JIMMA UNIVERSITY
JIMMA INSTITUTES OF TECHNOLOGY
SCHOOL OF POST GRADUATE STUDIES
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
MASTER OF SCEINCE PROGRAM IN HYDRAULIC ENGINEERING

ASSESMENT OF WATER SUPPLY COVERAGE AND WATER LOSS IN DISTRIBUTION SYSTEM WITH MODELING: A CASE OF NEKEMTE CITY

BY: MUKTAR YESUF

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

JUNE, 2019
JIMMA, ETHIOPIA

JIMMA UNIVERSITY

JIMMA INSTITUTES OF TECHNOLOGY

SCHOOL OF POST GRADUATE STUDIES

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

MASTER OF SCEINCE PROGRAM IN HYDRAULIC ENGINEERING

ASSESMENT OF WATER SUPPLY COVERAGE AND WATER LOSS IN DISTRIBUTION SYSTEM WITH MODELING: A CASE OF NEKEMTE CITY

BY: MUKTAR YESUF

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

ADVISOR: Dr. ZEINU AHMED (PhD)

CO-ADVISOR: Mr. BIRHAN TEKUAM (M.Sc.)

Approval Page

The undersigned certify that the thesis entitled" Assessment of Water Supply Coverage and Water Loss in Distribution System with Modeling (A Case Study of Nekemte City)" is the work of Muktar Yesuf. We hereby recommend for the acceptance by a school of Graduate Studies of Jimma University in partial fulfillment of the requirements for Degree of Master of Science in Hydraulic Engineering.

Dr.Ing. Zeinu Ahmed (PhD)	______________	18/10/11
Advisor	Signature	Date
Mr. Birhan Tekuam (MSc)	______________	18/10/2011 E.C
Co-Advisor	Signature	Date

As the member of Board Examiners of the MSc thesis Open Defense Examination, we certify that we have read that, evaluated the thesis prepared by Muktar Yesuf and examined the candidate. We recommended that the thesis could be accepted as fulfilling the thesis requirements for Degree of Master of Science in Hydraulic Engineering.

Dr. Zelalem Biru	______________	18/10/2011 E.C
External Examiner	Signature	Date
Mahmud Mustefa	______________	25/06/2019
Internal Examiner	Signature	Date
Dame Betela	______________	25/06/2019
Chairperson	Signature	Date

DECLARATION

This thesis of the title 'Assessment of Water Supply Coverage and Water Loss in Distribution System with Modeling (A Case Study of Nekemte City)' is my original work and that all sources that have been referred to and quoted have been dully indicated and acknowledged with complete references.

Muktar Yesuf 25/06/2019

Candidate **signature** **date**

This thesis has been submitted for examination with my approval as university advisor.

Zeinu Ahmed (PhD) 18/10/11

Main advisor **signature** **date**

Birhan Tekuam (MSc.) 18/10/2011 E.C

Co- advisor **signature** **date**

ABSTRACT

Safe drinking water is one of the basic necessities for human beings. However, billions of people in the world have not access to it today. Of this, significant number of the population is from the developing countries especially in sub Saharan countries. A loss in water distribution system is an important issue which can affect water companies and their consumers worldwide. Water losses is categorized apparent loss and real loss and it can be caused by various influences, especially on the pipe networks and are an essential part of the maintenance strategy for existing water distribution networks. The main objective of this study is to estimate the water supply coverage of Nekemte city and the total water loss in distribution system. Water production that is only for the city and the water consumption as aggregated from individual customer meter reading was used to evaluate the total water loss at the city level. Data was gathered using observation, questionnaires, structural interview and the probability sampling technique was adopted in selecting the sample from the population. The systematic sampling techniques conducted to the local communities, consultants, Nekemte Water Supply and sewerage service enterprise and from local Administrative. The result indicates that the city water supply coverage is 48.21%.Out of the total water production 3,050,269.97 Cubic meter per year 1,305,636.97 Cubic meter was considered as loss. This implies 42.69% out of the production was loss before reaching the consumer by different cause specially loss due to pressure and age of pipe. The distribution system model was used to evaluate two alternative scenarios to improve system performance. The objective of the first scenario was to increase the flow rate at taps of low supply by managing pressure and the second scenario aimed at adding taps to parts of the sub-system without easy access to running water. The first scenario was consisted extended period simulation to increase the flow rate at taps of low supply. This scenario was recommended for some parts of the city. The second scenario was hardly recommended to satisfy the community who did not get distribution network still.

Key words: *Apparent losses; Real losses; Water loss; Water supply coverage*

ACKNOWLEDGMENT

First of all, I would like to give my great thanks to Allah for helping me to arrive for this thesis in a great challenge without any problem.

Secondly I would like to express my gratitude to my advisor, Dr. Zeinu Ahmedfor his excellent guidance, encouragement and support. I have also great acknowledgement for my co-adviser Mr. Birhan Tekuam for his supporting me in any direction.

My works has not been successful without them. I would like to express my deepest acknowledgment to my sister Zenat Yesuf and my wife Nasra Hussein, who always makes valuable help and support for me in any direction.

Finally, I would like to express my gratitude to my family especially my brother Ahimed Yesuf who always my side and encouraging and helping me in taking of my burden.

TABLE OF CONTENTS

LIST OF TABLES

LISST OF FIGURES

ABBIRIVIATIONS AND ACRONYMS

ALC	Active Leakage Control
DMA	District Meter Area
ELL	Economic Level of Leakage
EPSs	Extended period simulations
GC	Gregorian calendar
GIS	Geographical Information System
IWA	International Water Association
MNF	Minimum Night Flow
NGO	Non-Governmental Organization
NRW	Non-Revenue Water
NWSSSE	Nekemte Water supply and sewerage service enterprise
PI	Performance Indicator
PVC	Polyvinyl chloride
RPF	Resettlement Policy Framework
SDG	Sustainable Development Goal
SIV	System Input Volume
UFW	Unaccounted For Water
UNICEF	United Nations Children's Fund
USEPA	United State Environmental Protection Agency
WDS	Water Distribution System
WHO	World Health Organization
2^{nd} GTP	Second Growth and Transformation Plan

CHAPTER ONE

INTRODUCTION

1.1 Back Ground

Water is an essential and very important compound for every living thing. Next to the air, the other important requirement for human life to exist is water. But, its coverage is low to supply for the community all over the world especially in Africa doe to different factors. According to WHO, Progress on Drinking Water, Sanitation and Hygiene: 2017 Update and SDG Baselines; In 2015, 71 per cent of the global population (5.2 billion people) used a safely managed drinking water service; that is, one located on premises, available when needed and free from contamination. One out of three people using safely managed drinking water services (1.9 billion) lived in rural areas. Eight out of ten people (5.8 billion) used improved sources with water available when needed. Three quarters of the global population (5.4 billion) used improved sources located on premises. Three out of four people (5.4 billion) used improved sources free from contamination. 89 per cent of the global population (6.5 billion people) used at least a basic service; that is, an improved source within 30 minutes' round trip to collect water. 844 million people still lacked even a basic drinking water service. 263 million people spent over 30 minutes per round trip to collect water from an improved source (constituting a limited drinking water service). 159 million people still collected drinking water directly from surface water sources, 58% lived in sub-Saharan Africa (UNICEF and WHO, 2017).

On the other hand, in Africa largest cities, only 43% inhabitants have house connection water supply services. The main problem that developing countries have been facing to provide access to safe water for their citizen's is shortage of resource. Moreover, the capacity of the citizens to pay for water that fully recovers the cost is very limited. Problem in providing satisfactory water supply to the rapidly growing population especially that of the developing countries are increasing from time to time. Water supply coverage system in urban areas are often unable to meet existing demands are not available to everyone rather some consumer takes disproportional amount of water and the poor is the first victim to the problem (Bereket, 2006).

Ethiopia's rapid urbanization is putting stress on inadequate water supply and sanitation system in urban areas. The country's population is 91.7 million (2012) and growing at about 3% per annum, of which 17 percent lives in urban centers. According to World Bank's Ethiopia's urbanization review, the rate of urbanization will be even faster, at about 5.4% a year. That would mean a tripling of the urban population even earlier by 2034, with 30% of the country's people in urban areas by 2028. Towns are growing horizontally and vertically and rural villages are also being clustered with small towns faster than ever before. The growing demand generated by rapid population growth, fast growing infrastructure development, service sector growth such as hotels, trade, and industrialization, as well as changes in way of life and awareness level of the residents have mounted pressure in the already inadequate Water Supply and Sanitation system (FDRE MoWIE, 2016).

Nekemte city is also one of the urban cities in Ethiopia whose population of the city is growing rapidly from time to time more than expected. Therefore, supplying an adequate drinking water in standard level is very difficult. Financial problem is also one of the major factors for the low water coverage of the water supply but poor management of the existing water supply also has a great impact for the low coverage. Beside to the overall low supply coverage, supply disparity existing among different localities.

Besides too low coverage, water losses in urban water supply is mainly arise from: -Leakage from water mains through faulty joints or corrosion, Leakage from reservoir, Leakage from in service and fitting inside or outside the consumers' premises, Leakage through abandoned service pipes, Leakage of valves. While developed cities have start using on-line continues operation and monitoring service, the developing cities have grate difficult even to collect information on their previously performed operation and maintenance activities that could help them developing a strategy for the future. Many developed countries use water audit procedures to determine the efficiency of the system and to identify the location and magnitude of water losses.

Moreover, managing and reducing losses of water at all level of a distribution system remains one of the major challenges facing many water utilities in most developing countries including Ethiopia. Besides, to this poor management of the existing infrastructure asset increases the level of water losses in water supply coverage system. Although there are many reasons for minimizing leakage in municipal water distribution networks, perhaps the most important one relates to quality of service. Additionally, during drought periods, system with a high leakage index cannot be properly manage and may demand frequency service interruption. Reducing water losses volume has the advantage of diminishing costly expansions of the system through hydraulic works. Water loss is also costly in terms of energy losses and causes high environmental cost (Bereket, 2006).

In fact, a lot of time is required in order to detect the leakage of water in a widely distribution of water supply networks and large amount of water goes waste. Non-revenue water (NRW) in a water distribution network is determine by deduction of metered and authorize un- metered consumptions from total inflow. Basically non-revenue water is divided into apparent losses and real losses. Apparent losses are produce by metering, human and management errors, and lead to consumption of water without charging. On the other hand, real losses include waste water and can be categories to pipe system leakage (report and unreported bursts and background losses), reservoir leakage and overflow and finally leakage from valves and pumps.

Leakage from a water distribution network can be determined by adopting several approaches. By using a field studies concept of yearly balance and minimum night flow (MNF) assessment, possibly in combination with "burst and background losses estimation", the total value of leakage in water supply network (at district meter area, DMA level) can be evaluated and its component is determined (Farley and Trow, 2003).

A more rigorous and refine approach, applicable to the distribution of leakage in the entire network, is to use the earlier approaches (water balance and minimum night flow) in combination with a hydraulic simulation model such as water GEMS, Water cad, Epanet and etc.

Water GEMS is a hydraulic modeling application for water distribution systems with advanced interoperability, geospatial model building, optimization, and asset management tools. From fire flow and constituent concentration analyses, to energy consumption and capital cost management, Water GEMS provides an easy-to-use environment for engineers to analyze, design, and optimize water distribution systems. This model uses an assortment of data, input, and output files. It is important to understand which essential, temporary holding places for results are and which must be transmitted when sending a model to another user. This model gives the choice between performing a steady-state analysis of the system and performing an extended-period simulation over any time period (Bentley, 2006).

1.2 Statement of the problem

Safe drinking water is one of the basic necessities for human beings. However, billions of people in the world have not access to it today. Of this, significant number of the population is from the developing countries especially in sub Saharan countries. Ethiopia is one of the continents with a challenge on inadequate water supply and sanitation system in urban areas due to rapid urbanization. Nekemte city is also one of the urban cities in Ethiopia whose population of the city is growing rapidly from time to time more than expected. Therefore, supplying an adequate drinking water in standard level is very difficult. Even the supplied water cannot meet the target demand due to water loss in distribution system. Water losses are a large source of unaccounted for water and cause by various influences, especially on the aging pipe networks and are essential part of the maintenance strategy for existing water distribution networks.

Leakage is a major problem for water utilities, as they affect the environmental and financial sustainability of urban water service and often a large source of unaccounted for water and is a result of either lack of maintenance or failure to renew ageing systems. Water losses in the distribution system require more water to be treat, which require additional energy and chemical usage, resulting in waste resources and losses revenue. Leakage may also be caused from poor management of pressure zones, which result in pipe or pipe joint failure. Although some leakage may go unnoticed for a long time, detection of visible leakage also requires good reporting which includes some level of public participation.

1.3 Objective

1.3.1 General Objective

The main objective of this research is to assess the water supply coverage and the amount of water loss in city water supply distribution system.

1.3.2 Specific objectives

In addition to the above general objective the following specific objectives are expected to achieve.

- To asses domestic water supply coverage in distribution system.
- To estimate the amount of water loss and identify the major causes of water loss in distribution system.

- To quantify the benefit of water loss reduction with that of demand satisfaction and economic benefit.
- To Model distribution system of the city for improving system performance.

1.4 Research Questions

1. How much water is consumed by consumer?
2. How much water is considered as a loss out of production and what are the causes of water loss in distribution system at the city level?
3. What is the advantage of water loss reduction with that of demand satisfaction and economical benefit?
4. How distribution system modeling improves system performance?

1.5 Scope of the Study

The scope of the study was limited to evaluating water supply coverage of the city, assessing the amount and causes of water loss in distribution system, modeling of distribution system to reduce pressure and increasing performance of the pipe and subject to lack of proper connection.

This study was included in 50% of all kebeles in Nekemte city. The selection of those kebeles for the study was depend up on existing water supply systems, their distribution, spatial variation and determinant factors that gained from office and field survey.

1.6 Significance of the study

The first objective of this study is to provide municipalities with a basic common method of accounting for the water used and loss in their water distribution system. The intent is to use standard terms that are recognize internationally, allowing municipalities to communicate readily and understand each other. By accounting for the water, municipalities can make operations, maintenance, and capital improvement decisions in the best interests of their local Administrative and the community they serve. This best practice helps municipalities prioritize their capital and operating decisions and better safeguard their systems from water loss.
Generally the significance of this studies are Nekemte water supply and sewerage service enterprise, environmental protection office, different organizations and community.

CHAPTER TWO
LITERATURE REVIEW

2.1 General

Problems in providing satisfactory water supply to the rapidly growing population especially that of the developing countries is increasing from time to time. Water supply system in urban areas are often unable to meet existing demands and are not available to everyone rather some consumers take disproportionate amounts of water and the poor is the first victim develop and expand water supply projects and one of the difficulties among the other is managing and reducing losses of water at all levels of a distribution system. As a result of the overall shortage of water many cities are faced a problem in distributing the available water impartially among the residents. Besides the poor management of existing infrastructure asset increases the level of water losses in water supply (UNICEF and WHO, 2017).

Continuous monitoring and maintenance of the distribution network is the key step in meeting pressure and flow requirements, and water quality standards. A recent drinking water infrastructure needs survey estimates an investment of 151 billion dollars over a period of 20 years to provide safe drinking water for US customers. Reducing water losses in pipe networks can minimize the maintenance costs and further improve the performance of pipe networks. (USEPA, 2009)

Leakage can be defined as unintentional or accidental loss of water from the pipe distribution network. Leaking pipes are a major concern for water utilities around the globe as they constitute a major portion of water losses. One of the primary reasons for leakage in pipes is aged and deteriorated networks. The condition of existing old networks can only worsen and further increase water losses. In the globe alone, 50% of supplied water is lost as leakage in some of the older networks Leakage rates are also related to length of pipes and number of connections. Improper connections can sometimes result in continuous escape of water from the distribution pipes (Desalegn, 2006).

2.2 Comparing Water Losses

Water losses occur in all water distribution networks, even new one and it is only the volume that varies. Thereby, the volume of this loss reflects the capacity of water authorities to manage their distribution networks (Dighade, 2014).

The amount of water loss differs from country to country, city to city and even from network to another network in the same city. Different countries use different indicators to evaluate their states in comparison with others and to compare the distribution of water loss from one location to other location of a distribution system in order to take action based on the level of loss. As stated above competition using unaccounted for water (UFW) expressed as percentage has limitation when used for comparison as it highly depends with the volume of water produced (AL-Ghamdi and Gutub, 2002).

The traditional performance indicators of water losses are frequently expressed as a percentage of input volume. However, this indicator fails to take account of any of main local influences. Consequently, it cannot be an appropriate performance indicator (PI) for comparison (WHO, 2001). According to (IWA, 2003), to avoid for the wide diversity of format and definitions related to water loss, many practitioner have identified an urgent need for a common international terminology that among them task forces from the international water association recently produced a standard approach for water balance calculation with a definition of all terms involved as indicated in table 2.1 below.

Table2. 1 IWA Standard International Terminologies

System Input Volume	Authorized Consumptions	Billed Authorized Consumption	Billed meter consumption	Revenue Water
			Billed unmetered consumption	
		Unbilled Authorized Consumption	Un Billed Consumption	Non-Revenue Water (NRW)
			Un Billed unmetered consumption	
	Water loss	Apparent Loss (Commercial losses)	Unauthorized Consumption	
			Customer Metering Inaccuracies and Data Handling Error	
		Real loss (Physical losses)	Leakage in Transmission and Distribution mains	
			Storage Leaks and Over flow from water storage tanks	
			Service Connection Leaks up to the Meter	

(Source: International water association, 2003)

According to IWA (2003) the above terminologies are defined as below:

System input volume;- is the annual volume input to the part of the water supply distribution system

Authorized consumption;- is the annual volume of metered and/or non-metered water take by registered customers, the water supplier and other who are implicitly or explicitly authorized to do so. It includes water exported, and leak and overflows after the point of customer metering.

Revenue water (RW): water that is consumed and for which the utility receives payment. Revenue water consumption volume is measure or estimate.

Non-Revenue Water (NRW);-is the difference between system input volumes and billed authorized consumption (water that is not billed and no payment is receive). Water losses;- are the difference between system input volume and authorized consumption, and consist of apparent losses and real losses.

Apparent losses;-consist of unauthorized consumption and all types of metering inaccuracies. Real losses;- are the annual volumes lost through all types of leaks, bursts and overflows on mains, service reservoir and service connections, up to the point of customer metering.

2.3 Causes of leakage

Water produced and delivered to the distribution system is intend to be sell to the customer, not loss or siphon from the distribution system without authorization. Not long ago, water companies sell water at a flat rate without metering. As water has become more valuable and metering technology has improved, more and more water system in the U.S. meters their customers. Although all customers may be meter in a given utility, a fairly sizable portion of the water most utilities produce does not pass through customer meters. Unmetered water includes unauthorized users, including losses from accounting errors, malfunctioning distribution system controls, thefts, inaccurate meters, or leaks (Harrison, 2012).

Leakage is usually the major component of water loss in developing countries, but this is not always the case in developing or partially developed countries, where illegal connections, meter error, or an accenting error are often more significant the other component of total water loss are non-physical losses, e.g. Meter under registration, illegal connections and illegal and unknown use (WHO, 2001).

There are different types of leakage including service line leakage, illegal connection, meter error and valves leakage but in most cases, the largest portion of unaccounted for water is loss through leaks in the mains. There are many possible causes of leaks and often a combination of factors leads to their occurrence. The material, composition, age and joining methods of the distribution system components can influence leaks occurrence.(AWWA, 2009)

2.4 Pressure and Leakage

In many water network systems, even though the total demand and the total loss of water can be known rather easily, information about the possible influence of local pressure upon demand is sadly lacking that as a result creates difficultly to assess and compare the demand and loss of water in its spatial distribution. Pressure distribution system on the one hand contributes to the shortage of water that as a result causes for unequal distribution of water among residents. To alleviate such problems, some water authorities develop a zoning scheme whereby the complete water distribution network is broken down in to manageable segments that can be easily metered and monitored and analyzed.

The leakage from water distribution system has been shown to be directly proportional to the square root of the distribution system pressure as indicated by the relationship below (Wallingford, 2003).

Leakage α (distribution system pressure)$^{0.5}$ ………………………………….. 2.1

Rates of water loss for an approximately circular hole can be determined using Greeley's equation. This is of the form:

$Q = 0.215A\sqrt{P}$ …………………………………………………………......... 2.2

Where; Q=leakage rate in liter per minute, A=cross sectional area of the leak in cm^2, P=pressure in the pipe in Pascal's

Leaks in joints or cracks can be estimated by an equation of the form

$Q = 0.0161A\sqrt{P}$ …………………………………………………….……..... 2.3

Where; Q=leakage rate in liter per minute, A=cross sectional area of the leak in cm^2, P=pressure in the pipe in Pascal's

Leakage detection techniques that are in use in the water industry involve two major steps. Those are Estimation of leakage rates and Location of leakage.

2.5 Pressure Management through Distribution System

In some countries, it is recognized for many years that effective management of pressure is the essential foundation for an effective leakage management strategy. The Spanish National Report considers pressure reduction to be 'the preventative measure par excellence'. Pressure management can thus be an immediate and cost-effective solution for decreasing real water losses in a distribution network, even at low initial pressure. However, leakage reduction is not the sole benefit. Pressure management also offers water conservation benefits because some types of water consumption will decline due to reduce average zone pressure. A study by the IWA water loss task force found that pressure reduction result in a significant decrease in new pipe breaks and bursts (Thornton, 2003).

All of these positive effects of pressure management usually result in high water saving and thus, have very short payback time. Some of the pressure management benefit reports by many different utilities include: Fewer emergency repairs, more planned work, Reduction of new burst frequencies on distribution mains and service connections, Reduction of flow rates of all leaks and bursts present in the system at any time, Reduction of new leaks on private pipes and overflows at private storage tanks, Reduction of some components of consumption subject to direct mains pressure, Reduction in annual repair costs (Babel.et.al, 2009).

2.6 Controlling water losses

Controlling water loss is not an easy task it requires many activities like: Water audit or water balance, Meter testing and repair or replacement, improving billing procedure, Leak detection and control program, Corrosion control, Pressure reduction, Public education program, Rehabilitation and Replacement Program(Grigg, 2007).

2.7 Leakage Monitoring and Control

Leakage management can be classified into two groups including passive leakage control and active leakage control. Passive leakage control is reacting to report bursts or a drop in passive, usually reports by customer or notes by the company's own staff while carrying out duties other than leak detection. This method can apply in areas with low cost supplies. Active leakage control (ALC) is when company staff is deployed to find leaks which have no reports by customer. The main ALC methods are regular survey and leakage monitoring (Kingdom.et.al, 2006).

The most appropriate leakage control policy is mainly dictate by the characteristics of the networks and local condition, which may include financial constraints on equipment and other resources.

2.7 Benefit of leak detection and Repair

The economic benefit of leak detection and repair can be easily estimated. Remember to factor in the costs of developing new water supplies and other "hidden" costs. Some other potential benefits of leaks detection and that are difficult to quantify include: Increase knowledge about the distribution system, more efficient use of existing supplies and utility employees (Thornton.et.al, 2008).

2.9 Distribution Systems Modeling

A water distribution system is principally made of links and nodes which delivers water from single or multiple supply sources to consumers. It is principally made of links and nodes. Links are pipe sections which can contain valves and bends. The nodes can be categorized as junction nodes, which join pipes and are the points of input or output of flow, and fixed-grade nodes such as tanks and reservoirs with fixed pressure and elevation. As defined in water distribution system models, reservoirs are nodes that represent infinite sources or sinks of water, such as lakes. Tanks are nodes with fixed storage capacity and varying volumes during distribution. Pumps are devices that impart energy to water thereby increasing its head. Valves limit the pressure or flow at points in the system (Pelletier.et.al, 2003).

2.9.1 Basic Principles of Hydraulic Modeling

In line with Jalal, (2008); the main reason for modeling a system is to assist designers, managers and planners to explore the governing laws of such systems and to accurately analyze their behavior. Hence, models are employed to resolve problems in system’s design and operation. ‘Model-based simulation is a method for mathematically approximating the behavior of real water distribution systems. To effectively utilize the capabilities of distribution system simulation software and interpret the results produced, the modeler must understand the mathematical principles involved’ (AbdelMeguid and Ulanicki, 2010).

In networks of interconnected hydraulic elements, every element is influenced by each of its neighbors; the entire system is interrelated in such a way that the condition of one element must be consistent with the condition of all other elements. These conditions are mainly controlled by two laws (Tomas.et.al, 2003).

Law of Conservation of Mass

The principle of conservation of mass dictates that the fluid mass entering any pipe will be equal to the mass leaving the pipe (since fluid is typically neither created nor destroyed in hydraulic systems). In network modeling, all outflows are lumped at the nodes or junctions.’(Tomas.et.al, 2003).

$$\sum_{pipes} (Q_i - U) = 0 \quad \ldots\ldots 2.4$$

Where; Q_i = Inflow to node in i^{th} pipe (L^3/T), U = Water used at node (L^3/T)

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

$$\sum_{pipes}^{.}(Q_i - U - dS/dt) = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.5$$

Where; $\frac{dS}{dt} = changeinstorage(\mathrm{L3/T})$

Therefore, the concept to conservation of mass is applied to all junction nodes and tanks in a water distribution networks.

Law of Conservation of Energy

According to Bernoulli's equation; 'The principle of conservation of energy dictates that the difference in energy between two points must be the same regardless of the path that is taken' (Tomas.et.al, 2003).

Within a hydraulic analysis, the equation is written in terms as follows:

$$Z1 + \frac{P1}{y} + \frac{V1^2}{2g} + \sum_{.}^{.}(h_p) = Z2 + \frac{P2}{y} + \frac{V2^2}{2g} + \sum_{.}^{.}(h_l) + \sum_{.}^{.}(h_m) \ldots\ldots\ldots\ldots\ldots 2.6$$

Where; Z= Elevation (L), P = Pressure ($M/L/T^2$), y = fluid specific weight ($M/L/T^2$), V = Velocity (L/T), g = gravitational acceleration constant (L/T^2), h_p = head added at pump (L), h_L = head loss in pipes (L), h_m = head loss due to minor losses (L).

Therefore, in water distribution modeling the difference in energy at any two points connected in a network is equal to the energy gains from pumps and energy losses in pipes and fittings that occur in the path between them (Tomas.et.al, 2003).

2.9.2 Water distribution network simulation

The term simulation generally refers to the process of imitating the behavior of one system through the functions of another. It can be used to predict system responses to events under a wide range of conditions without disrupting the actual system. Using simulations, problems can be anticipated in proposed or existing systems, and can be evaluated before time, money, and materials are invested in a real-world project (Almandoz.et.al, 2005).

As per Almandoz. et.al, 2005; in water distribution networks the most basic type of model simulations are either steady-state or extended-period simulation.

Steady-state simulations: -represent a particular view of point in time and are used to determine the operating behavior of a system under static conditions. It computes the hydraulic parameters such as flows, pressures, pump operating characteristics, and others by assuming that demands and boundary conditions were not change with respect to time. In general, this type of analysis was used to determining the short-term effect of demand conditions on the system.

Extended period simulations:-are determine the dynamic behavior of a system over a period of time, and it analyze the system on assumption that the hydraulic demands and boundary conditions were change with respect to time. Hence, 'extended period analysis used to evaluate system performance over time and allows the user to model pressures and flow rates changing, tanks filling and draining, and regulating valves opening and closing throughout the system in response to varying demand conditions and automatic control strategies formulated by the modeler. Therefore, regardless of project size, model-based simulation can provide valuable information to assist an engineer in making well-informed decisions.

Water GEMS is a hydraulic modeling application for water distribution systems with advanced interoperability, geospatial model building, optimization, and asset management tools. From fire flow and constituent concentration analyses, to energy consumption and capital cost management, Water GEMS provides an easy-to-use environment for engineers to analyze, design, and optimize water distribution systems. This model uses an assortment of data, input, and output files. It is important to understand which essential, temporary holding places for results are and which must be transmitted when sending a model to another user. In general, the model is contained in a file with the wtg.mdb extension. This file contains essentially all of the information needed to run the model. This model gives the choice between performing a steady-state analysis of the system and performing an extended-period simulation over any time period (Bentley, 2006).

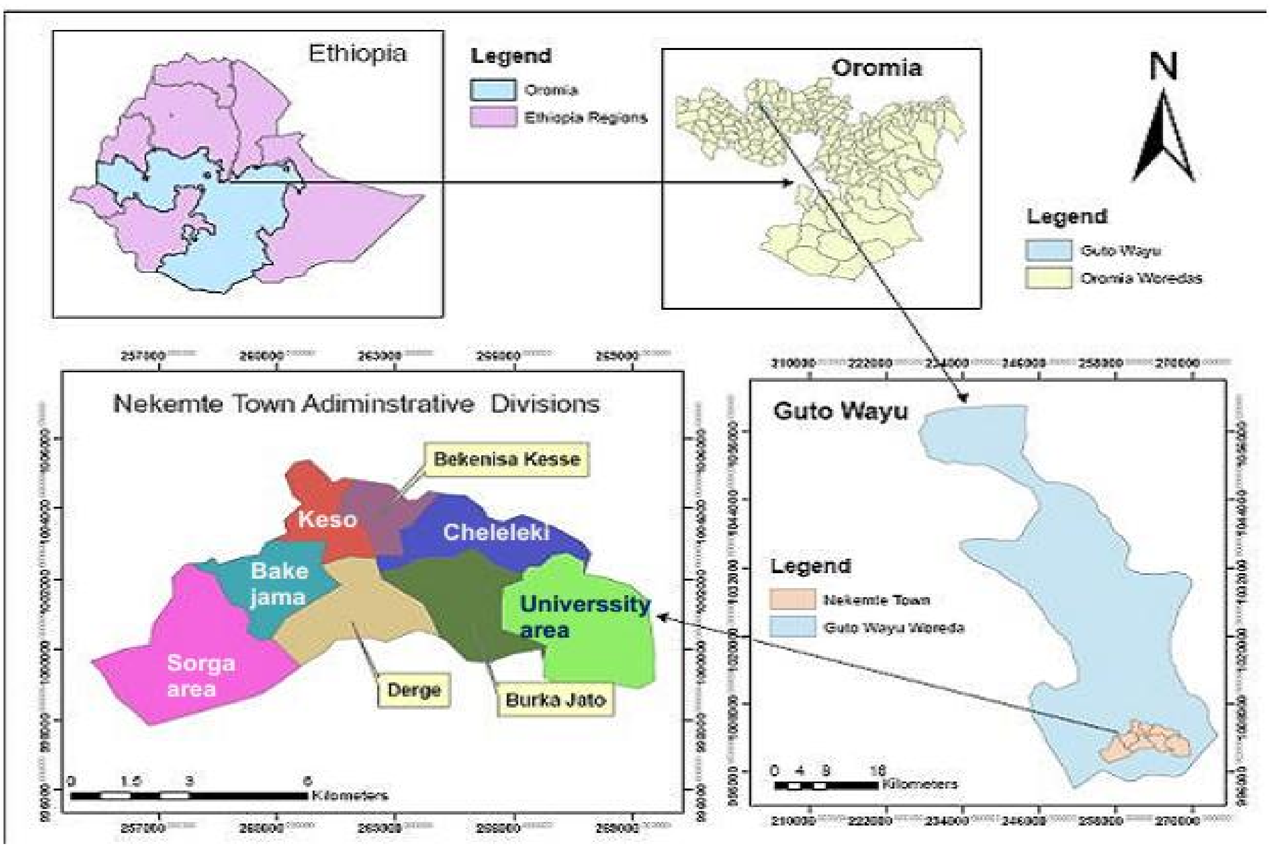
CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Description of the Study Area

Nekemte city is located in Oromia regional state of east wollega zone at 331 km from the capital city of Ethiopia Addis Ababa towards western direction situated along the highway Addis Ababa-Gimbi-Asosa. The geographical location of the town is extended $9^0$5`N to $9^0$8`33 N latitudes and 36^0 33` E to $36^0$ 55`E longitudes and the city has an average altitude of 2,088 m above mean sea level. It covers an area of 54.8 square kilometer.

Currently the city was divided into six sub-cities which are listed as: Burka jato, Cheleleki, Bekenisa kesse, Bake jama, Darge and Keso. Sorga and University areas shown on the map are not included in city administration but they are in the range of boundary administration. The total population of the city was estimated to be around 123,923.



Source: (Nekemte city administration office, 2018)
Figure 3.1 Locations of Nekemte Town and its Kebeles.

3.2 The Research Process

First of all, water supply coverage of the city was analyzed before evaluating water loss and its distribution model. This depends on the amount of consumption at the city level up on per capita consumption of the population of the city and level of house hold connection. Next the amount of water loss at the city level was also calculated depending up on the production and billed data gained from Nekemte water supply and sewerage service enterprise office. After analyzing the amount of water loss, the causes of the loss were also identified. In this study since there is the place where the city water supply distribution was not reach. So by different scenarios modeling of distribution system was also done at the end.

3.2.1 Selection of Sample Study Area

Sampling is very important in any research since it is very difficult and it takes more time to include all the study areas, research without sampling is also much cost; To select the sampling areas, the major factor was availability of the data. The criterions that was considered to select the sample kebeles include: Availability of the data gained from the office, Excess to water supply distribution system, Topography of the area and Life style of the community. Based on those main criterions 50% of the kebeles (3 kebeles out of 6 kebeles) in the city was selected for evaluation of water supply coverage and the loss in distribution system.

The Selection of those 3 kebeles out of 6 kebeles are not for evaluation of water supply coverage and water loss of the city. It is used to assessing only the causes of water loss in distribution system. Both water supply coverage and water loss are analyzed as a city level.

3.2.2 Sampling size and sampling procedures

The sample size that gets from the study area is just the representative sample size within the systematic sampling would be conducted and measure on peoples and existing water distribution system, consultants, owners (NWSSSE), and several possible participants**.** In the side of the owner the questioner was distributed for water users. To get information from those sample of Nekemte city and water users are assess.

3.2.2.1 Sample size

To get the sample size for a quantitative study the main criterion we have to consider is house hold connection at the city level and on the selected areas. According to Nekemte water supply and sewerage service enterprise (NWSSSE) around 15,932 house hold connection was exist at the city level and out of this 8,426 connection was found in three selected kebeles, which represents 53% of total connection. By taking 5% of the total households of target kebeles 421 was taken as a sample size. The systematic random sampling was used to select households as a single household represented about 20 households of selected kebeles as it was calculated in the following equation 3.1, The first water users would be taken by lottery method and then at every n^{th} interval individual household was interviewed by the following formula.

$$\text{Interval of water user} = \frac{\text{Total number of water users}}{\text{sample size}} \dots\dots\dots\dots.\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..3.1$$

$$\text{Interval of water user} \qquad = \frac{8426}{421} = 20$$

This implies that a single house hold represented 20 households of selected kebeles.

3.2.2.2 Sampling Procedures

Defining the Target Population:- The definition of targeting population had been in line with the objectives of water supply coverage and causes of leakage in distribution system.

Specifying the sampling frame**:-** The Sampling frame was designed from the list of participants in water supplier.

Specifying the sampling unit**:-** All parties become a sampling unit and all contractors engage in water supply construction projects become the sampling elements. After determining sample households, the sampling was conducted by calculating the proportion of the number of households existing in each *kebele* on the basis of the following formula.

$$\text{S} = \frac{\text{th}}{\text{TH}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..\dots.3.2$$

Where: S= Sample to be taken, th= target households in a kebele, TH= total household in all kebeles.

Table 3.1 procedure for selection of households

Target kebeles	**Calculation**	**Sample proportion**	**Absolute sample**
Burka Jato	$421 * \frac{2569}{8426}$	128.3585	128
Darge	$421 * \frac{2930}{8426}$	146.8957	147
Bakkenisa kesse	$421 * \frac{2927}{8426}$	146.2458	146
Total	$421 * \frac{8426}{8426}$	421	421

3.3 Water Supply Coverage

The water supply coverage of the city was evaluated based on per capita consumption of water and its level of connection at the city level having the number of population from statistical data. Per capita consumption was calculated from monthly consumption of each kebeles and also compared with the standards as the national stated in the second Ethiopian growth and transformation plan (2nd GTP). Per capita consumption of the city was calculated by equation 3.3 shown below.

$$\text{per capita consumption(liter/person/day} = \frac{\text{Annual consumption}}{\text{Population number of the city}} \ldots\ldots\ldots\ldots\ldots\ldots 3.3$$

level of connection is also one of the water supply coverage expression and it was calculated by equation 3.4 as indicated below.

$$\text{Connection per family} = \frac{\text{Total number fo connection of the city}}{\text{Population number of the city/family sise}} \ldots\ldots\ldots\ldots\ldots\ldots 3.4$$

Table 3.2 level of domestic water production and consumption at city level

Months	**Domestic water production (m^3)**	**Domestic water consumption (m^3)**
Jul. 2017	244,236.00	143,048.00
Aug. 2017	238,885.00	124,856.00
Sept. 2017	284,043.00	169,887.00
Oct. 2017	274,923.67	155,009.00
Nov. 2017	259,262.00	134,421.00
Dec. 2017	271,551.00	154,546.00
Jan. 2018	268,675.00	139,876.00
Feb. 2018	253,357.00	117,598.00
Mar. 2018	202,217.00	122,604.00
Apr. 2018	256,194.00	119,928.00
May. 2018	245,945.00	175,550.00
Jun. 2018	250,981.00	187,310.00
Total	3,050,269.97	1,744,633.00

(Source: Nekemte water supply and sewerage service enterprise, 2018)

3.4 Water Loss Analysis

The amount of water loss in distribution system at the city level was gained from the total volume of water produced and the total volume of billed water that gained from Nekemte water supply and sewerage service enterprise office (NWSSSE).

$$\text{Total water loss (\%)} = \frac{(\text{Total water production} - \text{Total billed water})}{\text{Total water production}} * 100 \ldots\ldots\ldots\ldots 3.5$$

3.4.1 Causes of Water Loss

Causes of water losses are assessed by field observation and face to face interview with a local experts and communities by preparing different causes of water loss in the form of questionery paper and to give a rank for each cause as indicated in appendix I.

3.5 Modeling of Distribution System

Modeling of distribution system is used for distributing water supply to the areas where there is no excess of water or where the water exists in small amount. The modeling of distribution was done by software which is called Water GEMS in different scenarios depending on the existing distribution system.

3.5.1 Water GEMS

Water GEMS is a hydraulic modeling application for water distribution systems with advanced interoperability, geospatial model building, optimization, and asset management tools. From fire flow and constituent concentration analyses, to energy consumption and capital cost management, Water GEMS provides an easy-to-use environment for engineers to analyze, design, and optimize water distribution systems (Bentley, 2006).

This model uses an assortment of data, input, and output files. It is important to understand which essential, temporary holding places for results are and which must be transmitted when sending a model to another user. In general, the model is contained in a file with the wtg.mdb extension. This file contains essentially all of the information needed to run the model. This model gives the choice between performing a steady-state analysis of the system or performing an extended-period simulation over any time period.

3.5.1.1 Input Parameters of Water GEMS

Reservoirs: -Reservoirs are a type of storage node. A Storage Node is a special type of node where a free water surface exists, and the hydraulic head is the elevation of the water surface above sea level. The water surface elevation of a reservoir does not change as water flows into or out of it during an extended period simulation.

Tanks: - Tanks are a type of Storage Node. A Storage Node is a special type of node where a free water surface exists, and the hydraulic head is the elevation of the water surface above sea level. The water surface elevation of a tank will change as water flows into or out of it during an extended period simulation.

Pumps: - Pumps are node elements that add head to the system as water passes through.

Valves:- A valve is a node element that opens, throttles, or closes to satisfy a condition you specify.

Pipes: - In Water GEMS, pipes are links connecting two nodes. Inputting pipes can be done using the text or the graphical interface.

Junction: - Discharging the required demand or recharge the inflow water from the system (to the system).

Table 3.3 Input parameters of Water GEMS

Elements	Input Data
Reservoir	Elevation
Tank	Base Elevation, Minimum Elevation, Initial Elevation, Maximum Elevation and Diameter
Pump	Elevation, Pump definition
Pipe	Length, Diameter, type of pipe
Junction	Elevation, Demand and Demand pattern
Valves	Elevation, Diameter, Pressure and status.

3.5.2Data Assembly

The following section describes the process of putting together the water distribution model in Water GEMs from the raw data collected in the field. The first step in starting the model is to set up some important parameters which define the input values used by the software.

3.5.2.1 Initial Setup

Throughout the process, International System Units (SI units) have been used. To request the use of these units in Water GEMs, the user chooses SI flow unit under the hydraulics option. Liter per second is selected for the model, which also defines all other units using the SI system. Hence lengths, pressures, head, elevations are taken in meters and Diameters of pipes are defined as millimeters. The Hazen-Williams equation was chosen for determining head-loss.

For pipe: - Pipe length and diameters are then inputted as well as roughness. A roughness of 150 was selected automatically for the polyvinyl chloride (PVC) pipes. The pipes are fairly new but considering the stagnation periods due to the intermittent nature of the system, build-up should have made roughness rise to such levels. Minor losses are also included as part of pipes, not at the tee or elbow junctions. These minor losses were ignored and assigned a null value because errors in elevation were assumed to outweigh the minor losses sufficiently that results would not significantly vary by considering such losses. As to the status of pipes, they were generally left with their default status of open. These were assigned the status of control valve, letting water flow only in the direction of their first to their second node. This setting is important to avoid backwards flow from tanks or reservoirs whose inlets discharge above surface water or for emitter taps which would become sources in the absence of flow.

3.6 Data Collection

In the study, both primary and secondary data was employed by qualitative and quantitative method. The data collection processes exercised in this study was questionnaires, structural interview and reviewing of previous documents. The questionnaire was open-ended questionnaires. The interview type is structured where necessary data is consumed in the form of face- to- face and by telephone.

3.6.1 Primary data collection

Primary data collection includes both face to face interview and field observation. Face-to-face interview was done with local administrative experts and communities of selected kebeles by which selected by sampling method to get the information about different causes of water loss, functionality of water meter and distribution coverage of the city. Field observation was done to check the reality of the secondary data gained from the office such as functionality of reservoir and pump

3.6.2 Secondary data collection

Secondary data collection includes reviewing of existing documents, books, journals, reports, internets and others sources from Nekemte water supply and sewerage service enterprise office (NWSSSE) and Nekemte city administration office.

The data that collected from NWSSSE includes: the city water distribution network in AutoCAD format, a one-year monthly production and consumption of water, number of house hold connection in each kebeles and other relevant documents. Population data and all information about the city were gained from Nekemte city Administration office.

3.7 Data Preparation

The city distribution network was given us in the form of AutoCAD format and monthly water production and consumption is in hard copy. The AutoCAD format contains the distribution network and contour map of the city together with some missing data, therefore it is very challenged to translate those networks into Water GEMs, and other important data was also collected in the form of hard copy from the office. For simulation of network it was mandatory to join together the network and all input parameters.

The only ways to draw and connecting the network with its input parameter is redrawing the network without missing its original line in the AutoCAD on WaterGEMs and putting all the necessary input parameters from AutoCAD and hardy copy.

CHAPTER FOUR
RESULT AND DISCUSSION

4.1 Water Supply Coverage

The growing demand of water supply due to rapid urbanization generated by rapid population growth, fast growing infrastructure development, service sector growth such as hotels, trade, and industrialization, as well as changes in way of life and awareness level of the residents have mounted pressure in the already inadequate Water Supply and Sanitation system.

Water supply coverage is usually evaluated based on the quality, quantity, paying capacity of the people, distance, etc. but the intention of this research is not to evaluate all those but related to the quantity of the supply and level of connection that are related to the water loss. In this part of the analysis, the number of domestic connection per family and the average daily per capital consumption is used to analysis the domestic water supply coverage for the city. The level of coverage has been also compared with the standards of the second growth and transformation plan of Ethiopia (2^{nd} GTP).

4.1.1Domestic Water Supply Coverage

Excess to water supply coverage of the city was calculated depending on the average per capita consumption of the city and level of connection. The average daily per capita consumption was derived from the yearly consumption of the city that collected from the individual domestic water meters and the number of population projected for 2018 from statistical data.

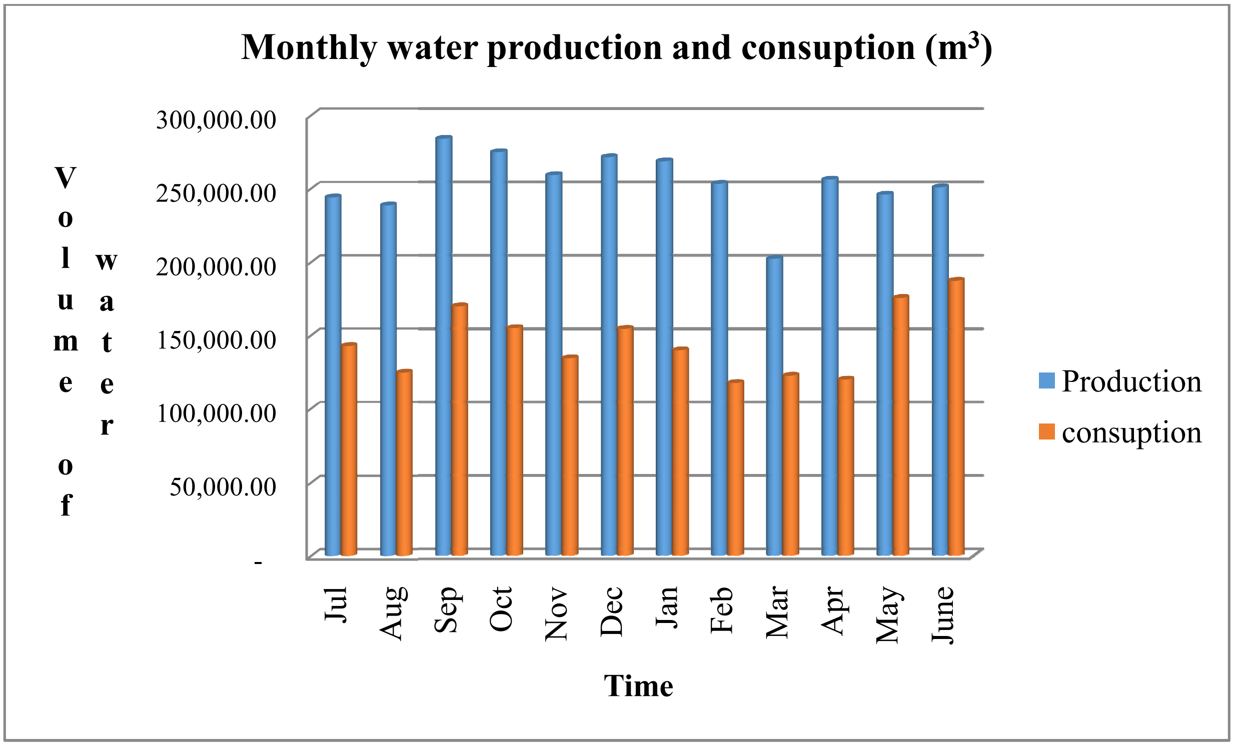


Figure 4.1 levels of domestic water production and consumption

4.1.1.1 Average Daily Per Capita Consumption

The amount of water consumed for domestic purpose was collected as a city level. Because, of analyzing the distribution of the water supply coverage among different localities. Statistical analysis was used to evaluate the distribution of the supply coverage in the entire city. Evaluating the exact domestic water supply coverage of the city only by using volume of consumption is difficult since there is the variation in supply between different localities.

According to Ethiopian statistical data of population in 2015 and its projection in 2018, the number of population of Nekemte city was estimated to be 123,923. Depending on this per capita consumption of the city was calculated as follow.

$$\text{per capita consuption (liter/person / day} = \frac{1{,}744{,}633.00\text{m3} * \frac{1000\text{liter}}{\text{m3}}}{123{,}923\text{person} * 365\text{day}}$$

$$= 38.57 \text{ liter/person/day}$$

This amount is very low when compared with the second growth and development of Ethiopia (2^{nd} GTP) which is stated as "for category 2 towns/cities (towns/cities with a population in the range of 100,000- 1million), per capita consumption must be minimum of 80 liter/capita/day within a distance of 250m", Accordingly the water supply coverage of the city was estimated to be 48.21%.

This does not mean the rest 51.8% of the community doesn't get water supply. Around 50% of the city's community doesn't consume more than 20 liter per person per day due to different factors such as: the cities temperature is cold so that the consumption is decreasing, the existence of many natural streams in the city, using rain water for different activities, since the ground water table is at lower elevation many people uses borehole in front of their home.

4.1.1.2 Level of connection

The other evaluation method of water supply coverage is Level of water connection. The total numbers of connection or water meter within the city are about 15,932. In order to compare the distribution of the water connection among the different sub-cites, the total numbers of connection per kebeles are converted to connection per family using the population data of each sub-cites. According to the census of the 2015, average family size of 4 is used for calculating the average number of connection per family as follow.

$$Connectionperfamly = \frac{15{,}932}{(123{,}923/4)} = 0.51$$

This implies that water supply coverage in terms of level of connection is 51 percent.

4.2 Water Loss Analysis

Water loss from a water distribution system is a significant factor affecting water delivery to customers that can be measured by many methods. But in this thesis water loss of Nekemte city was evaluated depending on the data of water supply production and consumption of the city that gained from Nekemte water supply sanitation and sewerage service enterprise and the field data that gained from field observation and the interview of the costumers and different parts of community.

4.2.1 Water Loss Analysis at the city level

To estimate the amount of water loss for the city the total annual water produced and distributed to the distribution system and the water billed that was aggregated from the individual customer meter readings were used. According to site investigation and the information gained from Nekemte water supply and sewerage service enterprise there is no unbilled water in Nekemte city. The total monthly water production and consumption of the city was given for 2017/2018 and the loss was also calculated depending on this data in the following formula.

Table 4.1 water supply production, consumption and loss

Months	**water production (m^3)**	**water consumption (m^3)**	**Water loss (m^3)**	**Water loss (%)**
Jul. 2017	244,236.00	143,048.00	101,188.00	41.43
Aug. 2017	238,885.00	124,856.00	114,029.00	47.73
Sept. 2017	284,043.00	169,887.00	114,156.00	40.19
Oct. 2017	274,923.67	155,009.00	119,914.67	43.62
Nov. 2017	259,262.00	134,421.00	124,841.00	48.15
Dec. 2017	271,551.00	154,546.00	117,005.30	43.09
Jan. 2018	268,675.00	139,876.00	128,799.00	47.94
Feb. 2018	253,357.00	117,598.00	135,759.00	53.58
Mar. 2018	202,217.00	122,604.00	79,613.00	39.37
Apr. 2018	256,194.00	119,928.00	136,266.00	53.19
May. 2018	245,945.00	175,550.00	70,395.00	28.62
Jun. 2018	250,981.00	187,310.00	63,671.00	25.37
Total	3,050,269.97	1,744,633.00	1,305,636.97	**42.69**

Water loss can be expressed in terms of percentage out of the production, loss per length of main pipe and water loss per service connection. Since the amount of water loss different for different length of main pipe and it is also not uniform loss across all connections, getting an appropriate result by the second and third expression is difficult. Water loss expressed as a percentage could be an appropriate means to show the extent of the loss within a given environment, but it is not a good indicator for comparing the loss from one area to another since the loss is not uniform for different areas.

According to the analysis on the above table 4.1, out of the total water production 3,050,269.97 Cubic meter per year 1,305,636.97 Cubic meter was considered as loss. When we put this value in terms of percent, 42.69% out of the production was loss before reaching the consumer.

Water loss per number of connection can be also evaluated depending on the total number of connection in the city. According to Nekemte water supply sanitation and sewerage service indicates there are 15,932 house hold connection at the city level. From the above analysis 1,305,636.97 metric cube of water was consider as a loss per year. Therefore, water loss per connection per day was given by the following expression.

$$\text{Waterloss} = \left(\frac{1{,}305{,}636.97}{15{,}932}\right) * \left(\frac{1000}{365}\right) = 276.223 \text{ liter/connection/day}$$

4.2.2 Evaluating causes of water loss

There are many reasons that cause a water loss in distribution system as a general. But in this section only the cause of water loss in Nekemte city was discussed as follow.

4.2.2.1 Poor pipe installation

Pipe must be installed appropriately as distributed on the design network. Otherwise it has its own side effects. Most of the leakage caused in Nekemte city was occurs at the connection of each pipes especially on the reduction of pipe size. This loss can be reduced easily by using an appropriate reducer and an educated man power in plumbing but in this city most of the worker doing as a plumber have no knowledge about pipe fitting rather than gaining from experience only.

4.2.2.2 Illegal connection

Illegal connection was not significant in distribution system in Nekemte city especially in the expansion areas or at the boarder of the city distribution system. There are a number of households who do not pay water rates but receive water from its distribution system without permission of the Authority. Especially as a field survey indicates that in 2017/18 this type of connection is increasing from time to time. As a consequence, they contribute to apparent losses and revenue loss to the water authority.

4.2.2.3 Loss due to Pressure

Due to the topographic nature of the city, the elevation differences are observed among different settlement areas that are getting water from the same service reservoir. The elevation differences might have a great impact on the magnitude of loss through leakage. Higher loss is expected in lower settlement areas than settlements located in elevated areas. Nevertheless, distance from the reservoir also has an impact due to head loss. Pressure increases as the elevation difference increases and also the leakage increases as the pressure increases.

4.2.2.4 Loss due to error of meter reading

Customer meter reading in Nekemte town is carried out using the traditional approach whereby meter readers visit individual meters and collect monthly readings manually. This approach of reading meters is susceptible to human errors particularly where readings are taken quickly to meet meter reading targets at the end of month.

4.2.2.5 Loss due to age of pipe network

Age of pipe is also a great contribution on water loss. In Nekemte city more than 40% of the pipe network in the city was laid over 20 years ago. As the age of pipe increases the amount of leakage is also increasing most leakages are easily detectable and the rest cannot maintain because of its long service age. So it was decided to change by new line. The long aged pipe is especially in the central part of the city and in densely population areas. It is therefore necessary to replace older pipe lines to reduce leakage in distribution system.

The causes of water loss discussed above are summarized in the next table 4.2 in percentage of their cause.

Table 4.2 causes of water loss in percentage

No.	Cause of water loss	Rank 1	2	3	4	5	6	total	percentage
		No. Expert							
1	Leakage due to pressure	8	5	1	-	-	-	77	26
2	Leakage due to age of pipe	4	4	5	1	-	-	67	23
3	Leakage due to meter error	2	4	5	2	1	-	60	20
4	Poor pipe installation	-	1	2	7	4	-	42	14
5	Illegal connection	-	-	-	3	6	5	26	9
6	Leakage due to water scheduling	-	-	1	1	3	9	22	8

(Source: - from field survey 2018)

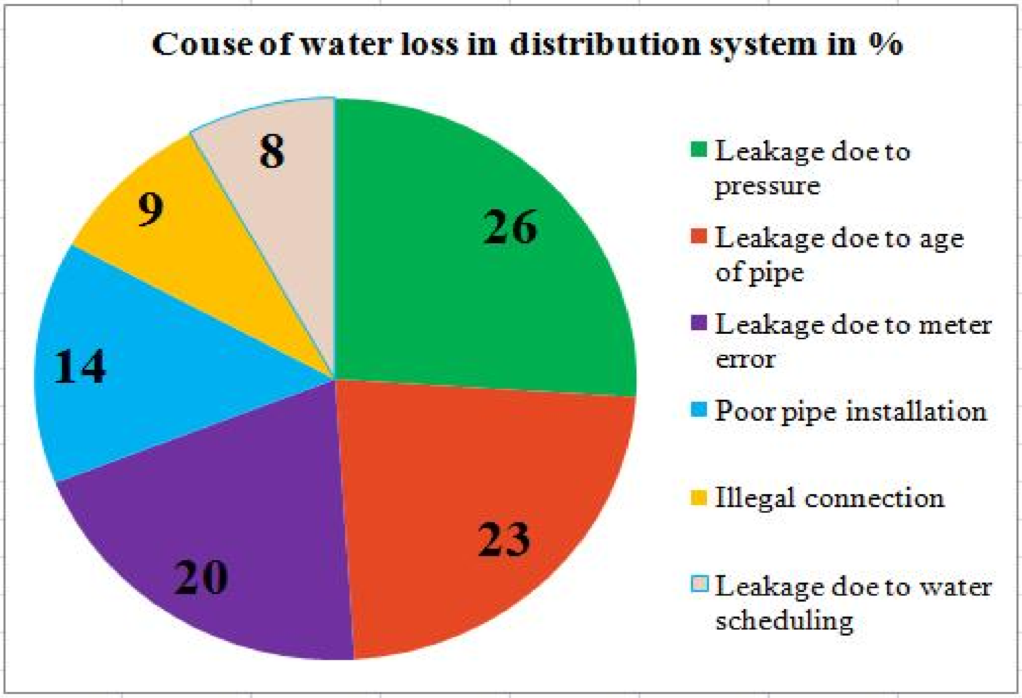


Figure 4.2 causes of water loss in percentage

4.3 Water Loss Reduction

From the previous analysis, the present level of water supply coverage in the entire city is very low while the water loss is high. The extent of the water loss is expected to be higher, if additional water supply sources are constructed without managing the loss properly. Therefore establishing an appropriate methodology to identify and reduce the loss considering the local conditions is vital. In the previous chapters, at the city the analysis was focusing to the total water loss. Identifying the total water loss is one step forward, but unless the types and particular locations of the losses are identified, it will be very difficult to intervene for the reduction of water loss. Due to its complex in nature, identifying and charactering the causes of water losses in a particular location is not an easy task and it needs an appropriate methodology. the methods that followed in this thesis includes improving billing system and meter reading for water loss identification and giving remedial measure for reduction of water loss.

4.3.1 Improving billing system and meter readings

Improving a billing system is one step forward for improving the overall demand management of the city and helps to a great extent to better evaluate the water balance and water loss. The most important part of determining how much water is being lost in a system is to accurately quantify the volume of water which is entering that system. But Customer meters also require careful management if representative and significant results are to be obtained. Billing system can be reviewed and updated for the integrity and quality of the data. The location and the historical records like ages of the meter, periods of calibration, etc. need also be integrated with the billing systems.

While the meter readings of the city has been reviewed for the purpose of this study, many non-active contracts with negative consumptions and repeated contracts were found included in the records. On the other hand, numbers of meters were having similar previous and last readings (zero consumption) for some continuous months which seem unpractical. Unless these problems are alleviated, it would be very difficult to get a realistic water balance.

4.3.2 Remedial measures to reduce water loss and leakage

Knowing the magnitude and the major causes of water loss greatly helps to give remedial measures for reduction of water loss in distribution system. Nevertheless, identification is not by itself an end in reducing the water loss. The following points are considered as the remedial actions to be taken for reduction of water loss and leakage in a distribution system but not limited:

4.3.2.1 Improving organizational management and provision of training

For an effective management of water supply service in general and water loss and leakage in particular, water supply providing institutions must have an appropriate organizational management. The organizational aspect related to the water loss management is well addressed in the organizational structure of NWSSSE, but shortage of qualified and experienced personnel is the major problem of the country in general and NWSSSE in particular. Capable management and technical staff are paramount in order to achieve better performance. Offering a continuous theoretical and practical training based on the need is also important due to the complex nature of water loss and leakage commitment of staffs at all level is also very important.

4.3.2.2 Establishing Pressure management

Pressure is one of the major causes of water loss in this town as stated in section 4.2.3.3 above. Therefore, pressure management is very important to reduce the amount of water loss in distribution system. It is recommended to use the reduced pressure that was done in distribution system modeling part of this study.

4.3.2.3 Proper maintenance and renewal

One of the major causes for the increase of water loss is the usage of poor quality materials and poor workmanship. In spite of the many pipe networks in the city seem to have younger ages, the loss found from the analysis reaches up to 42.69% of the production. The main reason for this might be the usage of poor quality of material and poor workmanship. Therefore, care should be taken while maintaining existing networks and installation of new ones. While rehabilitation of any mains is planned, due attention should be given to maintain as well the service connections fed from the mains. Most leakage occurs on service connections and, unless the service connections are also renewed, the benefit may not be a great as the first estimated.

4.3.2.4 Regular inspection of the water network

Ones the locations of highly suspected leaking networks are identified regular inspection supports to find the problematic areas and take action immediately before much water is wasted. Regular inspection should not be limited only to the network systems and supply meters but also to the customer meters.

4.3.2.5 Calibration and replacement of customer meters

One of the main causes for the water loss is the under-recording of customer meters. The usage of poor material quality also holds true for the customer meters. Unless meters are regularly calibrated and those not functioning well are either maintained or replaced the water loss reduction program will not be effective. Until recently, the water authority was checking the customer meters only if it is requested by the customers themselves, but this might only help the customer not to pay more as such requests are usually for over registration. Therefore systematic check up of the customer meters is important not only to identify the magnitude of the loss but also to maintain and replace when necessary.

4.3.3 Economical Dimension of Water Loss

In Nekemte city only starting from July 2017 to June 2018 the recorded water loss amount is 42.69% out of the total production. This amount is 1,305,636.97 cubic meter out of the total water production 3,050,269.97 Cubic meter per year. As Nekemte water supply and sewerage service data indicates the minimum selling cost of water supply is 4 Ethiopian birr (4 ETB) per metric cube. If it is assumed that unit water production cost is half price of selling, total cost of water loss for Nekemte city will be 7,833,821.82 Birr per year.

4.4 Distribution Systems Modeling

As a result of rapid population growth and high water losses from the distribution network, the total water demand of the system in Nekemte city exceeds available production capacity. To limit total demand and provide an equitable distribution of available water supplies with reduced system pressures are often introduced. The demand for water dependent only on the available pressure heads in the network. The objective of this modeling was not to predict the exact time at which different users get water but to develop a simplified model, node demand is dependent on the pressure at the junction nodes to reduce the water loss, maximize the flow rate at the low tap and extending the additional pipe line where the main pipe line was not reach.

4.4.1 Water GEMS

This model uses an assortment of data, input, and output files. It is important to understand which essential, temporary holding places for results are and which must be transmitted when sending a model to another user. In general, the model is contained in a file with the wtg.mdb extension. This file contains essentially all of the information needed to run the model. This model gives the choice between performing a steady-state analysis of the system or performing an extended-period simulation over any time period.

Distribution system was simulated by Water GEMs. which used to evaluate two alternative scenarios to improve system performance. The objective of the first scenario was to increase the flow rate at taps of low supply and the second scenario aimed at adding taps to parts of the sub-system without easy access to running.

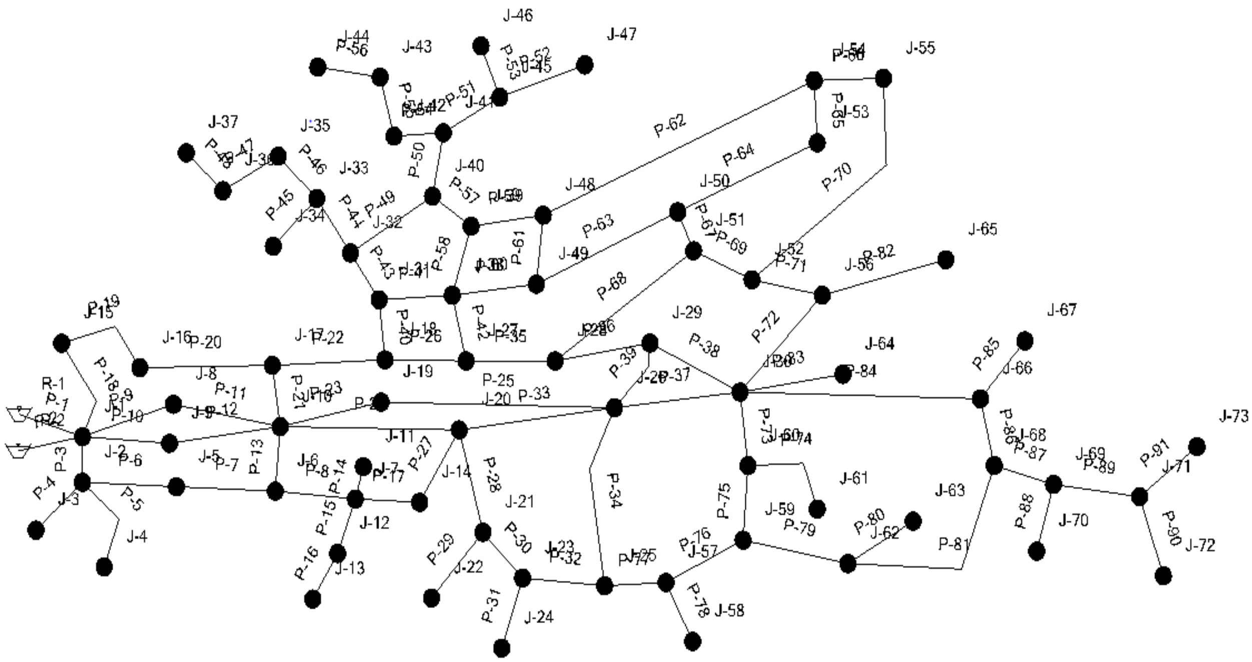


Fig.4.3 modeling of the main system

4.4.4.2 Results of distribution model

There are extremes of low and high pressure throughout the system mainly due to the topography of the area and the elevation of the distribution reservoirs and junction. Using two scenarios as Water GEMs output indicates pressure at deferent nodes are reduced for high pressure and also increased for low pressure at the junctions. In the second scenario of pipe distribution around 2150m length of new pipe was distributed and gain water sufficiently.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Nekemte city is one of the urban cities in Ethiopia whose population of the city is growing rapidly from time to time more than expected amount. Therefore, supplying an adequate drinking water in standard level is very difficult. Financial problem is also one of the major factors for the low water coverage of the water supply but poor management of the existing water supply also has a great impact for the low coverage.

The average water supply coverage in city distribution system was evaluated based on the daily per capital consumption and level of connection using the population data of the city. The average water supply coverage of the city is found to be 38.57 liter/person/day. This amount is very low when we compare with the second growth and development of Ethiopia (2nd GTP) which is stated as "for category 2 towns/cities (towns/cities with a population in the range of 100,000- 1million), per capita consumption must be minimum of 80 liter/capita/day within a distance of 250m", Accordingly the water supply coverage of the city was estimated to be 48.21%.

Result of this study indicates that, out of the total water production 3,050,269.97 Cubic meter per year 1,305,636.97 Cubic meter was considered as loss. When we put this value in terms of percent, 42.69% out of the production was loss before reaching the consumer by different causes like:- Poor pipe installation, Illegal connection, Loss due to pressure, Loss due to meter error, Loss due to age of pipe network.

Distribution system was simulated by Water GEMs. which used to evaluate two alternative scenarios to improve system performance. The first scenario consisted extended period simulation to increase the flow rate at taps of low supply. This scenario was recommended for some parts of the city. The second scenario was hardly recommended to satisfy the community who did not get distribution network still.

5.2 Recommendation

To improve the existing water supply services in the town in terms of quality and quantity, fair distribution, reliability and sustainability, the following measures need to be taken to alleviate the existing water supply and consumption problems.

- To deal with the problem of inadequate water supply in the town, it is highly recommended to reduce the amount of water loss in distribution system. If water loss controlled, water supply coverage of the city was increased from 38.57 liter/person/day to 67.44 liter/capita/day or from 48.21% to 84.3%.in addition, there must be additional water sources and pumping stations as well as there have to be many independent water connection networks in all kebeles including border of the town. Besides, extra pipes should be expanded to new residential areas.
- Since the topography of the city was at up and down elevation and also the major causes of water loss in this cities are leakage due to pressure, it is recommended to reduce pressure in distribution system as indicated in appendix III.
- Now-a-days, small streams become non-perennial; rivers are drying up due to frequent climate variability. Therefore, due attention has to be given to these drinking water sources so that proper conservation and protection need to be practiced to increase municipal water supply in the town.
- Households with a very low income cannot afford the cost of meter connection charges and pipes so that they should be provided short term credit to be beneficiary from the services.
- Since adequate annual rainfalls exist in the town, it is wise to use feasible techniques to use rainwater; experts need to introduce modern rainwater harvesting technology so that households can easily use it.

REFERENCES

AbdelMeguid H and Ulanicki B (2010). "Pressure and Leakage Management in Water Distribution Systems via Flow Modulation PRVs." *Proceedings of the 11th Water Distribution SystemAnalysis Conference (WDSA 2010)*, Tuscon, Arizona.

AL-Ghamdi A. S. and Gutub, S. A. (2002). "Estimation of leakage in the water distribution network of the holy city of Makkah." *Journal of Water Supply: Research and Technology-AQUA*, 51(6), 343-349.

Almandoz.et.al, (2005). "Leakage Assessment through Water Distribution Network Simulation." *Journal of Water Resources Planning and Management*, 13(1), 458-466.

AWWA, 2009. *Water Audits and Loss Control Programs: AWWA Manual M36.*. Denver, USA: American Water Works Association.

Babel.et.al.(2009). "Leakage Management in a low-pressure water distribution network of Bangkok." *Water Science and Technology: Water Supply*, 9(2), 141-147.

Bereket B.(2006). Evaluation of water supply systems in selected urban poor areas of Addis Ababa. MSc Thesis. UNESCO-IHE Institute for Water Education, Delft, The Netherlands. 135p

Dessalegh, W.B.(2006). *Water supply coverage and water loss in distribution systems, the case of Addis Ababa.* Thesis submitted to the International Institute for Geo-information Science and Earth Observation, Enscede, The Netherland.

Dighade.et.al(2014),*Challenges in water loss management ofwater distribution system in developing countries.* International Journal of Innovative Research in Science, Engineering and Technology, 3 (6), 13838 – 13846

Farley M and Trow S (2003), Losses in Water Distribution Networks: A Practitioner's Guide to Assessment, Monitoring and Control. IWA Publishing, Alliance House, 12 Caxton St., London, UK.

Federal democratic republic of Ethiopia ministry of water, irrigation and electricity (2016). urban water supply and sanitation project-II Revised Draft Resettlement Policy Framework (RPF), Addis Ababa, Ethiopia. Page1

Federal democratic republic of Ethiopia ministry of water, irrigation and electricity(2015), Second Growth and Transformation National Plan for the Water Supply and Sanitation Sub Sector,Addis Ababa, Ethiopia

Grigg,N.S.(2007). *Main Break Prediction, Prevention, and Control,* Denver, Colorado: AWWA Research Foundation.

Harrison E.M(2012). *Water Loss Management Tools and Methods for Developing Countries.* Netherland: CRC Press/Balkema.

IWA (2003). *Assessing Non-Revenue Water and its Components, IWA* 21(2). 458-462

Kingdom.et.al, (2006). *The Challenge of Reducing Non-Revenue Water (NRW) in Developing Countries,* Washington DC, USA: The World Bank.

Pelletier.et.al, (2003). "Modeling water pipe breaks-three case studies." *Journal of Water Resources Planning and Management*, 129(2), 115-123.

Thornton.et.al, (2008). *Water Loss Control,* New York: McGraw-Hill.

Thornton,J(2003). *Managing Leakage by Managing Pressure.Journal of Water Resources Planning and Management, 21(3), 325-327*

Tomas.et.al, (2003). *Advanced water distribution modeling and management.* USA: Haestad Press.

UNICEF and WHO, (2017). *Progress on Drinking Water, Sanitation and Hygiene,* Geneva: WHO.

USEPA, (2009). *Review draft control and mitigation of drinking water losses in distribution systems*.

Wallingford.HR(2003). *Handbook for the Assessment of Catchment Water Demand and Use.*

WHO, 2001. *World Health Organization, Global Water Supply and Sanitation assessment,*

APPENDIX I Data collection instruments

A) Questioner paper filled by local experts

Name of the company____

Position____

1. Is there any difference in level of water distribution among different localities?

   a) Yes b) No c) I don't know

   If yes, how do you balance the supply?____

   ____?

2. Is there any seasonal difference in volume of water supply?

   a) Yes b) No c) I don't know

   If yes to what extent? ____

3. If the failure of pump or pipe crack will occur do you have any spare parts to replace immediately? _______

4. If yes from where? ____

5. Are there any unmetered water consumptions at city level?_______If so for what purpose_ ____and how do you measure the volume of unmetered consumed water?____

   ____

6. How do you estimate the residential water demand?_______________________________ ____________Do you have any standard?_______________

7. How do you know if there is leakage or breakage of water pipes in distribution system?__

   ____

8. In what method the communities support you in reporting leakage or breakage of pipes?__

   ____

9. How do you know if water meters become defective?______________________________

   ____

10. Do the customers report on time in case of defective water meter?_____________If yes, do they report equally for both in case of the defect causing over readings and under readings?___________In case they didn't report how do you monitor it?_______________

11. What are the cause of loss that you encounter from the following? Give a rank in the box provided in front of each cause.

Illegal connection		Leakage due to meter error		Poor pipe installation	
Leakage due to pressure		Leakage due to age of pipe		Leakage due to water scheduling	

Others, Specify____

12. How do you manage the pressure with the big elevation difference of the city?__________

____

13. Do you have a plan to replace the old pipes and water meters?_____, What major criteria do you use for prioritization of replacement?______________________________________

14. Do you have any plan regarding leakage reduction in the city?______________________

B) Questioner paper filled by local community

Name of the kebele ___________________________Sex _______________

Age ________Work___________________________level of education______________________

______size (number of your family)________________________

1) Do you have pipe connected to your home? (A) Yes (B) No

- If yes, how many days does your tap flow in a week? _______________
- If not, how far do you walk to fetch water? _______________________

2) On the average how many buckets (34 cm size/ 4 gallons) of water do you need for your household per day?

3) . Is the water you fetch sufficient to meet your household requirements? (1) Yes (2) No

4) If you have pipe connected to your home, how much do you pay (on the average) as water bill per month?

5) What do you think are the possible causes of the water problems in your area?

APPENDIX II Water GEMs output paramètres for curent system

A) For Steady state analyses

FlexTable: Junction Table

ID	Label	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C	Minor Loss Coefficient (Local)	Flow (L/s)	Velocity (m/s)	Headloss Gradient (m/m)	Length (User Defined) (m)
105	P-1	R-1	J-1	500.0	PVC	150.0	0.000	361	1.84	0.004	4,800
106	P-2	J-1	R-2	200.0	PVC	150.0	0.000	-31	0.98	0.004	4,800
107	P-3	J-1	J-2	150.0	PVC	150.0	0.000	20	1.11	0.007	1,250
108	P-4	J-2	J-3	80.0	PVC	150.0	0.000	4	0.80	0.008	1,100
109	P-5	J-2	J-4	80.0	PVC	150.0	0.000	4	0.80	0.008	700
110	P-6	J-2	J-5	100.0	PVC	150.0	0.000	7	0.84	0.007	700
111	P-7	J-5	J-6	250.0	PVC	150.0	0.000	2	0.03	0.000	500
112	P-8	J-6	J-7	250.0	PVC	150.0	0.000	8	0.15	0.000	700
113	P-9	J-1	J-8	400.0	PVC	150.0	0.000	123	0.98	0.002	700
114	P-10	J-1	J-9	400.0	PVC	150.0	0.000	123	0.98	0.002	700
115	P-11	J-8	J-10	400.0	PVC	150.0	0.000	113	0.90	0.002	900
116	P-12	J-9	J-10	400.0	PVC	150.0	0.000	113	0.90	0.002	900
117	P-13	J-10	J-6	100.0	PVC	150.0	0.000	10	1.32	0.016	700
118	P-14	J-7	J-11	80.0	PVC	150.0	0.000	3	0.60	0.005	400
119	P-15	J-7	J-12	100.0	PVC	150.0	0.000	8	1.02	0.010	800
120	P-16	J-12	J-13	50.0	PVC	150.0	0.000	3	1.78	0.061	750
121	P-17	J-7	J-14	200.0	PVC	150.0	0.000	-9	0.30	0.000	800
122	P-18	J-1	J-15	400.0	PVC	150.0	0.000	97	0.77	0.001	600
123	P-19	J-15	J-16	400.0	PVC	150.0	0.000	88	0.70	0.001	1,500
124	P-20	J-16	J-17	400.0	PVC	150.0	0.000	80	0.64	0.001	950
125	P-21	J-17	J-10	300.0	PVC	150.0	0.000	-50	0.71	0.001	200
126	P-22	J-17	J-18	350.0	PVC	150.0	0.000	119	1.24	0.003	700
127	P-23	J-10	J-19	300.0	PVC	150.0	0.000	62	0.88	0.002	700
128	P-24	J-10	J-20	300.0	PVC	150.0	0.000	83	1.18	0.003	1,600
129	P-25	J-19	J-26	250.0	PVC	150.0	0.000	49	1.01	0.003	1,750
130	P-26	J-18	J-27	300.0	PVC	150.0	0.000	73	1.03	0.003	950
131	P-27	J-20	J-14	100.0	PVC	150.0	0.000	13	1.72	0.025	200
132	P-28	J-20	J-21	200.0	PVC	150.0	0.000	21	0.68	0.002	550
133	P-29	J-21	J-22	80.0	PVC	150.0	0.000	3	0.60	0.005	600
134	P-30	J-21	J-23	150.0	PVC	150.0	0.000	13	0.76	0.003	450
135	P-31	J-23	J-24	80.0	PVC	150.0	0.000	4	0.80	0.008	600
136	P-32	J-23	J-25	100.0	PVC	150.0	0.000	5	0.69	0.005	300
137	P-33	J-20	J-26	250.0	PVC	150.0	0.000	36	0.74	0.002	850
138	P-34	J-26	J-25	150.0	PVC	150.0	0.000	12	0.70	0.003	850
139	P-35	J-27	J-28	200.0	PVC	150.0	0.000	25	0.80	0.003	700
140	P-36	J-28	J-29	150.0	PVC	150.0	0.000	8	0.45	0.001	400
141	P-37	J-26	J-30	300.0	PVC	150.0	0.000	42	0.60	0.001	1,500
142	P-38	J-30	J-29	200.0	PVC	150.0	0.000	-19	0.61	0.002	600
143	P-39	J-29	J-26	200.0	PVC	150.0	0.000	-16	0.52	0.001	400
144	P-40	J-18	J-31	200.0	PVC	150.0	0.000	38	1.22	0.006	950

ID	Label	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C	Minor Loss Coefficient (Local)	Flow (L/s)	Velocity (m/s)	Headloss Gradient (m/m)	Length (User Defined) (m)
145	P-41	J-31	J-38	250.0	PVC	150.0	0.000	-18	0.37	0.001	400
146	P-42	J-38	J-27	150.0	PVC	150.0	0.000	-42	2.37	0.029	100
147	P-43	J-31	J-32	200.0	PVC	150.0	0.000	49	1.55	0.009	150
148	P-44	J-32	J-33	100.0	PVC	150.0	0.000	16	2.04	0.035	700
149	P-45	J-33	J-34	150.0	PVC	150.0	0.000	2	0.11	0.000	700
150	P-46	J-33	J-35	80.0	PVC	150.0	0.000	9	1.79	0.036	1,250
151	P-47	J-35	J-36	80.0	PVC	150.0	0.000	5	0.99	0.012	800
152	P-48	J-36	J-37	80.0	PVC	150.0	0.000	2	0.40	0.002	850
153	P-49	J-32	J-40	200.0	PVC	150.0	0.000	27	0.85	0.003	200
154	P-50	J-40	J-41	150.0	PVC	150.0	0.000	17	0.99	0.006	300
155	P-51	J-41	J-45	100.0	PVC	150.0	0.000	7	0.83	0.007	500
156	P-52	J-45	J-47	100.0	PVC	150.0	0.000	2	0.25	0.001	700
157	P-53	J-45	J-46	150.0	PVC	150.0	0.000	2	0.11	0.000	600
158	P-54	J-41	J-42	100.0	PVC	150.0	0.000	8	0.95	0.009	600
159	P-55	J-42	J-43	80.0	PVC	150.0	0.000	5	0.90	0.010	1,000
160	P-56	J-43	J-44	80.0	PVC	150.0	0.000	2	0.40	0.002	290
161	P-57	J-40	J-39	100.0	PVC	150.0	0.000	5	0.66	0.004	600
162	P-58	J-39	J-38	100.0	PVC	150.0	0.000	-8	1.08	0.011	450
163	P-59	J-39	J-48	200.0	PVC	150.0	0.000	10	0.31	0.000	450
164	P-60	J-38	J-49	100.0	PVC	150.0	0.000	8	1.03	0.010	700
165	P-61	J-49	J-48	100.0	PVC	150.0	0.000	-3	0.44	0.002	900
166	P-62	J-48	J-54	50.0	PVC	150.0	0.000	3	1.62	0.051	250
167	P-63	J-49	J-50	100.0	PVC	150.0	0.000	6	0.71	0.005	300
168	P-64	J-50	J-53	80.0	PVC	150.0	0.000	5	1.01	0.012	450
169	P-65	J-53	J-54	50.0	PVC	150.0	0.000	1	0.54	0.007	600
170	P-66	J-54	J-55	100.0	PVC	150.0	0.000	1	0.16	0.000	300
171	P-67	J-50	J-51	100.0	PVC	150.0	0.000	-4	0.51	0.003	500
172	P-68	J-51	J-28	100.0	PVC	150.0	0.000	-12	1.50	0.020	400
173	P-69	J-51	J-52	80.0	PVC	150.0	0.000	3	0.55	0.004	550
174	P-70	J-52	J-55	50.0	PVC	150.0	0.000	1	0.64	0.009	950
175	P-71	J-52	J-56	150.0	PVC	150.0	0.000	-3	0.17	0.000	300
176	P-72	J-56	J-30	100.0	PVC	150.0	0.000	-9	1.21	0.013	650
177	P-73	J-30	J-60	80.0	PVC	150.0	0.000	12	2.33	0.058	400
178	P-74	J-60	J-61	50.0	PVC	150.0	0.000	3	1.53	0.046	3,500
179	P-75	J-60	J-59	50.0	PVC	150.0	0.000	3	1.38	0.038	200
180	P-76	J-59	J-57	100.0	PVC	150.0	0.000	-2	0.22	0.001	500
181	P-77	J-57	J-25	80.0	PVC	150.0	0.000	-11	2.13	0.049	600
182	P-78	J-57	J-58	80.0	PVC	150.0	0.000	3	0.60	0.005	950
183	P-79	J-59	J-62	150.0	PVC	150.0	0.000	0	0.02	0.000	650
184	P-80	J-62	J-63	100.0	PVC	150.0	0.000	3	0.38	0.002	700
185	P-81	J-62	J-68	80.0	PVC	150.0	0.000	-7	1.31	0.020	1,050
186	P-82	J-56	J-65	100.0	PVC	150.0	0.000	3	0.32	0.001	300
187	P-83	J-30	J-64	100.0	PVC	150.0	0.000	3	0.32	0.001	800
188	P-84	J-30	J-66	200.0	PVC	150.0	0.000	27	0.86	0.003	1,200

ID	Label	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C	Minor Loss Coefficient (Local)	Flow (L/s)	Velocity (m/s)	Headloss Gradient (m/m)	Length (User Defined) (m)
189	P-85	J-66	J-67	100.0	PVC	150.0	0.000	2	0.25	0.001	250
190	P-86	J-66	J-68	150.0	PVC	150.0	0.000	21	1.19	0.008	750
191	P-87	J-68	J-69	100.0	PVC	150.0	0.000	10	1.34	0.016	250
192	P-88	J-69	J-70	80.0	PVC	150.0	0.000	2	0.40	0.002	500
193	P-89	J-69	J-71	100.0	PVC	150.0	0.000	5	0.64	0.004	350
194	P-90	J-71	J-72	80.0	PVC	150.0	0.000	1	0.30	0.001	250
195	P-91	J-71	J-73	80.0	PVC	150.0	0.000	1	0.30	0.001	450

FlexTable: Junction Table

ID	Label	Elevation (m)	Demand (L/s)	Hydraulic Grade (m)	Pressure (m H2O)
32	J-1	2,038.00	29	2,200.21	162
33	J-2	2,058.00	5	2,191.37	133
34	J-3	2,060.00	4	2,182.64	122
35	J-4	2,060.00	4	2,185.81	126
36	J-5	1,950.00	5	2,186.61	236
37	J-6	2,070.00	5	2,186.61	116
38	J-7	2,080.00	6	2,186.54	106
39	J-8	2,035.00	10	2,198.96	164
40	J-9	2,040.00	10	2,198.96	159
41	J-10	2,045.00	20	2,197.59	152
42	J-11	1,955.00	3	2,184.67	229
43	J-12	1,950.00	5	2,178.80	228
44	J-13	2,010.00	3	2,132.89	123
45	J-14	2,072.00	4	2,186.90	115
46	J-15	2,050.00	9	2,199.52	149
47	J-16	2,050.00	8	2,198.07	148
48	J-17	2,050.00	11	2,197.31	147
49	J-18	2,030.00	8	2,195.05	165
50	J-19	2,050.00	13	2,196.14	146
51	J-20	2,010.00	12	2,191.99	182
52	J-21	2,072.00	5	2,190.87	119
53	J-22	2,035.00	3	2,188.07	153
54	J-23	2,070.00	4	2,189.30	119
55	J-24	2,110.00	4	2,184.54	74
56	J-25	2,030.00	7	2,187.91	158
57	J-26	2,083.00	15	2,190.44	107
58	J-27	2,080.00	6	2,192.42	112
59	J-28	2,090.00	6	2,190.48	100
60	J-29	2,085.00	5	2,189.95	105
61	J-30	2,073.00	10	2,188.95	116
62	J-31	2,070.00	8	2,189.33	119
63	J-32	2,010.00	6	2,187.93	178
64	J-33	2,070.00	5	2,163.49	93
65	J-34	2,070.00	2	2,163.42	93
66	J-35	1,950.00	4	2,118.91	169
67	J-36	2,050.00	3	2,109.31	59
68	J-37	2,030.00	2	2,107.44	77
69	J-38	2,080.00	7	2,189.54	109
70	J-39	2,070.00	4	2,184.71	114
71	J-40	2,070.00	4	2,187.31	117
72	J-41	2,075.00	3	2,185.60	110
73	J-42	2,070.00	3	2,180.45	110

ID	Label	Elevation (m)	Demand (L/s)	Hydraulic Grade (m)	Pressure (m H2O)
74	J-43	2,070.00	3	2,170.57	100
75	J-44	1,995.00	2	2,169.93	175
76	J-45	2,065.00	3	2,182.30	117
77	J-46	2,060.00	2	2,182.24	122
78	J-47	2,055.00	2	2,181.79	127
79	J-48	2,060.00	3	2,184.50	124
80	J-49	2,065.00	6	2,182.65	117
81	J-50	2,055.00	5	2,181.18	126
82	J-51	2,045.00	5	2,182.53	137
83	J-52	2,055.00	5	2,180.30	125
84	J-53	2,045.00	4	2,175.66	130
85	J-54	2,070.00	3	2,171.65	101
86	J-55	2,075.00	3	2,171.56	96
87	J-56	2,052.00	4	2,180.36	128
88	J-57	2,070.00	6	2,158.39	88
89	J-58	1,980.00	3	2,153.96	174
90	J-59	2,090.00	4	2,158.11	68
91	J-60	2,060.00	6	2,165.73	106
92	J-61	2,085.00	3	2,004.69	-80
93	J-62	2,110.00	4	2,158.11	48
94	J-63	2,110.00	3	2,157.01	47
95	J-64	2,090.00	3	2,188.06	98
96	J-65	2,065.00	3	2,180.02	115
97	J-66	2,095.00	4	2,185.16	90
98	J-67	2,095.00	2	2,184.97	90
99	J-68	2,130.00	4	2,179.10	49
100	J-69	2,135.00	3	2,175.10	40
101	J-70	2,115.00	2	2,174.00	59
102	J-71	2,150.00	2	2,173.68	24
103	J-72	2,160.00	1	2,173.36	13
104	J-73	2,145.00	1	2,173.10	28

B) First scenario extended period simulation

FlexTable: Pipe Table

Current Time: 0.000 hours

ID	Label	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C	Flow (L/s)	Velocity (m/s)	Headloss Gradient (m/m)	Length (User Defined) (m)
105	P-1	R-1	J-1	500	PVC	150	284	1.44	0.003	4,800
106	P-2	J-1	R-2	200	PVC	150	-24	0.75	0.002	4,800
107	P-3	J-1	J-2	150	PVC	150	26	1.44	0.012	1,250
108	P-4	J-2	J-3	80	PVC	150	4	0.83	0.009	1,100
109	P-5	J-2	J-4	80	PVC	150	4	0.7	0.006	700
110	P-6	J-2	J-5	100	PVC	150	13	1.64	0.023	700
111	P-7	J-5	J-6	250	PVC	150	8	0.16	0	500
112	P-8	J-6	J-7	250	PVC	150	18	0.37	0.001	700
114	P-10	J-1	J-9	400	PVC	150	256	2.04	0.007	700
115	P-11	J-8	J-10	400	PVC	150	-9	0.07	0	900
116	P-12	J-9	J-10	400	PVC	150	248	1.97	0.007	900
117	P-13	J-10	J-6	100	PVC	150	14	1.83	0.029	700
118	P-14	J-7	J-11	80	PVC	150	3	0.54	0.004	400
119	P-15	J-7	J-12	100	PVC	150	7	0.89	0.008	800
120	P-16	J-12	J-13	50	PVC	150	3	1.5	0.045	750
121	P-17	J-7	J-14	200	PVC	150	3	0.1	0	800
123	P-19	J-15	J-16	400	PVC	150	-9	0.07	0	1,500
124	P-20	J-16	J-17	400	PVC	150	-16	0.12	0	950
125	P-21	J-17	J-10	300	PVC	150	-103	1.46	0.005	200
126	P-22	J-17	J-18	350	PVC	150	78	0.81	0.001	700
127	P-23	J-10	J-19	300	PVC	150	46	0.64	0.001	700
128	P-24	J-10	J-20	300	PVC	150	56	0.8	0.002	1,600
129	P-25	J-19	J-26	250	PVC	150	34	0.69	0.002	1,750
130	P-26	J-18	J-27	300	PVC	150	72	1.02	0.003	950
132	P-28	J-20	J-21	200	PVC	150	18	0.57	0.001	550
133	P-29	J-21	J-22	80	PVC	150	3	0.6	0.005	600
134	P-30	J-21	J-23	150	PVC	150	11	0.6	0.002	450
135	P-31	J-23	J-24	80	PVC	150	4	0.7	0.006	600
136	P-32	J-23	J-25	100	PVC	150	4	0.5	0.003	300
137	P-33	J-20	J-26	250	PVC	150	26	0.54	0.001	850

ID	Label	Start Node	Stop Node	Diameter	Material	Hazen-Williams C	Flow	Velocity	Head loss Gradient	Length (User Defined)
138	P-34	J-26	J-25	150	PVC	150	10	0.57	0.002	850
139	P-35	J-27	J-28	200	PVC	150	17	0.55	0.001	700
140	P-36	J-28	J-29	150	PVC	150	4	0.24	0	400
142	P-38	J-30	J-29	200	PVC	150	-37	1.16	0.006	600
143	P-39	J-29	J-26	200	PVC	150	-36	1.15	0.005	400
145	P-41	J-31	J-38	250	PVC	150	-35	0.71	0.002	400
146	P-42	J-38	J-27	150	PVC	150	-50	2.83	0.04	100
147	P-43	J-31	J-32	200	PVC	150	29	0.91	0.004	150
148	P-44	J-32	J-33	100	PVC	150	10	1.29	0.015	700
149	P-45	J-33	J-34	150	PVC	150	2	0.09	0	700
150	P-46	J-33	J-35	80	PVC	150	5	0.9	0.01	1,250
151	P-47	J-35	J-36	80	PVC	150	3	0.5	0.003	800
152	P-48	J-36	J-37	80	PVC	150	1	0.2	0.001	850
153	P-49	J-32	J-40	200	PVC	150	14	0.46	0.001	200
154	P-50	J-40	J-41	150	PVC	150	10	0.56	0.002	300
155	P-51	J-41	J-45	100	PVC	150	3	0.41	0.002	500
156	P-52	J-45	J-47	100	PVC	150	1	0.13	0	700
157	P-53	J-45	J-46	150	PVC	150	1	0.06	0	600
158	P-54	J-41	J-42	100	PVC	150	4	0.48	0.002	600
159	P-55	J-42	J-43	80	PVC	150	2	0.45	0.003	1,000
160	P-56	J-43	J-44	80	PVC	150	1	0.2	0.001	290
161	P-57	J-40	J-39	100	PVC	150	2	0.31	0.001	600
162	P-58	J-39	J-38	100	PVC	150	-5	0.68	0.005	450
163	P-59	J-39	J-48	200	PVC	150	5	0.15	0	450
164	P-60	J-38	J-49	100	PVC	150	4	0.57	0.003	700
165	P-61	J-49	J-48	100	PVC	150	-1	0.13	0	900
166	P-62	J-48	J-54	50	PVC	150	2	0.78	0.013	250
167	P-63	J-49	J-50	100	PVC	150	1	0.16	0	300
168	P-64	J-50	J-53	80	PVC	150	3	0.52	0.004	450
169	P-65	J-53	J-54	50	PVC	150	1	0.3	0.002	600
170	P-66	J-54	J-55	100	PVC	150	1	0.08	0	300
171	P-67	J-50	J-51	100	PVC	150	-4	0.46	0.002	500
172	P-68	J-51	J-28	100	PVC	150	-8	1.08	0.011	400
173	P-69	J-51	J-52	80	PVC	150	2	0.48	0.003	550
174	P-70	J-52	J-55	50	PVC	150	1	0.32	0.003	950

ID	Label	Start Node	Stop Node	Diameter	Material	Hazen-Williams C	Flow	Velocity	Head loss Gradient	Length (User Defined)
175	P-71	J-52	J-56	150	PVC	150	-2	0.09	0	300
176	P-72	J-56	J-30	100	PVC	150	-5	0.63	0.004	650
177	P-73	J-30	J-60	80	PVC	150	7	1.41	0.023	400
178	P-74	J-60	J-61	50	PVC	150	1	0.76	0.013	3,500
179	P-75	J-60	J-59	50	PVC	150	1	0.71	0.011	200
180	P-76	J-59	J-57	100	PVC	150	-1	0.14	0	500
181	P-77	J-57	J-25	80	PVC	150	-7	1.48	0.025	600
182	P-78	J-57	J-58	80	PVC	150	2	0.42	0.002	950
183	P-79	J-59	J-62	150	PVC	150	1	0.03	0	650
184	P-80	J-62	J-63	100	PVC	150	1	0.19	0	700
185	P-81	J-62	J-68	80	PVC	150	-4	0.78	0.008	1,050
186	P-82	J-56	J-65	100	PVC	150	1	0.16	0	300
187	P-83	J-30	J-64	100	PVC	150	1	0.16	0	800
188	P-84	J-30	J-66	200	PVC	150	15	0.48	0.001	1,200
189	P-85	J-66	J-67	100	PVC	150	1	0.13	0	250
190	P-86	J-66	J-68	150	PVC	150	12	0.68	0.003	750
191	P-87	J-68	J-69	100	PVC	150	5	0.67	0.004	250
192	P-88	J-69	J-70	80	PVC	150	1	0.2	0.001	500
193	P-89	J-69	J-71	100	PVC	150	3	0.32	0.001	350
194	P-90	J-71	J-72	80	PVC	150	1	0.15	0	250
195	P-91	J-71	J-73	80	PVC	150	1	0.15	0	450
199	P-92	J-1	PRV-1	400	PVC	150	0	0	0	268
200	P-93	PRV-1	J-8	400	PVC	150	0	0	0	432
202	P-94	J-1	PRV-2	400	PVC	150	0	0	0	284
203	P-95	PRV-2	J-15	400	PVC	150	0	0	0	316
205	P-96	J-20	PRV-3	100	PVC	150	0	0	0	63
206	P-97	PRV-3	J-14	100	PVC	150	0	0	0	137
208	P-98	J-18	PRV-4	200	PVC	150	0	0	0	466
209	P-99	PRV-4	J-31	200	PVC	150	0	0	0	484
211	P-100	J-26	PRV-5	300	PVC	150	0	0	0	653
212	P-101	PRV-5	J-30	300	PVC	150	0	0	0	847

Flex Table: Junction Table

Current Time: 0.000 hours

ID	Label	Elevation (m)	Demand (L/s)	Hydraulic Grade (m)	Pressure (m H2O)
32	J-1	2,038.00	25	2,207.85	56
33	J-2	2,058.00	5	2,193.48	23
34	J-3	2,060.00	4	2,184.12	67
35	J-4	2,060.00	4	2,189.13	29
36	J-5	1,950.00	5	2,177.14	47
37	J-6	2,070.00	4	2,177.09	38
38	J-7	2,080.00	5	2,176.72	97
39	J-8	2,035.00	9	2,197.12	62
40	J-9	2,040.00	9	2,203.00	63
41	J-10	2,045.00	19	2,197.13	52
42	J-11	1,955.00	3	2,175.19	20
43	J-12	1,950.00	4	2,170.68	22
44	J-13	2,010.00	3	2,137.23	17
45	J-14	2,072.00	3	2,176.68	49
46	J-15	2,050.00	9	2,196.03	46
47	J-16	2,050.00	7	2,196.05	76
48	J-17	2,050.00	9	2,196.09	64
49	J-18	2,030.00	6	2,195.05	38
50	J-19	2,050.00	12	2,196.33	24
51	J-20	2,010.00	12	2,194.40	74
52	J-21	2,072.00	4	2,193.59	52
53	J-22	2,035.00	3	2,190.80	55
54	J-23	2,070.00	3	2,192.57	22
55	J-24	2,110.00	4	2,188.85	29

ID	Label	Elevation (m)	Demand (L/s)	Hydraulic Grade (m)	Pressure (m H2O)
56	J-25	2,030.00	7	2,191.80	42
57	J-26	2,083.00	14	2,193.53	-23
58	J-27	2,080.00	5	2,192.50	10
59	J-28	2,090.00	5	2,191.54	17
60	J-29	2,085.00	4	2,191.38	42
61	J-30	2,073.00	8	2,188.08	15
62	J-31	2,070.00	6	2,187.84	-30
63	J-32	2,010.00	4	2,187.31	27
64	J-33	2,070.00	4	2,176.88	17
65	J-34	2,070.00	2	2,176.84	32
66	J-35	1,950.00	2	2,164.54	24
67	J-36	2,050.00	1	2,161.87	12
68	J-37	2,030.00	1	2,161.36	31
69	J-38	2,080.00	5	2,188.52	18
70	J-39	2,070.00	3	2,186.45	16
71	J-40	2,070.00	2	2,187.11	58
72	J-41	2,075.00	3	2,186.51	-56
73	J-42	2,070.00	1	2,185.08	19
74	J-43	2,070.00	1	2,182.35	56
75	J-44	1,995.00	1	2,182.17	67
76	J-45	2,065.00	1	2,185.60	20
77	J-46	2,060.00	1	2,185.58	25
78	J-47	2,055.00	1	2,185.45	13
79	J-48	2,060.00	2	2,186.40	26
80	J-49	2,065.00	4	2,186.22	12

ID	Label	Elevation (m)	Demand (L/s)	Hydraulic Grade (m)	Pressure (m H2O)
81	J-50	2,055.00	2	2,186.12	101
82	J-51	2,045.00	3	2,187.22	87
83	J-52	2,055.00	3	2,185.50	30
84	J-53	2,045.00	2	2,184.51	39
85	J-54	2,070.00	1	2,183.12	53
86	J-55	2,075.00	1	2,183.09	48
87	J-56	2,052.00	2	2,185.53	93
88	J-57	2,070.00	4	2,176.84	17
89	J-58	1,980.00	2	2,174.56	94
90	J-59	2,090.00	2	2,176.72	-37
91	J-60	2,060.00	4	2,178.92	39
92	J-61	2,085.00	1	2,134.31	49
93	J-62	2,110.00	3	2,176.71	67
94	J-63	2,110.00	1	2,176.41	66
95	J-64	2,090.00	1	2,187.83	98
96	J-65	2,065.00	1	2,185.43	32
97	J-66	2,095.00	2	2,186.80	-18
98	J-67	2,095.00	1	2,186.75	28
99	J-68	2,130.00	3	2,184.65	55
100	J-69	2,135.00	2	2,183.54	48
101	J-70	2,115.00	1	2,183.24	68
102	J-71	2,150.00	1	2,183.15	33
103	J-72	2,160.00	1	2,183.06	23
104	J-73	2,145.00	1	2,182.99	46

C) Second Scenario EPS Distribution Network

Flex Table: Pipe Table

Current Time: 0.000 hours

ID	Label	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C	Flow (L/s)	Velocity (m/s)	Headloss Gradient (m/m)	Length (User Defined) (m)
105	P-1	R-1	J-1	500.0	PVC	150.0	289	1.47	0.003	4,800
106	P-2	J-1	R-2	200.0	PVC	150.0	-24	0.77	0.003	4,800
107	P-3	J-1	J-2	150.0	PVC	150.0	18	1.00	0.006	1,250
108	P-4	J-2	J-3	80.0	PVC	150.0	4	0.83	0.009	1,100
109	P-5	J-2	J-4	80.0	PVC	150.0	4	0.70	0.006	700
110	P-6	J-2	J-5	100.0	PVC	150.0	5	0.65	0.004	700
111	P-7	J-5	J-6	250.0	PVC	150.0	0	0.00	0.000	500
112	P-8	J-6	J-7	250.0	PVC	150.0	5	0.11	0.000	700
113	P-9	J-1	J-8	400.0	PVC	150.0	97	0.77	0.001	700
114	P-10	J-1	J-9	400.0	PVC	150.0	96	0.77	0.001	700
115	P-11	J-8	J-10	400.0	PVC	150.0	87	0.69	0.001	900
116	P-12	J-9	J-10	400.0	PVC	150.0	88	0.70	0.001	900
117	P-13	J-10	J-6	100.0	PVC	150.0	9	1.16	0.012	700
118	P-14	J-7	J-11	80.0	PVC	150.0	3	0.54	0.004	400
119	P-15	J-7	J-12	100.0	PVC	150.0	7	0.89	0.008	800
120	P-16	J-12	J-13	50.0	PVC	150.0	3	1.50	0.045	750
121	P-17	J-7	J-14	200.0	PVC	150.0	-10	0.31	0.000	800
122	P-18	J-1	J-15	400.0	PVC	150.0	78	0.62	0.001	600
123	P-19	J-15	J-16	400.0	PVC	150.0	69	0.55	0.001	1,500
124	P-20	J-16	J-17	400.0	PVC	150.0	58	0.46	0.000	950
125	P-21	J-17	J-10	300.0	PVC	150.0	-35	0.50	0.001	200
126	P-22	J-17	J-18	350.0	PVC	150.0	79	0.82	0.002	700
127	P-23	J-10	J-19	300.0	PVC	150.0	48	0.68	0.001	700
128	P-24	J-10	J-20	300.0	PVC	150.0	64	0.90	0.002	1,600
129	P-25	J-19	J-26	250.0	PVC	150.0	36	0.73	0.002	1,750
130	P-26	J-18	J-27	300.0	PVC	150.0	49	0.69	0.001	950
131	P-27	J-20	J-14	100.0	PVC	150.0	13	1.66	0.024	200
132	P-28	J-20	J-21	200.0	PVC	150.0	17	0.55	0.001	550
133	P-29	J-21	J-22	80.0	PVC	150.0	3	0.60	0.005	600
134	P-30	J-21	J-23	150.0	PVC	150.0	10	0.57	0.002	450
135	P-31	J-23	J-24	80.0	PVC	150.0	4	0.70	0.006	600
136	P-32	J-23	J-25	100.0	PVC	150.0	3	0.42	0.002	300
137	P-33	J-20	J-26	250.0	PVC	150.0	21	0.44	0.001	850
138	P-34	J-26	J-25	150.0	PVC	150.0	10	0.56	0.002	850
139	P-35	J-27	J-28	200.0	PVC	150.0	19	0.61	0.002	700
140	P-36	J-28	J-29	150.0	PVC	150.0	8	0.45	0.001	400

ID	Label	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C	Flow (L/s)	Velocity (m/s)	Headloss Gradient (m/m)	Length (User Defined) (m)
141	P-37	J-26	J-30	300.0	PVC	150.0	25	0.36	0.000	1,500
142	P-38	J-30	J-29	200.0	PVC	150.0	-12	0.39	0.001	600
143	P-39	J-29	J-26	200.0	PVC	150.0	-8	0.26	0.000	400
144	P-40	J-18	J-31	200.0	PVC	150.0	24	0.76	0.003	950
145	P-41	J-31	J-38	250.0	PVC	150.0	-9	0.17	0.000	400
146	P-42	J-38	J-27	150.0	PVC	150.0	-25	1.41	0.011	100
147	P-43	J-31	J-32	200.0	PVC	150.0	26	0.84	0.003	150
148	P-44	J-32	J-33	100.0	PVC	150.0	4	0.53	0.003	700
149	P-45	J-33	J-34	150.0	PVC	150.0	-3	0.15	0.000	700
150	P-46	J-33	J-35	80.0	PVC	150.0	3	0.56	0.004	1,250
151	P-47	J-35	J-36	80.0	PVC	150.0	1	0.16	0.000	800
152	P-48	J-36	J-37	80.0	PVC	150.0	-1	0.13	0.000	850
153	P-49	J-32	J-40	200.0	PVC	150.0	18	0.57	0.001	200
154	P-50	J-40	J-41	150.0	PVC	150.0	12	0.67	0.003	300
155	P-51	J-41	J-45	100.0	PVC	150.0	5	0.59	0.003	500
156	P-52	J-45	J-47	100.0	PVC	150.0	2	0.30	0.001	700
157	P-53	J-45	J-46	150.0	PVC	150.0	1	0.06	0.000	600
158	P-54	J-41	J-42	100.0	PVC	150.0	4	0.55	0.003	600
159	P-55	J-42	J-43	80.0	PVC	150.0	3	0.56	0.004	1,000
160	P-56	J-43	J-44	80.0	PVC	150.0	2	0.31	0.001	290
161	P-57	J-40	J-39	100.0	PVC	150.0	4	0.52	0.003	600
162	P-58	J-39	J-38	100.0	PVC	150.0	-6	0.75	0.006	450
163	P-59	J-39	J-48	200.0	PVC	150.0	7	0.22	0.000	450
164	P-60	J-38	J-49	100.0	PVC	150.0	5	0.65	0.004	700
165	P-61	J-49	J-48	100.0	PVC	150.0	-1	0.19	0.000	900
166	P-62	J-48	J-54	50.0	PVC	150.0	1	0.72	0.011	250
167	P-63	J-49	J-50	100.0	PVC	150.0	2	0.31	0.001	300
168	P-64	J-50	J-53	80.0	PVC	150.0	2	0.48	0.003	450
169	P-65	J-53	J-54	50.0	PVC	150.0	0	0.22	0.001	600
170	P-66	J-54	J-55	100.0	PVC	150.0	1	0.10	0.000	300
171	P-67	J-50	J-51	100.0	PVC	150.0	-2	0.29	0.001	500
172	P-68	J-51	J-28	100.0	PVC	150.0	-7	0.85	0.007	400
173	P-69	J-51	J-52	80.0	PVC	150.0	2	0.38	0.002	550
174	P-70	J-52	J-55	50.0	PVC	150.0	0	0.25	0.002	950
175	P-71	J-52	J-56	150.0	PVC	150.0	-2	0.11	0.000	300
176	P-72	J-56	J-30	100.0	PVC	150.0	-5	0.67	0.004	650
177	P-73	J-30	J-60	80.0	PVC	150.0	7	1.48	0.025	400
178	P-74	J-60	J-61	50.0	PVC	150.0	1	0.76	0.013	3,500
179	P-75	J-60	J-59	50.0	PVC	150.0	2	0.88	0.017	200
180	P-76	J-59	J-57	100.0	PVC	150.0	0	0.04	0.000	500
181	P-77	J-57	J-25	80.0	PVC	150.0	-7	1.32	0.020	600

ID	Label	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C	Flow (L/s)	Velocity (m/s)	Headloss Gradient (m/m)	Length (User Defined) (m)
182	P-78	J-57	J-58	80.0	PVC	150.0	2	0.42	0.002	950
183	P-79	J-59	J-62	150.0	PVC	150.0	0	0.00	0.000	650
184	P-80	J-62	J-63	100.0	PVC	150.0	1	0.19	0.000	700
185	P-81	J-62	J-68	80.0	PVC	150.0	-4	0.86	0.009	1,050
186	P-82	J-56	J-65	100.0	PVC	150.0	1	0.16	0.000	300
187	P-83	J-30	J-64	100.0	PVC	150.0	1	0.16	0.000	800
188	P-84	J-30	J-66	200.0	PVC	150.0	15	0.49	0.001	1,200
189	P-85	J-66	J-67	100.0	PVC	150.0	1	0.13	0.000	250
190	P-86	J-66	J-68	150.0	PVC	150.0	12	0.71	0.003	750
191	P-87	J-68	J-69	100.0	PVC	150.0	5	0.67	0.004	250
192	P-88	J-69	J-70	80.0	PVC	150.0	1	0.20	0.001	500
193	P-89	J-69	J-71	100.0	PVC	150.0	3	0.32	0.001	350
194	P-90	J-71	J-72	80.0	PVC	150.0	1	0.15	0.000	250
195	P-91	J-71	J-73	80.0	PVC	150.0	1	0.15	0.000	450
205	P-92	J-16	J-74	80.0	PVC	150.0	4	0.87	0.009	200
206	P-93	J-74	J-17	80.0	PVC	150.0	-4	0.89	0.010	150
207	P-94	J-74	J-75	50.0	PVC	150.0	4	1.83	0.064	100
208	P-95	J-75	J-37	50.0	PVC	150.0	2	1.19	0.029	115
209	P-96	J-37	J-79	50.0	PVC	150.0	1	0.34	0.003	120
210	P-97	J-79	J-44	50.0	PVC	150.0	0	0.12	0.000	230
211	P-98	J-44	J-80	50.0	PVC	150.0	0	0.17	0.001	140
212	P-99	J-80	J-79	50.0	PVC	150.0	0	0.08	0.000	80
213	P-100	J-34	J-74	50.0	PVC	150.0	-4	2.16	0.087	50
214	P-101	J-48	J-76	50.0	PVC	150.0	2	0.92	0.018	90
215	P-102	J-76	J-77	50.0	PVC	150.0	1	0.51	0.006	150
216	P-103	J-77	J-54	50.0	PVC	150.0	0	0.21	0.001	300
217	P-104	J-77	J-78	50.0	PVC	150.0	0	0.21	0.001	200
218	P-105	J-78	J-47	50.0	PVC	150.0	-1	0.47	0.005	150
219	P-106	J-47	J-76	50.0	PVC	150.0	0	0.23	0.001	70

Flex Table: Junction Table

Current Time: 0.000 hours

ID	Label	Elevation (m)	Demand (L/s)	Hydraulic Grade (m)	Pressure (m H2O)
32	J-1	2,038.00	25	2,207.34	56
33	J-2	2,058.00	5	2,200.02	23
34	J-3	2,060.00	4	2,190.67	67
35	J-4	2,060.00	4	2,195.68	29
36	J-5	1,950.00	5	2,197.11	47
37	J-6	2,070.00	4	2,197.11	38
38	J-7	2,080.00	5	2,197.07	97
39	J-8	2,035.00	9	2,206.55	62
40	J-9	2,040.00	9	2,206.55	63
41	J-10	2,045.00	19	2,205.70	52
42	J-11	1,955.00	3	2,195.54	20
43	J-12	1,950.00	4	2,191.03	22
44	J-13	2,010.00	3	2,157.58	17
45	J-14	2,072.00	3	2,197.46	49
46	J-15	2,050.00	9	2,206.89	46
47	J-16	2,050.00	7	2,205.97	76
48	J-17	2,050.00	9	2,205.56	64
49	J-18	2,030.00	6	2,204.50	38
50	J-19	2,050.00	12	2,204.82	24
51	J-20	2,010.00	12	2,202.27	74
52	J-21	2,072.00	4	2,201.51	52
53	J-22	2,035.00	3	2,198.71	55
54	J-23	2,070.00	3	2,200.59	22
55	J-24	2,110.00	4	2,196.87	29

ID	Label	Elevation (m)	Demand (L/s)	Hydraulic Grade (m)	Pressure (m H2O)
56	J-25	2,030.00	7	2,200.01	42
57	J-26	2,083.00	14	2,201.68	-23
58	J-27	2,080.00	5	2,203.25	10
59	J-28	2,090.00	5	2,202.08	17
60	J-29	2,085.00	4	2,201.54	42
61	J-30	2,073.00	8	2,201.10	15
62	J-31	2,070.00	6	2,202.11	-30
63	J-32	2,010.00	4	2,201.65	27
64	J-33	2,070.00	4	2,199.61	17
65	J-34	2,070.00	2	2,199.73	32
66	J-35	1,950.00	2	2,194.40	24
67	J-36	2,050.00	1	2,194.06	12
68	J-37	2,030.00	1	2,194.31	31
69	J-38	2,080.00	5	2,202.16	18
70	J-39	2,070.00	3	2,199.67	16
71	J-40	2,070.00	2	2,201.36	58
72	J-41	2,075.00	3	2,200.52	-56
73	J-42	2,070.00	1	2,198.66	19
74	J-43	2,070.00	1	2,194.47	56
75	J-44	1,995.00	1	2,194.06	67
76	J-45	2,065.00	1	2,198.77	20
77	J-46	2,060.00	1	2,198.75	25
78	J-47	2,055.00	1	2,198.06	13
79	J-48	2,060.00	2	2,199.56	26
80	J-49	2,065.00	4	2,199.17	12

ID	Label	Elevation (m)	Demand (L/s)	Hydraulic Grade (m)	Pressure (m H2O)
81	J-50	2,055.00	2	2,198.85	101
82	J-51	2,045.00	3	2,199.31	87
83	J-52	2,055.00	3	2,198.18	30
84	J-53	2,045.00	2	2,197.44	39
85	J-54	2,070.00	1	2,196.70	53
86	J-55	2,075.00	1	2,196.66	48
87	J-56	2,052.00	2	2,198.21	93
88	J-57	2,070.00	4	2,187.82	17
89	J-58	1,980.00	2	2,185.53	94
90	J-59	2,090.00	2	2,187.80	-37
91	J-60	2,060.00	4	2,191.11	39
92	J-61	2,085.00	1	2,146.50	49
93	J-62	2,110.00	3	2,187.80	67
94	J-63	2,110.00	1	2,187.50	66
95	J-64	2,090.00	1	2,200.85	98
96	J-65	2,065.00	1	2,198.12	32
97	J-66	2,095.00	2	2,199.75	-18
98	J-67	2,095.00	1	2,199.70	28
99	J-68	2,130.00	3	2,197.46	55
100	J-69	2,135.00	2	2,196.35	48
101	J-70	2,115.00	1	2,196.05	68
102	J-71	2,150.00	1	2,195.96	33
103	J-72	2,160.00	1	2,195.87	23
104	J-73	2,145.00	1	2,195.80	46
198	J-74	2,040.00	1	2,204.10	24
199	J-75	2055.00	1	2,197.66	29

ID	Label	Elevation (m)	Demand (L/s)	Hydraulic Grade (m)	Pressure (m H2O)
200	J-76	2,060.00	1	2,197.96	38
201	J-77	2,070.00	1	2,197.05	27
202	J-78	2,040.00	1	2,197.29	57
203	J-79	2,020.00	1	2,193.96	74
204	J-80	2,030.00	1	2,193.95	14

D) Flex Table: PRV Table

Current Time: 0.000 hours

ID	Label	Elevation (m)	Diameter (Valve) (mm)	Minor Loss Coefficient (Local)	Pressure Setting (Initial) (m H2O)	Flow (L/s)	Headloss (m)	Downstream Pipe	Status (Initial)
198	PRV-1	2,085.00	200.0	0.000	15	8	0.00	P-93	Active
201	PRV-2	2,040.00	200.0	0.000	34	12	0.00	P-95	Active
204	PRV-3	2,060.00	150.0	0.000	22	6	0.00	P-97	Active
207	PRV-4	2,040.00	100.0	0.000	30	3.5	0.00	P-99	Active
210	PRV-5	2,065.00	120.0	0.000	45	2	0.00	P-101	Active

E) Reservoir

I. For steady state analisis

FlexTable: Reservoir Table

ID	Label	Elevation (m)	Zone	Flow (Out net) (L/s)	Hydraulic Grade (m)
30	R-1	2,221.40	<None>	361	2,221.40
31	R-2	2,219.60	<None>	31	2,219.60

II. For extended period simulation

FlexTable: Reservoir Table

Current Time: 0.000 hours

ID	Label	Elevation (m)	Zone	Flow (Out net) (L/s)	Hydraulic Grade (m)
30	R-1	2,221.40	<None>	284	2,221.40
31	R-2	2,219.60	<None>	24	2,219.60

III. For scenario management

FlexTable: Reservoir Table (Current Time: 0.000 hours) (Scenario Management..wtg)

Current Time: 0.000 hours

ID	Label	Elevation (m)	Zone	Flow (Out net) (L/s)	Hydraulic Grade (m)
30	R-1	2,221.40	<None>	289	2,221.40
31	R-2	2,219.60	<None>	24	2,219.60

Current Time: 1.000 hours

ID	Label	Elevation (m)	Zone	Flow (Out net) (L/s)	Hydraulic Grade (m)
30	R-1	2,221.40	<None>	289	2,221.40
31	R-2	2,219.60	<None>	24	2,219.60

Current Time: 2.000 hours

ID	Label	Elevation (m)	Zone	Flow (Out net) (L/s)	Hydraulic Grade (m)
30	R-1	2,221.40	<None>	289	2,221.40
31	R-2	2,219.60	<None>	24	2,219.60

Current Time: 3.000 hours

ID	Label	Elevation (m)	Zone	Flow (Out net) (L/s)	Hydraulic Grade (m)
30	R-1	2,221.40	<None>	289	2,221.40
31	R-2	2,219.60	<None>	24	2,219.60

Current Time: 4.000 hours

ID	Label	Elevation (m)	Zone	Flow (Out net) (L/s)	Hydraulic Grade (m)
30	R-1	2,221.40	<None>	272	2,221.40
31	R-2	2,219.60	<None>	22	2,219.60

Current Time: 5.000 hours

ID	Label	Elevation (m)	Zone	Flow (Out net) (L/s)	Hydraulic Grade (m)
30	R-1	2,221.40	<None>	272	2,221.40
31	R-2	2,219.60	<None>	22	2,219.60

Current Time: 6.000 hours

ID	Label	Elevation (m)	Zone	Flow (Out net) (L/s)	Hydraulic Grade (m)
30	R-1	2,221.40	<None>	272	2,221.40
31	R-2	2,219.60	<None>	22	2,219.60

Current Time: 7.000 hours

ID	Label	Elevation (m)	Zone	Flow (Out net) (L/s)	Hydraulic Grade (m)
30	R-1	2,221.40	<None>	272	2,221.40
31	R-2	2,219.60	<None>	22	2,219.60

Current Time: 8.000 hours

ID	Label	Elevation (m)	Zone	Flow (Out net) (L/s)	Hydraulic Grade (m)
30	R-1	2,221.40	<None>	593	2,221.40
31	R-2	2,219.60	<None>	52	2,219.60

Current Time: 9.000 hours

ID	Label	Elevation (m)	Zone	Flow (Out net) (L/s)	Hydraulic Grade (m)
30	R-1	2,221.40	<None>	593	2,221.40
31	R-2	2,219.60	<None>	52	2,219.60

Current Time: 10.000 hours

ID	Label	Elevation (m)	Zone	Flow (Out net) (L/s)	Hydraulic Grade (m)
30	R-1	2,221.40	<None>	593	2,221.40
31	R-2	2,219.60	<None>	52	2,219.60

Current Time: 11.000 hours

ID	Label	Elevation (m)	Zone	Flow (Out net) (L/s)	Hydraulic Grade (m)
30	R-1	2,221.40	<None>	593	2,221.40
31	R-2	2,219.60	<None>	52	2,219.60

Current Time: 12.000 hours

ID	Label	Elevation (m)	Zone	Flow (Out net) (L/s)	Hydraulic Grade (m)
30	R-1	2,221.40	<None>	616	2,221.40
31	R-2	2,219.60	<None>	54	2,219.60

Current Time: 13.000 hours

ID	Label	Elevation (m)	Zone	Flow (Out net) (L/s)	Hydraulic Grade (m)
30	R-1	2,221.40	<None>	616	2,221.40
31	R-2	2,219.60	<None>	54	2,219.60

Current Time: 14.000 hours

ID	Label	Elevation (m)	Zone	Flow (Out net) (L/s)	Hydraulic Grade (m)
30	R-1	2,221.40	<None>	616	2,221.40
31	R-2	2,219.60	<None>	54	2,219.60

Current Time: 15.000 hours

ID	Label	Elevation (m)	Zone	Flow (Out net) (L/s)	Hydraulic Grade (m)
30	R-1	2,221.40	<None>	616	2,221.40
31	R-2	2,219.60	<None>	54	2,219.60

Current Time: 16.000 hours

ID	Label	Elevation (m)	Zone	Flow (Out net) (L/s)	Hydraulic Grade (m)
30	R-1	2,221.40	<None>	366	2,221.40
31	R-2	2,219.60	<None>	31	2,219.60

Current Time: 17.000 hours

ID	Label	Elevation (m)	Zone	Flow (Out net) (L/s)	Hydraulic Grade (m)
30	R-1	2,221.40	<None>	366	2,221.40
31	R-2	2,219.60	<None>	31	2,219.60

Current Time: 18.000 hours

ID	Label	Elevation (m)	Zone	Flow (Out net) (L/s)	Hydraulic Grade (m)
30	R-1	2,221.40	<None>	366	2,221.40
31	R-2	2,219.60	<None>	31	2,219.60

Current Time: 19.000 hours

ID	Label	Elevation (m)	Zone	Flow (Out net) (L/s)	Hydraulic Grade (m)
30	R-1	2,221.40	<None>	366	2,221.40
31	R-2	2,219.60	<None>	31	2,219.60

Current Time: 20.000 hours

ID	Label	Elevation (m)	Zone	Flow (Out net) (L/s)	Hydraulic Grade (m)
30	R-1	2,221.40	<None>	692	2,221.40
31	R-2	2,219.60	<None>	61	2,219.60

Current Time: 21.000 hours

ID	Label	Elevation (m)	Zone	Flow (Out net) (L/s)	Hydraulic Grade (m)
30	R-1	2,221.40	<None>	692	2,221.40
31	R-2	2,219.60	<None>	61	2,219.60

Current Time: 22.000 hours

ID	Label	Elevation (m)	Zone	Flow (Out net) (L/s)	Hydraulic Grade (m)
30	R-1	2,221.40	<None>	692	2,221.40
31	R-2	2,219.60	<None>	61	2,219.60

Current Time: 23.000 hours

ID	Label	Elevation (m)	Zone	Flow (Out net) (L/s)	Hydraulic Grade (m)
30	R-1	2,221.40	<None>	692	2,221.40
31	R-2	2,219.60	<None>	61	2,219.60

Current Time: 24.000 hours

ID	Label	Elevation (m)	Zone	Flow (Out net) (L/s)	Hydraulic Grade (m)
30	R-1	2,221.40	<None>	289	2,221.40
31	R-2	2,219.60	<None>	24	2,219.60