AJ-4	455	235707	105670000	0.223	13625	14022	14416	14825	15250	30.39	31.28	32.16	33.07	34.02
70	JK-12	199	243706	105670000	0.231	13625	14022	14416	14825	15250	31.42	32.34	33.25	34.19	35.17
71	H-12	96	257853	105670000	0.244	13625	14022	14416	14825	15250	33.25	34.22	35.18	36.18	37.21
72	JK-67	329	262321	105670000	0.248	13625	14022	14416	14825	15250	33.82	34.81	35.79	36.80	37.86
73	JK-39	98	262868	105670000	0.249	13625	14022	14416	14825	15250	33.89	34.88	35.86	36.88	37.94
74	JK-21	108	263345	105670000	0.249	13625	14022	14416	14825	15250	33.96	34.94	35.93	36.95	38.01
75	JK-9	493	269528	105670000	0.255	13625	14022	14416	14825	15250	34.75	35.77	36.77	37.81	38.90
76	JK-28	73	278099	105670000	0.263	13625	14022	14416	14825	15250	35.86	36.90	37.94	39.02	40.13
77	H-15	72	283343	105670000	0.268	13625	14022	14416	14825	15250	36.53	37.60	38.65	39.75	40.89
78	JK-4	77	293709	105670000	0.278	13625	14022	14416	14825	15250	37.87	38.97	40.07	41.21	42.39
79	JK-55	316	308926	105670000	0.292	13625	14022	14416	14825	15250	39.83	40.99	42.15	43.34	44.58
80	JK-25	383	311546	105670000	0.295	13625	14022	14416	14825	15250	40.17	41.34	42.50	43.71	44.96
81	JK-54	90	315867	105670000	0.299	13625	14022	14416	14825	15250	40.73	41.91	43.09	44.31	45.59
82	H-19	277	329086	105670000	0.311	13625	14022	14416	14825	15250	42.43	43.67	44.90	46.17	47.49
83	G-7	1687	332400	105670000	0.315	13625	14022	14416	14825	15250	42.86	44.11	45.35	46.63	47.97
84	H-22	227	335744	105670000	0.318	13625	14022	14416	14825	15250	43.29	44.55	45.80	47.10	48.45
85	H-17	340	377365	105670000	0.357	13625	14022	14416	14825	15250	48.66	50.07	51.48	52.94	54.46
86	JK-78	1693	377848	105670000	0.358	13625	14022	14416	14825	15250	48.72	50.14	51.55	53.01	54.53
87	H-11	484	407170	105670000	0.385	13625	14022	14416	14825	15250	52.50	54.03	55.55	57.12	58.76
88	JK-8	461	410790	105670000	0.389	13625	14022	14416	14825	15250	52.97	54.51	56.04	57.63	59.28
89	H-14	265	448532	105670000	0.424	13625	14022	14416	14825	15250	57.83	59.52	61.19	62.93	64.73
90	H-3	287	457095	105670000	0.433	13625	14022	14416	14825	15250	58.94	60.65	62.36	64.13	65.97
91	G-4	88	459602	105670000	0.435	13625	14022	14416	14825	15250	59.26	60.99	62.70	64.48	66.33
92	JK-75	262	564224	105670000	0.534	13625	14022	14416	14825	15250	72.75	74.87	76.97	79.16	81.43
93	H-1	247	620026	105670000	0.587	13625	14022	14416	14825	15250	79.95	82.28	84.59	86.99	89.48
94	JK-26	232	666049	105670000	0.630	13625	14022	14416	14825	15250	85.88	88.38	90.87	93.44	96.12
95	JK-20	175	717019	105670000	0.679	13625	14022	14416	14825	15250	92.45	95.15	97.82	100.59	103.48
96	JK-57	91	740830	105670000	0.701	13625	14022	14416	14825	15250	95.52	98.31	101.07	103.93	106.91
97	AJ-6	510	781670	105670000	0.740	13625	14022	14416	14825	15250	100.79	103.72	106.64	109.66	112.81
98	JK-56	417	831051	105670000	0.786	13625	14022	14416	14825	15250	107.16	110.28	113.38	116.59	119.93
99	JK-3	409	859284	105670000	0.813	13625	14022	14416	14825	15250	110.80	114.02	117.23	120.55	124.01
100	JK-2	68	1125630	105670000	1.065	13625	14022	14416	14825	15250	145.14	149.37	153.56	157.92	162.45
101	JK-80	1696	1134370	105670000	1.074	13625	14022	14416	14825	15250	146.26	150.53	154.76	159.15	163.71
102	AJ-1	106	1152040	105670000	1.090	13625	14022	14416	14825	15250	148.54	152.87	157.17	161.63	166.26
103	H-20	343	1218290	105670000	1.153	13625	14022	14416	14825	15250	157.09	161.66	166.20	170.92	175.82
104	AJ-5	334	1279080	105670000	1.210	13625	14022	14416	14825	15250	164.92	169.73	174.50	179.45	184.59
105	G-8	125	1357530	105670000	1.285	13625	14022	14416	14825	15250	175.04	180.14	185.20	190.46	195.91
106	AJ-2	127	1463250	105670000	1.385	13625	14022	14416	14825	15250	188.67	194.17	199.62	205.29	211.17
107	JK-1	1804	2001520	105670000	1.894	13625	14022	14416	14825	15250	258.07	265.59	273.06	280.80	288.85
108	JK-22	472	2716140	105670000	2.570	13625	14022	14416	14825	15250	350.22	360.42	370.55	381.06	391.99
109	G-1	331	2818550	105670000	2.667	13625	14022	14416	14825	15250	363.42	374.01	384.52	395.43	406.77
110	JK-24	323	4377250	105670000	4.142	13625	14022	14416	14825	15250	564.40	580.84	597.17	614.11	631.71
111	JK-81	1844	4893510	105670000	4.631	13625	14022	14416	14825	15250	630.97	649.35	667.60	686.54	706.22
112	AJ-3	372	5507620	105670000	5.212	13625	14022	14416	14825	15250	710.15	730.84	751.38	772.69	794.84
113	H-13	183	6189280	105670000	5.857	13625	14022	14416	14825	15250	798.04	821.29	844.37	868.33	893.22
114	JK-40	349	6325490	105670000	5.986	13625	14022	14416	14825	15250	815.60	839.37	862.95	887.44	912.88
115	JK-27	371	9271610	105670000	8.774	13625	14022	14416	14825	15250	1195.47	1230.31	1264.88	1300.76	1338.05
116	JK-51	419	15143900	105670000	14.331	13625	14022	14416	14825	15250	1952.64	2009.54	2066.00	2124.62	2185.53
117	JK-74	270	17495500	105670000	16.557	13625	14022	14416	14825	15250	2255.85	2321.59	2386.82	2454.54	2524.90
Total			105670000		100.000						13624.49	14021.47	14415.46	14824.44	15249.43

Appendix-V: Future nodal pressures at a peak-hour condition

FlexTable: Junction Table

Current Time: 5:00 AM

Label	2009 Demand (m^3/day)	2009 Pressure (kPa)	2010 Demand (m^3/day)	2010 Pressure (kPa)	2011 Demand (m^3/day)	2011 Pressure (kPa)	2012 Demand (m^3/day)	2012 Pressure (kPa)	2013 Demand (m^3/day)	2013 Pressure (kPa)
AJ-1	0	0	0	0	0	0	0	0	0	0
AJ-2	0	0	0	0	0	0	0	0	0	0
AJ-3	0	0	0	0	0	0	0	0	0	0
AJ-4	0	0	0	0	0	0	0	0	0	0
AJ-5	0	0	0	0	0	0	0	0	0	0
AJ-6	0	0	0	0	0	0	0	0	0	0
G-1	581	654	598	649	615	643	633	638	651	632
G-2	11	167	11	163	12	158	12	154	12	150
G-3	10	167	10	163	10	158	10	155	11	150
G-4	94	182	97	169	100	166	103	174	106	171
G-5	9	173	10	169	10	164	10	160	11	156
G-6	45	222	46	218	47	213	49	208	50	203
G-7	69	424	71	419	73	414	75	410	77	404
G-8	280	129	289	104	296	77	305	49	313	19
H-1	128	322	132	318	135	313	139	309	143	304
H-2	34	-471	35	-540	36	-612	37	-688	38	-770
H-3	93	-448	96	-518	100	-589	103	-666	106	-747
H-4	15	-342	15	-412	16	-483	16	-559	17	-641
H-5	10	-311	10	-381	11	-452	11	-528	11	-610
H-6	29	-285	30	-355	31	-426	32	-502	33	-583
H-7	38	-271	39	-340	40	-411	41	-487	42	-568
H-8	19	-285	19	-354	20	-425	21	-501	21	-583
H-9	32	-255	33	-324	34	-395	35	-471	36	-553
H-10	44	-478	45	-548	46	-619	47	-695	49	-777
H-11	84	-369	86	-439	89	-510	91	-586	94	-668
H-12	53	-391	55	-461	56	-533	58	-609	60	-691
H-13	1,277	-552	1,314	-627	1,351	-704	1,389	-785	1,429	-872
H-14	93	-315	95	-385	98	-457	101	-534	104	-616
H-15	58	-358	60	-428	62	-499	64	-576	65	-657
H-16	27	-307	28	-377	28	-449	29	-525	30	-607
H-17	78	-375	80	-444	82	-515	85	-590	87	-671
H-18	34	-287	35	-356	36	-427	37	-502	38	-583
H-19	68	-176	70	-245	72	-316	74	-391	76	-472
H-20	251	-322	259	-392	266	-464	273	-541	281	-623
H-21	34	-198	35	-266	36	-336	37	-411	38	-490
H-22	69	-296	71	-365	73	-436	75	-511	78	-592
JK-1	416	200	428	140	437	79	449	14	462	-56
JK-2	232	86	239	22	246	-44	253	-114	260	-189
JK-3	178	-13	183	-77	188	-143	193	-213	198	-288
JK-4	61	-62	62	-127	64	-193	66	-265	68	-341
JK-5	9	-164	9	-229	10	-296	10	-367	10	-443
JK-6	27	-246	27	-311	28	-377	29	-449	30	-525
JK-7	41	-226	42	-291	43	-358	44	-429	45	-506
JK-8	85	-211	87	-277	90	-344	92	-415	95	-492
JK-9	56	-234	57	-299	59	-366	60	-438	62	-514
JK-10	48	-309	50	-375	51	-443	53	-516	54	-593
JK-11	26	-266	27	-332	28	-400	29	-473	29	-550
JK-12	50	-147	52	-212	53	-280	55	-351	56	-428
JK-13	16	-146	16	-213	16	-281	17	-353	17	-431
JK-14	19	-90	20	-157	21	-225	21	-297	22	-375
JK-15	26	-78	27	-144	28	-212	29	-284	30	-361
JK-16	40	-78	41	-143	43	-211	44	-283	45	-360
JK-17	42	-223	44	-288	45	-356	46	-427	47	-504
JK-18	42	-247	43	-313	44	-380	45	-451	47	-528
JK-19	35	-103	36	-168	37	-235	38	-306	39	-383
JK-20	148	-8	152	-73	157	-140	161	-211	166	-287
JK-21	54	23	56	-42	57	-109	59	-180	61	-256

JK-22	560	75	577	8	593	-60	610	-133	627	-211
JK-23	44	-7	45	-74	47	-144	48	-218	49	-297
JK-24	903	-137	929	-208	955	-281	983	-359	1,011	-442
JK-25	64	32	66	-34	68	-101	70	-172	72	-248
JK-26	137	-56	141	-122	145	-189	150	-261	154	-338
JK-27	1,913	42	1,968	-25	2,024	-94	2,081	-167	2,141	-246
JK-28	57	-79	59	-145	61	-213	62	-285	64	-363
JK-29	21	-2	22	-69	22	-138	23	-211	23	-289
JK-30	17	-75	17	-141	18	-209	18	-282	19	-360
JK-31	29	-16	30	-83	31	-152	32	-225	33	-303
JK-32	18	-83	19	-149	19	-218	20	-290	20	-368
JK-33	19	-67	20	-135	20	-204	21	-278	22	-358
JK-34	14	-101	14	-169	15	-239	15	-313	16	-392
JK-35	24	-141	24	-209	25	-279	26	-353	26	-433
JK-36	23	-163	24	-231	24	-300	25	-374	26	-453
JK-37	21	-44	21	-111	22	-180	22	-253	23	-331
JK-38	22	-137	23	-205	24	-275	24	-349	25	-428
JK-39	54	-269	56	-337	57	-407	59	-481	61	-561
JK-40	1,305	-50	1,343	-119	1,381	-190	1,420	-265	1,461	-346
JK-41	25	-256	25	-325	26	-396	27	-472	27	-552
JK-42	12	-280	12	-349	13	-420	13	-495	13	-576
JK-43	12	-270	12	-339	13	-409	13	-484	13	-565
JK-44	13	-272	13	-341	14	-412	14	-487	15	-568
JK-45	16	-211	17	-281	17	-353	18	-429	18	-511
JK-46	10	-328	10	-396	10	-466	11	-541	11	-621
JK-47	14	-323	15	-391	15	-461	15	-535	16	-615
JK-48	13	-153	13	-221	13	-291	14	-366	14	-446
JK-49	9	-225	10	-294	10	-364	10	-438	10	-518
JK-50	21	-212	21	-280	22	-350	22	-425	23	-505
JK-51	3,124	-6,160	3,215	-6,536	3,306	-6,892	3,399	-7,326	3,497	-7,760
JK-52	20	-245	21	-313	22	-383	22	-458	23	-538
JK-53	16	-407	16	-475	17	-545	17	-619	17	-699
JK-54	65	-406	67	-474	69	-544	71	-619	73	-699
JK-55	64	-441	66	-509	67	-579	69	-654	71	-734
JK-56	171	-448	176	-516	181	-587	187	-661	192	-741
JK-57	153	-260	157	-328	162	-399	166	-474	171	-554
JK-58	19	-330	19	-398	20	-468	20	-543	21	-624
JK-59	19	-335	20	-403	21	-473	21	-548	22	-628
JK-60	5	-355	5	-423	5	-494	6	-568	6	-648
JK-61	15	-239	16	-308	16	-378	17	-453	17	-532
JK-62	7	-350	7	-418	8	-489	8	-563	8	-643
JK-63	8	-325	8	-394	8	-464	8	-539	9	-619
JK-64	8	-337	8	-406	9	-476	9	-551	9	-632
JK-65	6	-334	6	-403	6	-473	6	-548	7	-628
JK-66	4	-260	4	-329	5	-399	5	-474	5	-555
JK-67	54	-215	56	-283	57	-354	59	-429	61	-509
JK-68	5	-191	6	-259	6	-330	6	-405	6	-486
JK-69	3	-241	4	-310	4	-380	4	-455	4	-536
JK-70	8	-187	8	-256	8	-326	9	-401	9	-482
JK-71	11	-182	11	-253	12	-325	12	-403	12	-485
JK-72	30	-74	31	-145	32	-218	33	-295	34	-378
JK-73	33	-150	34	-224	34	-301	35	-383	36	-470
JK-74	3,609	-630	3,715	-726	3,819	-824	3,927	-928	4,040	-1,040
JK-75	116	-44	120	-113	123	-184	127	-260	130	-341
JK-76	12	-185	13	-254	13	-325	13	-400	14	-481
JK-77	20	-159	21	-228	21	-299	22	-374	22	-455
JK-78	78	-452	80	-516	82	-581	85	-651	87	-726
JK-79	13	-190	13	-255	14	-322	14	-393	14	-469
JK-80	234	-102	241	-173	248	-246	255	-323	262	-406
JK-81	1,005	198	1,034	138	1,068	77	1,098	12	1,130	-57