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Analysis of Hydraulic Performance and Water Loss Status Using Water Balance Software in the Water Supply Distribution System of Yeka Abado Condominium in Addis Ababa

By

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A Thesis Submitted to the School of Graduate Studies of Africa Center of Excellences for water management Addis Ababa University in partial Fulfillment of the Requirement for the Degree of Master Science in Water Management (Water supply and Sanitation)

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APPROVAL PAGE

This M.Sc. Thesis entitled on "Analysis of Hydraulic Performance and Water Loss Status Using Water Balance Software in the Water Supply Distribution System of Yeka Abado Condominium in Addis Ababa" by Ms. Emebet Dejene is approved for the degree of "Master of Science in Water supply and sanitation" is submitted to Africa Centre of excellence for Water Management, Addis Ababa University.

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other university and that all sources of material used for this thesis have been dully acknowledged.

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ABSTRACT

Water is a valuable resource that must be managed holistically in order to avoid scarcity. This study was carried out as part of the management to analyze hydraulic performance and water loss status in the water supply distribution system of Yeka Abado Condominium in Addis Ababa using water balancing software. To analyze water loss components and evaluate the system's performance, water balancing software was employed. The condominium's present water supply coverage was assessed using statistical analysis, and the hydraulic performance of the water distribution system was assessed using WaterGEMS V8i software. It was also used to add pressure-reducing valves to the system and assess the pressure reduction after they were installed. The average daily per capita water consumption and level of connection per family, according to the analysis, were 65 l/p/d and 17.3 percent, respectively. This demonstrates a lack of water supply coverage for condominium residents, which is mostly impacted by water scarcity. The findings of the water loss analysis, on the other hand, revealed that the overall water loss in the study area water supply system was 24.6 percent of the system input volume, with 96 percent of this being true loss and only 4% being apparent loss. The results revealed that the water loss value was modest, indicating that the system is in good working order. The WaterGEMS model, on the other hand, found that a number of junctions had pressures exceeding the maximum permissible pressure of 60 m. Pressure lowered valves were installed in the system to solve the high-pressure problem and reduce pipe leakage, and the changed pressures were within the standard's optimum level. As a result, maintaining appropriate pressure in the system to meet customer demands is necessary, as is restricting the optimal values to prevent leakage flow rate and the risk of pipe burst or fracture.

Keywords: Hydraulic performance, water balance software, WaterGEMS, Water loss

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ABBREVIATIONS AND ACRONYMS

AAWSA …………………………………. Addis Ababa Water and Sewerage Authority

ACEWM …………………………………... Africa center of excellence for water management

ALC …………………………………. …Active Leakage Control

AWWA ………………………… ………. American Water Work Associations

CARL …………………………………….. Current annual real losses

DMA ………………………………………. District metered Area

EPS ……………………………………………Extended period simulation

ERF ………………………………………… Estimation reference flow

ILI …………………………………………. Infrastructural leakage index

IWA …..International water association

LNF …….…………………………...............Legitimate Night flow

MNF …. ……………………………………. Minimum Night Flow

NRW …. …………………………... ……... ... Non-Revenue Water

PI ……….…………………………………. Performance indicator

PRVS …………………………………....... Pressure reduction Valves

TCVS ……………………………………..... Throttle Control Valves

UARL ……………………………………………. Unavoidable annual real losses

UFW ………………………………………… Uncounted for Water

WDS ………………………… ……….......... Water distribution system

WL ……………………………………...Water Loss

1 INTRODUCTION

1.1 Background of the Study

Most water utilities, particularly public service providers, are finding it difficult to provide adequate and consistent water supply in developing countries. Water consumption in these countries has risen dramatically as a result of a variety of causes, including population increase as a result of rural-to-urban migration. As a result, several countries' public utility utilities have failed to provide basic water and sanitation services to their citizens. As a result, several countries' public utility utilities have failed to provide basic water and sanitation services to their citizens. Aside from service coverage, public service providers face other issues such as high Unaccounted for Water (UfW) and financial difficulties caused by a combination of cheap tariffs, inadequate services, poor user records, and inefficient billing processes (Kimey, 2008).

The significant disparity between the amount of water supplied into the distribution system and the amount of water invoiced to consumers, known as "Non-Revenue Water," is one of the biggest difficulties affecting water utilities in the developing world (NRW). According to current statistics surveys, NRW in developing nations is between 45 and 50 percent, or half of the overall system input volume. One of the major issues affecting water utilities in the developing world is the considerable difference between the amount of water put into the distribution system and the amount of water billed to consumers called “Non-Revenue Water” (NRW). Current statistical surveys indicated that NRW in developing countries is around 45 to 50%, i.e. half of the total system input volume. Despite the fact that it is widely accepted that NRW levels in developing nations are quite high, there are very little data in the literature on exact figures. This is significant because most developing-world water utilities lack adequate monitoring methods for analyzing water losses, and many nations lack national reporting systems that gather and integrate data on water utility performance (Dighade et al., 2014).

One of the major issues affecting water utilities in the developing world is the considerable difference between the amount of water put into the distribution system and the amount of water billed to consumers called “Non-Revenue Water” (NRW). Current statistical surveys indicated that NRW in developing countries is around 45 to 50%, i.e. half of the total system input volume. Although, it is widely acknowledged that NRW levels in developing countries are very high, in fact, very few data are available in the literature regarding the actual figures. This is large because most water utilities in the developing world do not have adequate monitoring systems for assessing water losses and many countries lack national reporting systems that collect and consolidate information on water utility performance (Dighade et al., 2014)**.**

Currently, the water supply system in developing countries does not meet the need of people and industries. High levels of water losses are indicative of poor governance and poor physical condition of the WDS. The amount of water loss in water distribution systems varies widely between different countries, regions, and systems from as low as 3 - 7% to as high as 50 % of distribution input volume in the well-maintained systems of developed countries and less maintained system in developing countries, respectively (Dighade et al., 2014)**.**

A water distribution system is a hydraulic infrastructure that consists of different elements like pipes, valves, pumps, tanks, and reservoirs. This infrastructure helps to deliver water to the consumer with appropriate quality, quantity, and pressure. Designing and operating a water distribution system is the most important consideration for a lifetime of expected loading conditions. However, abnormal conditions such as pipe breakage, mechanical failure of pipes, valves, and control systems, power outages and inaccurate demand projections and corrosion cause water loss (Paneria, 2017)

Many water supply distribution systems in most Addis Ababa Water and Sewerage Authority branch offices suffer from a lack of water supply quantities and a sharp lack of pressure, necessitating the improvement and improvement of the water distribution operating and management systems in order to meet consumer demand at satisfactory levels. The persistent and recurring underperformance of current and future water delivery networks has become one of the most pressing concerns in the water supply sector, requiring quick response. As the demand for water grows owing to population expansion and per capita consumption, flaws in the water network's functioning have a negative impact on numerous socioeconomic sectors. This is because to an out-of-date piping system, particularly in older districts of Addis Ababa (Fitaye, 2015).

To remedy this condition, scenario simulations created using the Water CAD water distribution modeling program can be used to examine various water network sectorization options. Water loss can be reduced significantly by reconfiguring the water distribution system. Furthermore, if offered to the system's management, the digital model of the water network can be a useful tool for better managing water resources, with both environmental and financial benefits (Cordeiro, 2013).

1.2 Problem Statement

Water loss occurs in all distribution systems; in many water networks, losses exceed 30% to 40%, due to aging, corrosion of system components such as pipes and valves, and poor management (Fontana et al., 2012). Large volumes of water loss may result in undetected leakage locations receiving intermittent service, posing a substantial health concern by allowing sewerage to enter leak pipes during supply interruptions and at very low pressure levels. The public health risk can be mitigated to some extent by reducing leakage and permitting a standard continuous supply, although most researches are focused on calculating the volume of water lost.

Leaking pipes can threaten the integrity of the drinking water distribution system and cause major operational issues if they go unnoticed. Leaks, for example, raise downstream demands, increase energy costs, reduce utility revenue, and jeopardize water quality (Buchberger and Nadimpalli, 2004).

The Addis Ababa water and sewerage authority is in charge of water distribution in the city (AAWSA). Water supply is currently insufficient to meet the needs of the entire city; as a result, some areas of the city are receiving water via distribution on a rotational basis; two days per week. The consumer gets four days a week in Yeka Abado, which does not meet the potential need of the consumers in the condominium.

According to a research published by the World Bank Group in 2015, Addis Ababa is already experiencing water shortage, which is anticipated to worsen as a result of growing urbanization, rising individual water demand earnings, and the effects of climate change. Surface and groundwater are used to produce 450,000 m3/day, although it is estimated that 36.5 percent of this water is lost owing to leaks and other system inefficiencies. The anticipated per capita distribution is roughly 40 liters per day, significantly below the city's aim of 110 liters per day.

According to a World Bank Group study published in 2015, Addis Ababa already has a water scarcity, which is expected to deteriorate as a result of growing urbanization, rising individual water demand incomes, and climate change effects. Surface and groundwater are used to create 450,000 m3/day, while leaks and other system inefficiencies are predicted to lose 36.5 percent of this water. The expected per capita distribution is around 40 liters per day, far less than the city's goal of 110 liters per day.

The total loss of water can be easily approximated by comparing invoicing on water use and total water produced and distributed to the network system, and the water pressure and optimal pressure are computed using a hydraulic model. According to the water utility officer of the Yeka Abado condominium, the condominium has a pipe leaking problem, but the source and solutions have yet to be determined. Furthermore, there is no documentation indicating the corresponding water loss for Addis Ababa's Yeka Abado Condominium. The study's goal is to quantify the loss and then recommend ways to reduce it.

1.3 Research Objectives

1.3.1 General objective

The main objective of this study is to analysis the hydraulic performance and water loss status using water balance software in the water supply distribution system of Yeka Abado condominium in Addis Ababa.

1.3.2 Specific objectives

- To evaluate the water supply coverage
- To estimate water losses in the distribution network using water balance software (WB-EasyCalc V4.05).
- To analyse the pressure in the distribution system using WaterGEMS V8i.

1.4 Research Questions

In pursuing the above specific objectives, the study was strive to answer the following questions:

- What is the water supply coverage in the study area?
- What is the total water loss in the distribution network?
- Is the water pressure in the distribution system affecting the water supply to residents in condominium?

1.5 Significance of the Study

The study has the potential to help solve the water loss problem at Yeka Abado condominium. The findings of this study could be used by the Addis Ababa Water and Sewerage Authority (AAWSA) to upgrade the existing system and reduce water losses. Water supply to residents can be enhanced if management systems are implemented. The knowledge gap about water demand and supply, as well as system construction and maintenance, that this study addresses, may help with efficient planning and management of water services in the area.

1.6 Scope of the Study

The study used water balancing software to analyze hydraulic performance and water loss status in the water supply distribution system of the Yeka Abado condominium in Addis Ababa. The study also looked at the area's water supply coverage and used WaterGEMS V8i to analyze the distribution system's water pressure.

2. LITERATURE REVIEW

2.1 Introduction

Water consumption has risen considerably in recent years due to an expanding human population and an improved standard of living around the world. As a result, critical water resources were jeopardized. Furthermore, water is typically delivered through a massive network of pipes known as transmission mains and distribution systems in order to satisfy the aforementioned increasing demand and to provide effective water supply to end-users. As a result, a water distribution network is a necessary infrastructure for supplying autochthonous freshwater throughout cities. Its goal is to provide enough water at the right pressure to end customers under a variety of demand circumstances in a large-scale network while simultaneously generating money for water utility companies and the government.

However, maintaining the seamless operation of large-scale water delivery networks remains a significant engineering issue. This is due to the fact that not all of the water generated at water treatment plants reaches end-users, generating money for the water industry and the government. Instead, a large percentage of this water is wasted and never reaches the ultimate customer.

2.2 Urban Water Supply Coverage

Water supply coverage, according to Adebo (2016), is the percentage of inhabitants in a town who have access to water supply. To meet the rapidly increasing water supply needs of the urban population, water supply service providers must manage existing water supply infrastructure in a way that meets the demand efficiently. It has been found that financial constraints, inadequate water supply system management, and a lack of human resource capacity all have a significant impact on the limited coverage of water supply distribution. Furthermore, the issue is not only one of limited supply coverage, but also one of supply volatility in different parts of the population.

Water supply coverage gives a picture of a country's or city's water supply situation and allows for comparisons across countries as well as inter- and intra-city distribution within a country.

The percentages of people with or without a piped water connection are a useful indicator for comparing water supply coverage in urban regions (Abebaw, 2015)

When assessing water supply coverage, the focus was on the volume of consumption and the level of water connection, both of which are closely linked to the issue of water loss. Following an assessment of the town's water supply coverage, the water loss from the utility's distribution system was investigated (Zewdu, 2014).

Every day, thousands of children die around the world and in Ethiopia due to a lack of safe drinking water, proper sanitation, and hygiene. To address this issue, Ethiopia's government ratified the Universal Access Program (UAP) in 2005, which allows all people of the country to have access to safe drinking water. In addition, in 2010, the first Growth and Transformation Plan (GTP-1) spanning the years 2011 to 2015 was approved, and it is currently being implemented. This strategy aims to enhance rural, urban, and overall access to water supply coverage to 98 percent, 100 percent, and 98.5 percent, respectively, while lowering the number of failed schemes from 20% to 10%. Various initiatives have been done to accomplish the aim throughout the last four GTP years (2011-2014), with water supply access coverage reaching 75.5 percent, 84.1 percent, and 76.7 percent in urban, rural, and national areas, respectively. The international community agreed to meet the Millennium Development Goal (MDG) of halving the proportion of people without access to safe drinking water and basic sanitation by 2015. (MWIE report, 2015).

In relation to this strategy, water supply coverage lags behind (Ministry of Finance and Economic Development, 2010), and water supply coverage in Ethiopia's main city, Addis Ababa, was reported to be 60.67 percent in 2009. (Kabeto, 2011).

The capital city, Addis Ababa, has the highest population density, and services are straining to keep up with increased demand due to urbanization. The city's water coverage is over 90%, however supply is inconsistent, with certain sub-cities receiving water for only 12 hours per day for less than three days per week. Keeping up with the demand created by the city's extensive housing development is a never-ending challenge (World Bank report, 2015).

2.3 Water Loss and Leakage

Water supply issues can be exacerbated by large amounts of water lost through leaks in some urban water distribution networks (physical or real water losses) and volumes of water provided without being billed (apparent water losses), especially in developing nations. The amount of non-revenue water (NRW) in a water delivery system is made up of real and apparent water losses, as well as unbilled allowed usage (for example, flushing mains or firefighting).

According to a World Bank research, the water distribution system loses over 48 billion cubic meters of water each year, costing water utilities around the world about US 14 billion per year (Kingdom et al., 2006). The amount of genuine losses (45 million m3/daily) that occur in underdeveloped countries would be enough to feed 200 million people. Every day, about 30 million m3 of water is given to users but is not invoiced due to theft, corruption, and technical manipulation, as well as faulty metering (UNW-DPC,2011).

Clearly, the loss of such a big amount of drinkable water poses a significant issue in meeting the predicted demand. As a result, it is critical to adopt a sustainable water loss target as soon as feasible, despite the fact that reducing NRW to the least desirable range necessitates considerable capital, efficient management, and control systems (AAWSA, 2014).

2.3.1 Definitions of water loss

Water losses might be genuine (physical) or fictitious (apparent). Leakage from water pipe joints, service connections, pipe bursts, pipe cracks, and overflows from storage tanks are the leading causes of real losses. Illegal water consumption and faulty customer metering are the main causes of apparent losses. The difference between the system input volume and the volume of approved consumption is the total volume of losses (actual and apparent) (Mckenzie and Seagon, 2005; Tabesh et al., 2009; Amir and Mehdi, 2012; Quevedo et al., 1994).

According to Mimi et al. (2016), there are a variety of terminology that can be used to describe water losses, including non-revenue water and uncounted water (UFW). Physical losses (known as leakage) and nonphysical losses combine to make up water losses throughout distribution. Physical losses are the quantity of water that is lost without being consumed owing to distribution system problems and defects. Leaking pipes, leaking pipe connections, and leaking fittings are all examples of this (gate valves, hydrants, etc.). The amount of water that is not reported owing to measurement errors or water theft is referred to as nonphysical losses.

2.3.2 Methods of measuring or estimation of water losses

To quantify water loss in the distribution system, different studies employ different approaches. The majority of studies used a stochastic model (Loureiro et al., 2010), annual water balance and MNF analyses combined with hydraulic simulation models (such as EPANET and GIS models) (Tabesh et al., 2009; Cheung et al., 2010; Karadirek et al., 2012), and developing an empirical model for estimating background leakage rates to estimate water losses in water distribution networks (Hunaidi 2010). Statistical modeling was proposed in other research to forecast changes in pipe failure rates in water main pipes (Kanakoudis and Tolikas, 2001; Pelletier et al., 2003; Cannarozzo et al., 2006).

1) Water audits

Water audits entail a thorough examination of the flow of water into and out of the distribution system. The audits assist in identifying places where there is a lot of leakage. It does not, however, provide information on the location of leaks. Continuous metering of the input into supply districts, as well as zero consumption measurements for tiny districts, are used to determine water audits. Measurements taken over a short period of time using the pressure feed method and the minimum night flow (Mimi et al., 2016).

Study preliminary water audit begins with the following information and simple calculations, according to (EPA, 2010):

1) Calculate the amount of water that will be added to the system over the course of a year.

2) Calculate water losses (water losses = system input – permitted consumption) and 2) Determine authorized consumption (billed + unbilled).

The sum of unlawful usage, customer meter inaccuracies, and billing errors and adjustments is used to calculate apparent losses. Real losses, on the other hand, are defined by the difference between water and perceived losses.

This is an example of a top-down audit, which begins with existing data and records at the "top." Because no additional fieldwork is necessary, it is sometimes known as a desktop audit or a paper audit. In Ambo University, Ethiopia, Bhagat et al. (2019) employed a top-down method. As a result, the revenue loss for this study in 2017 and 2018 was 1562 and 1566 dollars, respectively.

The top-down water balance method is neither pressure-dependent nor does it require considerable field labor. It is a cost-effective assessment that should be employed first and repeated every year, allowing for regular internal and external monitoring of actual losses. However, its apparent loss assumptions aren't necessarily appropriate to different water utilities, especially in underdeveloped countries. A key issue is the lack of an objective methodology for quantifying unlawful usage. The principle of assigning assumptions to specific WL subcomponents may have a negative impact. When a sub-component is presumed to be constant at a specific level, it can no longer be monitored for reduction measures. This would be a key issue for utilities with substantial apparent losses and regular monitoring of the degree of apparent losses as a top priority.

A bottom-up audit, on the other hand, is frequently implemented after numerous top-down audits have been completed and can better estimate loss volumes that the top-down audit did not disclose. A bottom-up audit will look at components or separate sections in the utility's operations to assist find apparent and real losses.

Al-Bulushi et al. (2018) used AWWA audit software to calculate water losses in Muscat, including real and perceived losses, NRW, water balance, and cost. According to the findings, the average apparent loss, true loss, and NRW from 2010 to 2014 were 19.5, 21 percent, and 40%, respectively. Zewdu (2014) employed water audit software to determine water loss in Axum town, resulting in a total water loss of 39.1 percent, with 9.5 percent being apparent and 29.6 percent being genuine.

The software was created using Microsoft Excel and a number of work sheets. Once the data is entered, the computer calculates losses, revenue, and NRW, as well as the detailed water balance. As a result, the data was loaded into the software, and the findings were generated and displayed in a water balance sheet using internationally defined nomenclature. The values in the water balance were derived from measurements and estimates of water intake, water consumption, and water losses in the system (Al-Bulushi et al., 2018).

Water balancing software (WB-EasyCalc), on the other hand, is a spreadsheet-based free program created by Liemberger and collaborators and supported by the World Bank Institute (WBI) (www.liemberger.cc.) The model is used to calculate a network's WB as well as some of its basic PIs (Table 1). It has the advantage of not only requesting physical data, but also information about the accuracy of that data. It can calculate the NRW volume and its numerous components, as well as the volume's precision. It may, for example, determine that NRW is 21% with a 66 percent accuracy, implying that the true NRW level is between 7 and 35%. (Farley et al., 2008).

2) Hydraulic model

Modeling of water supply schemes is a powerful tool for assessing real-world critical issues, emergency response, planning, estimation, and understanding of various types of water losses. A model is also necessary for water distribution systems because of their complicated topology, regular maintenance, and changes (Mengistu,2016).

Because field measurements are expensive in a big municipal water network, modeling in conjunction with field observations, such as supplied by specialist hydraulic simulation models, is a more practical and cost-effective technique (Motiee et al., 2007). EPANET and WaterGEMS were the most commonly used models to determine water loss in this category.

The US Environmental Protection Agency developed EPANET, a simulated distribution network model (Rossman, 2000). For assessing physical UFW in Ghazvin city, Motiee et al. (2007) employed an approximation method based on a combination of GIS and EPANET modeling. Leakage discharges from the network are quantified after hydraulic simulation using mathematical equations, and the findings provide estimates of the percentage of physical UFW, allowing comparison with modeling and measurements of total UFW in the network. Physical losses in Ghazvin city were 13%, and non-physical losses (such as under-registering of metered amounts) were 19.7%, totaling 32.7 percent of total water provided.

WaterGEMS is a new piece of software. The NRW components of real and apparent loss are used to quantify water loss in the distribution system. Mengistu (2016) estimated apparent loss using annual water use from aggregated bill data, and minimum night flow data was used to calculate background leakages at nodes and pipes for different hours. He evaluated daily, monthly, and annual leakage rates in Addis Ababa Bole sub-city using WaterGEMS based on the FAVAD concept, in addition to the annual water balance approach. The real loss was calculated to be 21.04 percent, the apparent loss to be 4.74 percent, and the NRW to be 131,522.2 m3/year, or 25.8%.

Amir and Mehdi (2012) developed a hybrid of GA and Neuro-Fuzzy model to estimate leakage rate in Kerman, Iran, in addition to using the models separately. The pressure differences associated with leakages are recorded by placing pressure sensors at various positions along the main pipe and causing various leakages in various areas of the system. The suggested approach employed the information provided from the leakage simulation to estimate the leakage rate based on pressure fluctuations.

3) Minimum night flow (MNF) method

The real losses in a separate small portion of the network are estimated using MNF analysis. After estimating real losses, subtract the volume of real losses from the overall volume of water loss to calculate apparent losses.

A MNF analysis is often carried out in a District Metered Area (DMA), which is a hydraulically isolated section of the network. DMA is a discrete zone defined by flow meters and/or closed valves and has a permanent border (Farley and Trow, 2007). It usually includes between 500 and 3000 customer service connections, as well as supply input flow measurements (AWWA 2009; Thornton et al., 2008). DMAs may already exist in the distribution system, or a temporal DMA will be created to conduct MNF analysis (Fanner, 2004). Several publications provide detailed considerations for designing and establishing DMAs, after which a flow meter and data logger are installed at the DMA's inlet. To determine the pressures in the DMA, numerous pressure gauges and data loggers are normally mounted at various sites across the DMA (AWWA, 2009; Chisakuta et al., 2011; Farley and Trow, 2007; Farley et al., 2008; Morrison et al., 2007; Thornton et al., 2008).

Normal nighttime consumption and leakage make up the minimum nightly flow approach. By subtracting the determined normal nightly consumption from the minimum nightly flow, the leakage can be computed. 2012 (Amir and Mehdi).

Table 2.1 Summary of methods used by different researchers to estimate water loss

Methods	**Country or city**	**Reference**
1.water audit	Hantana	Peiris et al.,2008
	Addis Ababa	Kabeto, 2011
	Ambo University, Ethiopia	Bhagat et al.,2019
WB-EasyCalc	Intan Banjar (Banjar Regency & Banjarbaru City)	Setianingsih & Karnaningroem,2019
	Mojokerto	Mustafidah & Karnaningroem, 2019
AWWA Water Audit software	Muscat	Al-Bulushi et al., 2018
	Axum	Zewdu, 2014
2.Hydraulic model		
Epanet	Iran	Tabesh et al.,2009
Epanet with GIS	Gazvin	Motiee et al., 2007
.WaterGEMS	Addis Ababa Bole sub-city	Ephrem., 2016
Hybrid of GA and Neuro-Fuzzy Models	Iran	Amir and Mehdi, 2012
3.Minimum night flow	Zarqa, Jordan	Al-washali et al., 2018
	Kinta Valley, Perak	Jaber,2013
	Harara, Zimbabwe	Makaya, 2015
	Rammallah, Palestine	Mimi et al.,2016

2.3.3 Water balance sheet and performance indicator

I. Water balance

It is also critical to define and apply the same standard vocabulary before developing a standard water auditing approach. In this sense, it is now widely regarded in most nations throughout the world that the International Water Association's (IWA) standard nomenclature is the most rigorous and complete approach (Seago and Mckenzie, 2007).

Figure 2.1 depicts the elements of the IWA water balance. This water balance is the result of years of discussion and debate, and it is widely accepted by water auditing and leakage management experts around the world (Seago and Mckenzie, 2007).

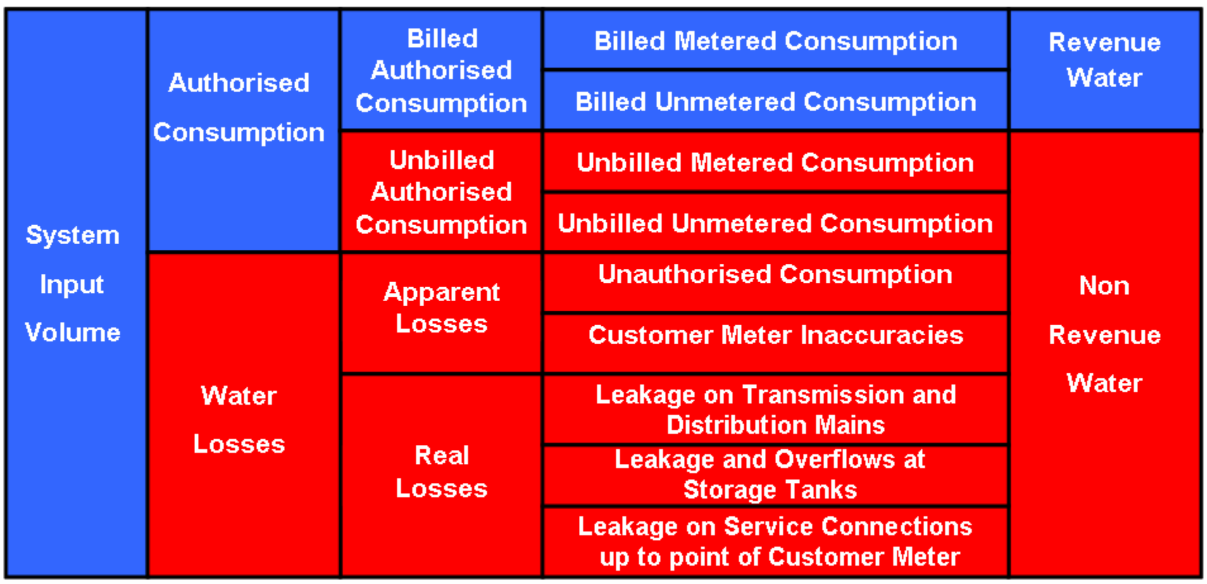

Figure 2.1 IWA water balance

II. Calculation of performance indicator

Performance indicators are a way to track and compare how operations are progressing (Rizzo, 2007). Unaccounted water can be conveyed in a variety of ways. The difference between water supplied and water sold, given as a percentage of net water supplied, is the most frequent (Balkaran and Wyke, 2002). Although the use of percentage figures to describe unaccounted for water is common (Farley, 2001), it is not normally suggested when comparing leakage rates between systems. Farley (2001) claims that this indicator fails to account for any of the major local effects. Balkaran and Wyke (2002), on the other hand, suggested that percentages are beneficial for comparing leakage rates for the same system from year to year. Because percentages can be used to make comparisons from one year to the next within the same utility.

Although the IWA does not support using percentages to characterize water losses, the word is commonly accepted and used in the South African water business. As a result, it has been kept, however it should be used with caution due to the fact that it might be misleading at times. The % NRW is determined using the formula below, and the numbers are described in Table 2.2 (Mckenzie et al., 2012):

$$\%\text{NRW} = \frac{\text{System input volume} - (\text{Billed consumpton} + \text{free basic water})}{\text{System input volume}} \times 100$$

Table 2.2 Percentage value description (McKenzie et al., 2012)

Values (%)	**Description**
< 15	Low level of NRW, very good performance
15-30	Low level of NRW, good performance
30-40	The average level of NRW, average performance
40-50	High level of NRW, poor performance
> 50	Very high level of NRW, Very poor performance

III. Determining real loss performance indicators

When compared to the theoretical minimum level of leakage that can be reached, the ILI gives an indication of how significant the leakage in a certain location is (Seago et al., 2004). At the current operating pressure, the ILI is a measure of how successfully a distribution network is managed (kept, repaired, and rehabilitated) for the control of real losses. The ratio of current annual volume or real losses (CARL) to unavoidable annual real losses (UARL) is known as the CARL/UARL ratio (Peiris et al., 2008).

ILI = CARL /UARL

The length of the mains, the number of connections, the length of the supply pipe, and the average operating pressure define UARL; a low ILI value is only likely to be economically justified when the water supply's marginal costs are relatively high or water is scarce (Lambert and McKenzie, 2002).

UARL (liters/day) =18xLm+0.8xNC+25xLP) x P

Where Lm= Mains length (km) NC= number of service connection Lp = total length of private pie, property boundary to customer meter (km), P = average pressure (m).

The real loss must be compared to the distribution network system's background losses. As a result, utilities employ a kind of PI type of ILI for real loss to enhance and evaluate network development, as well as a matrix guide to rate the level of leakage in the system by categorizing the findings as shown in the table below (Mengistu, 2016).

In nations with varying levels of network strain, the physical loss goal matrix (Table 2.3) shows the projected amount of ILI and physical losses in l/c/day from utilities (Farley, et al., 2008).

• Category A – Good: Additional loss reduction may be uneconomic; thus a thorough examination is required to uncover cost-effective solutions.

• Category B - Significant improvement potential: Consider pressure management, active leakage control, and maintenance.

• Category C – Poor: Tolerable only if water is plentiful and inexpensive, and even then, NRW reduction measures should be stepped up.

• Bad: The utility is inefficiently consuming resources, and NRW reduction strategies are required.

Table 2.3 Physical loss target matrix (Farley et al., 2008)

Technical performance Category		**ILI**	**Physical Losses [liters/connection/day] (When the system is Pressured) at an average pressure (m) of**				
			10	**20**	**30**	**40**	**50**
Developed Country	A	1-2		<50	<75	<100	<125
	B	2-4		50-100	75-150	100-200	125-250
	C	4-8		100-200	150-300	200-400	250-500
	D	>8		>200	>300	>400	>500
Developing Country	A	1-4	<50	<100	<150	< 200	<250
	`B	4-8	50 – 100	100- 200	150- 300	200-400	250-500
	C	8-16	100-200	200-400	300-600	400-800	500-1000
	D	>16	>200	>400	>600	>800	>1000

IV. Performance indicators for the apparent loss

The PI for apparent loss is calculated as a percentage of water delivered to customers; however, this "commonly used indicator that reflects commercial losses as a percentage of water delivered is misleading because it does not reflect the full value of lost revenue." The best metric at the moment is to calculate commercial losses as a proportion of allowed consumption (Farley, et al., 2008).

In addition, a recent and alternative way to express the performance indicator for apparent loss based on the IWA is to use a base value of 5% of water sales as a reference, and the actual apparent loss value is calculated using the benchmark of calculated loss value to the amount of 5% water sales value.

Apparent Loss Index (ALI) = Apparent loss value ÷ 5% of water sales

Table 2.4 ALI performance bands (source: Mutikanga et al., 2010b)

Region	Technical performance group	ALI	Remarks
Developed Country	A	1-2	Acceptable performance. Further reduction may be uneconomical unless if the cost of water is very high
	B	2-3	There is room for improvement
	C	3-4	High revenue losses, acceptable where cost of water is very low.
	D	>4	Very inefficient with poor meter management practices and in adequate policies for revenue protection. Urgent action required to minimize revenue losses.
Developing Country	A	1-2	Acceptable performance. Further reduction may be uneconomical unless if the cost of water is very high.
	B	2-4	There is room for improvement
	C	4-6	High revenue losses, acceptable where cost of water is very low
	D	>6	Very inefficient with poor meter management practices and in adequate policies for revenue protection. Urgent

2.3.4 Methods for leak location detection

There are two types of leakage detection activities: reactive and proactive. Once it is decided that a sufficiently serious problem has emerged, water company staff execute reactive leak detection. Customer contacts or other information can be used to identify problems. Several research and development initiatives have looked into the possibility of finding leaks by looking for pressure signal variances across various pressure monitoring locations (Mounce et al., 2010).

Electro-acoustic approaches, leak finding using correlator analysis (Transit time method), and leak location using the Gas Tracer Technique are the three methods for pinpointing leaks. The system pressure, the distance between listening stations, the size and shape of the leak, the pipe material, and the pipe diameter all affect the effectiveness of such leak detection approaches (MWIE Operation and Maintenance Manual, 2018).

Utilities commonly used noise detectors to detect and find leaks. The effectiveness of such leak detection systems is influenced by the system pressure, the distance between listening stations, the size and shape of the leak, the pipe material, and the pipe diameter. Leak noise characteristics have been used to discover leaks for many years by listening on valves, hydrants, stop taps, and the ground surface above the pipe line (De Silva et al., 2011). The full responsibility for detecting and locating leaks falls to a water utility. Because excavation is so expensive, finding the leaks necessitates tremendous precision (Makaya, 2015).

2.3.5 Causes of water loss

Water loss is an issue that all water distribution systems face. Leakage is the most common cause of water loss. Inappropriate or excessive usage of water can also be deemed a loss. Water that goes unaccounted for due to measurement problems, such as incorrect meters, forgotten users, and unmeasured consumption, is another source of water loss (Gawande, 2015).

In industrialized countries, leakage is frequently the most significant source of water loss; however, this is not always the case in poor or partially developed countries, where illicit connections, meter inaccuracy, or accounting errors are more common (Farley and Trow, 2003). Non-physical losses, such as meter under-registration, illegal connections, and illegal and unknown use, make up the rest of total water loss (WHO, 2001).

Illegal connections, the age of the pipe network, the substance of the pipes, inadequate network maintenance, water scheduling, data handling errors, corrosion, and pressure are some of the key causes of excessive water loss in distribution systems (Ozturk et al., 2007; Saghi and Aval, 2015).

2.3.6 Effect of water loss

Leaks in a distribution system have mostly financial consequences. Water loss is reduced. The ongoing rise in operating and maintenance costs, such as electricity, chemicals, and other goods, will be exacerbated by the increase in water loss owing to leakage. Leaks have a significant impact on service quality, in addition to directly affecting production and administration expenses. Water escaping from leaks has the potential to destroy infrastructure, including sinking roads and other properties. When a leak becomes more significant or a pipe bursts, service may be completely disrupted, affecting a large number of people (Desalegn, 2005).

I. Effects on water utilities

Utility NRW is generally associated with low efficiency, resulting in higher water collection, treatment, and distribution costs (Farley, 2003). Additionally, when water sales decline, capital investment initiatives become the last resort for meeting the ever-increasing demand (Farley et al., 2008). The dilemma is terrible for developing countries with severe capital constraints, and it frequently leads to deprivation of other economic sectors (Balkaran and Wyke, 2002; Farley, 2003). Because of limited raw water availability or water rationing, high physical water losses frequently result in intermittent water supply (Makaya, 2015).

II. Effects on customers

According to Ndegwa (2016), a water utility's major goal is to meet customer demand, yet unpredictable water supply has a negative impact on customer relations with water utilities, resulting in a lower willingness to pay. In addition, in order to recoup losses from NRW, the utility typically raises its water delivery tariffs. Paying consumers are harmed unfairly because they subsidize the rates of those who steal water. These circumstances exacerbate the vicious NRW cycle.

In addition to providing poor service, unpredictable water delivery poses serious health dangers (Liemberger, 2007). Furthermore, clients will be dissatisfied with the inconsistent water supply, resulting in a low desire to pay for the services supplied (Tiltnes, 1998). Leaks in pipe networks significantly reduce flow rates, resulting in excessive pressure losses that affect consumers and frequently lead to supply outages during peak demand hours (Girard and Stewart, 2007).

2.3.7 Effects of water pipe leaks on water quality

If there is a loss of physical integrity, such as a crack in a pipe, drinking water distribution systems are vulnerable to external pollutant entry. Failure to maintain enough pressure in the distribution system is the primary cause of an incursion occurrence. Low and negative pressure events have the potential to result in pollutant infiltration: negative pressures cause a suction effect inside the pipe, which can lead to contaminant intrusion via pipe leaks (Collins and Boxall, 2013). Furthermore, dirty water may enter the supply mains through leaking joints during non-supply hours, polluting the supplies and causing a health problem (Dighade, 2014).

Adverse pressure conditions can occur as a result of pressure transients, interruptions in water delivery, and system depressurization. Sudden pump shutdowns, power outages, and rapid changes in demand can all cause pressure transients (also known as water hammer). These are short-term events (typically lasting a few milliseconds to a few minutes) and can be caused by sudden pump shutdowns, power outages, and rapid changes in demand. Intermittent water supply distribution systems are the most prone to incursion occurrences. During times of water scarcity, water distribution systems are frequently turned on and off (Fontanazza et al., 2015).

High and low pressures are well established to increase costs and put systems at danger, from high-pressure pipe bursts to low-pressure contaminant ingress and poor firefighting conditions (Ghorbanian et al., 2016).

2.3.8 What is an acceptable water loss?

The AWWA Leak Detection and Accountability Committee suggested a baseline of 10% for UFW. In terms of UFW levels and actions required, ten percent is acceptable, monitoring and control is required, ten to twenty-five percent is intermediate and might be lowered, and more than twenty-five percent is a cause for concern, and reduction is required (Sharma, 2008).

2.3.9 Strategies to reduce water loss

Water loss reduction and control are becoming increasingly important as demand rises in various parts of the world. Many utilities have established or are developing techniques to minimize losses to a level that is economically feasible or acceptable (Kanakoudis et al., 2011; Mutikanga et al., 2011; Tooms and Pilcher, 2006; Tsitsifli et al., 2011).

1) pressure management; 2) active leakage control; 3) speed and quality of repairs; and 4) pipe material selection, installation, maintenance, renewal, and replacement are the four primary strategies for managing real losses (Lambert and McKenzie, 2002; Karadirek et al., 2015).

1. Leakage monitoring and control

Because of the service interruption, repair costs, and damage to the surrounding property and infrastructure, pipe breaks can be highly costly. However, by adopting a continuous monitoring technique to minimize break detection and location time, these expenses can be decreased (Misiunas et al., 2005).

Passive leakage control and active leakage control are the two types of leakage management. Passive control is the process of responding to reported bursts or pressure drops, which are frequently reported by customers or noticed by firm employees while doing activities other than leak detection. In regions where goods are plentiful or inexpensive, this strategy can be justified.

It is the first step toward improvement in a less developed supply system where the occurrence of subsurface leaks is less well understood. When a company's staff is deployed to detect leaks that have not been reported by customers or other means, this is known as active leakage control (ALC) (Farley and Trow, 2003).

Water leakage must be reduced in order to preserve water, energy, and money for water utilities, as A baseline evaluation and ongoing monitoring of leakage levels in the networks at full-scale as well as at a zonal size of District Metered Area (DMA), which is a hydraulically isolated segment of the network, are required when designing a leakage control strategy. The top-down water audit is a common practice for leakage assessment across the entire network, in which apparent losses such as customer meter inaccuracies, data handling errors, and unauthorized consumption are estimated first, and then the level of leakage can be estimated from the total volume of water loss. well as to provide water access for social and economic activities.

Leak detection entails splitting the distribution system into well-defined sections, each of which can be served by a single pipe equipped with a flow meter capable of sensing low flow rates. District metering areas, or DMAs, are the names given to these places (Hunaidi et al., 2004).

2. Pressure management through distribution system

Pressure management in the distribution system is defined as the practice of regulating system pressures to ensure adequate and efficient supply to legal uses and consumers while eliminating or reducing pressure transients and variations, faulty level controls, and unnecessary pressures, all of which cause the distribution system to leak and break unnecessarily. Pump controls, altitude controls, and sustaining valves are just a few of the techniques that can be utilized to perform pressure management (Kingdom et al., 2006).

Leakage reduction in water distribution networks can be accomplished in a variety of ways. Some of them are structural, such as the placement of pressure lowering valves or pump stations at strategic locations. Non-structural solutions, which are addressed through management strategies and are very effective while requiring no capital expenditure, are also available (Nazif et al., 2010).

According to studies by Nazif et al. (2010) and Nicolini and Zovatto (2009), pressure control is one of the techniques for reducing leakage. This takes into account the direct relationship between pressure and leakage. This is because pipe pressure has a variety of effects on leakage, and pressure management can result in a significant reduction in leakage. The lower the pressure, the less likely it is that a pipe will burst. Additionally, frequent pressure swings, particularly in plastic pipes, can lead to pipe fatigue failure (Hunaidi and Wang, 2006)

Pump controls, altitude controls, and sustaining valves are just a few of the techniques that can be utilized to perform pressure management (Lambert et al., 2006; Ozturk et al., 2007). Study throttle control valves (TCVs) or pressure-reducing valves (PRVs) can be employed to limit leakage, according to Covelli et al. (2016).

By employing a pressure-reducing valve to reduce water pressure to an ideal amount, Karadirek et al. (2012) significantly reduced physical water losses (PRV). EPANET was used to calculate the ideal pressure value. This hydraulic model was also used to simulate leakage and estimate how much water could be saved by lowering pressure.

The pressure dynamics of a water distribution network should be considered while developing a leakage management strategy. This is due to the fact that pressure plays an important part in amplifying the size of water leaks. This is because the leakage flow rate and pressure have a physical relationship. As a result, the pressure applied by gravity or by water pumps causes a change in the leakage rate. The frequency of new pipe bursts is likewise a function of pressure, with higher or lower pressure resulting in greater or lesser leakage. Burst frequency is greatly influenced by pressure level and pressure cycling.

As a result, water utilities should keep an eye on the pressure in their distribution networks. Pressure lowering valves (manual or automatic) and variable speed pump controllers are two of the most important means of regulating pressure. A pressure reduction valve is normally employed to maintain a constant downstream pressure regardless of upstream pressure dynamics (Makaya, 2015).

According to DFID (2003), one of the simplest ways to reduce water demand is to reduce pressure in a water distribution system. Pressure control can help save water in a variety of ways. When the amount of water consumed is based on time rather than the volume of water discharged, high pressures increase water losses through leaks and increase use. McKenzie et al. (2002) also noted that most systems are intended to maintain a constant minimum working pressure throughout the day in order to meet the highest possible demand. Demand, on the other hand, varies throughout the day. Because most systems are designed to maintain a constant minimum pressure throughout the day, they are typically built to meet this need during peak demand hours when friction losses are largest and inlet pressures are lowest. Most systems are subjected to higher pressures than necessary throughout the other non-peak demand times as a result of this design style.

2.3.10 Use of modeling application for reduction of water loss

Due to the significant economic impact of water losses, numerous solutions have been proposed to address this issue. Traditional ways to addressing water loss issues, on the other hand, are insufficient to make a major difference. New approaches involving enhanced automation and monitoring are required to address this issue.

For identifying minor, continuous background and burst leakages in WDNs, a hydraulic model for leakage detection and estimation could be a promising technique. Because leakage outflows in large-scale water distribution networks are sensitive to pipe pressure, numerous pressure management systems have been proposed as viable means of controlling such leakages (Adedeji et al, 2018)

Zewdu (2014), tested the accuracy of water meters, and the results were used in the analysis of total water loss components. The top-down water balancing approach was used to analyze both apparent and real water loss, and the AWWA water audit software version 4.2 was used to perform a full analysis of the water loss components.

On the other hand, there are multiple types of computer programs that use various factors to replicate the conditions and pressures of a water system. Water CAD, Water Gems, and EPANET are three popular computer programs that mimic both steady-state and extended period analyses.

Many studies have been conducted using the EPANET software, which was developed by the US Environmental Protection Agency's National Risk Management Research Laboratory's Water Supply and Water Resources Division (previously the Drinking Water Research Division) (User's manual, 2000). It's free to copy and distribute because it's public domain software. EPANET, on the other hand, receives no formal assistance. Both the Water CAD and EPANET software can run simulations for long periods of time to assess water quality behavior and water loss detection in pressurized pipe networks.

Bentley WaterGEMS V8i is easy-to-use software that can be used as a decision-making tool in the water distribution network. This soft computing tool can be used to better understand how infrastructure behaves as a system and how it responds to operational strategies. This software models the development of a water supply system as population and demand grow. WaterGEMS V8i is hydraulic modeling software for water distribution systems that includes sophisticated interoperability, GIS model creation, optimization, and asset management functions. From fire flow, water quality modeling, and constituent concentration analysis to criticality, energy consumption, and capital cost management, it provides an easy-to-use environment for engineers to evaluate, design, and optimize water distribution networks (Udhane, Kataria, Sankhe, Pore, & Motegaonkar, 2018)

Gumbo et al. (2002) found that hydraulic modeling is quite helpful when it comes to pressure management. This is a model that simulates hydraulic dynamics in pressurized pipe networks. A network is made up of pipes and nodes (pipe junctions, pumps, valves, storage tanks or reservoirs.) Pressure and flow patterns inside a management zone can be calculated using hydraulic behavior simulation. These patterns aid decision-makers in identifying systemic problems and determining the best course of action to address them. Valves that are closed inside the system, for example, can be easily identified using the simulation.

2.4 Performance Evaluation of Urban Water Distribution System

The capacity of a water distribution network to supply a needed quantity of water under appropriate pressure and at an acceptable quality during various normal and abnormal operational scenarios is known as performance (Tabesh and Doulakhah, 2006). The water industry must evaluate the performance of water delivery systems in order to provide competent service. A competent distribution system should be capable of delivering water to all targeted locations inside the city with a reasonable pressure head and enough water to meet various sorts of demand. Four performance metrics were used to evaluate the performance of the urban water delivery scheme: hydraulic, structural, water quality, and customer perception.

2.4.1. Hydraulic performance

A water distribution system's hydraulic performance is defined as its ability to offer a reliable water supply at an acceptable level of service, that is, fulfilling all demands placed on the system while ensuring adequate pressure, fire protection, and the continuity of supply (Tabesh and Doulakhah, 2006). As a result, hydraulic simulation modeling is the most widely utilized tool among water supply engineers and management today.

2.5 Water Distribution Simulation

Under various physical and hydraulic factors or situations, the network system must be modeled, examined, and its performance evaluated. Simulation is the term for this procedure. The goal of water distribution network simulation is to find solutions to the differential algebraic equations that are used to represent a WDS mathematically. Before implementing different operational actions (e.g. valves opening and closing) or control techniques to an actual water network, simulation is a useful tool for assessing WDS reaction.

A WDS simulation is a difficult problem; the solution cannot be obtained analytically. The flow continuity equation can be used to find a solution for tree-shaped networks, however WDSs are almost never pure tree-shaped networks in practice. The analysis of a water network in a loop configuration poses additional difficulties. (Paluszczyszyn and colleagues, 2015)

WDS simulation techniques can be grouped into three types, according to (Paluszczyszyn et al., 2015): I steady-state simulation, (ii) extended-period simulation, and (iii) transient simulation.

1) Steady-state simulations represent

Demands and pressures at all nodes, as well as flows in all pipelines, do not change over time in this snapshot of the WDS functioning. However, in real systems, the loading conditions and states change throughout time (Paluszczyszyn et al., 2015).

The operating behavior of the system at a certain situation is determined by steady-state analysis (flow rates and hydraulic grades remain constant over time). This form of research is important for evaluating pressures and flow rates under minimum, average, and peak conditions, as well as the short-term impact of fire flows on the system (www.bentley.com).

The network equation is determined and solved for this sort of analysis, with tanks being treated as fixed grade of analysis are instantaneous of the value sand may or may not be indicative of the values of the system a few hours, or even a few minutes later in time (www.bentley.com).

2) An extended-period simulation

The EPS is a tool for analyzing a WDS's performance over time. This type of research looks at oscillations in tank water levels and demand over time intervals, but assumes that the system is stable during each interval (Paluszczyszyn et al., 2015).

When the variation of the system attributes over time is important, an extended period simulation is appropriate. This type of analysis allows you to model wet wells filling and draining, regulating valves opening and closing, and pressures and flow rates changing throughout the system in response to varying load condition and automatic control strategies formulated by the software.

3) The transient simulation

It provides the most accurate simulation of WDS as it considers naturally unsteady flow conditions incorporating transient analysis. Due to the complexity of this approach it is not yet adopted by many practitioners; mainly limited to specialized applications such as surge studies due to switching control elements (Paluszczyszyn et al., 2015).

2.5.1 Principle of water distribution network modeling

The flow state in a real water supply system is so complex that for analysis and calculations, it's usually believed that the flow is in a continuous uniform state. The error is permitted by the project's scope. The conservation of mass and energy laws are frequently used to explain numerous types of substances and their operation rules, and they may also be used to describe the operation of a water supply network system. The law of mass conservation is mostly used in hydraulics to distribute water demand among nodes. On the other side, Bernoulli's equation describes the law of energy conservation, which reflects pipe kinetic energy and pressure energy consumption and delivery. The hydraulic model, which is based on the law of mass and energy conservation and employs specialized algorithms for network adjustment calculation, is widely considered as a useful tool for network dynamic modeling (Xu and Zhang, 2012).

Two major equations are employed to model the dynamical behavior of the WDN: energy balance and mass balance (Todini, 2011). The energy losses inside a pipe are defined as pressure losses in the energy balance equation. Based on the inflow and outflow, the mass balance equation estimates the volume of water storage at each node (Vela et a., 2014).

2.5.2. Model calibration and validation

Calibration is an iterative technique of parameter evaluation and refinement for the majority of water distribution models, resulting from a comparison of simulated and observed values of interest. In reality, model validation is a continuation of the calibration process. Its goal is to ensure that the calibrated model accurately assessments all variables and conditions that can influence model findings, as well as to demonstrate the model's capacity to forecast field observations for time periods other than the calibration effort (Geta, 2018).

According to Walski et al. (2003), comparing time series data to model outputs is an important step in calibrating and validating a long period simulation. The model is calibrated when the field data and model results are within acceptable bounds. If there are major differences, numerous model parameters can be tweaked to enhance the match. One set of data should ideally be provided for calibration, and another set of data should be available to verify that the model has been appropriately calibrated.

3. MATERIALS AND METHODS

3.1 Description of the Study Area

The study focused on the water supply mains and distribution infrastructure at the Yeka Abado Condominium in Addis Ababa. The Yeka Abado condominium is in the Yeka sub-city, which is in the north-eastern portion of Addis Ababa, near the city's Oromia Region boundary. The area's residential building types are dominated by condominiums. It is located at 9o 9'3"N or 9.06750 latitude and 38o 5222.3 E or 38.87290 longitude, with an elevation of 2530 to 2640 meters above mean sea level. The condominium experiences moderate rain on average, with a maximum temperature of 17 degrees Celsius and a low temperature of 10 degrees Celsius.

This area was primarily agricultural land and farmer's houses prior to the condominium building in 2012. According to the AAWSA data from 2014, there were 17,418 residential houses. In 2020, the condominium had 67,930 residents, based on the average family size of 3.9. (CSA, 2013). The study region is depicted in Figure 3.1 as a location map.

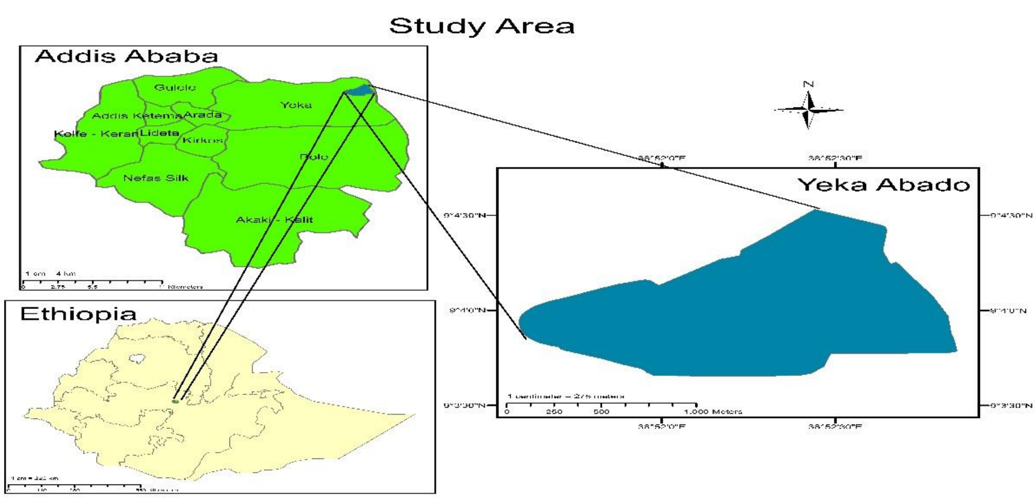

Figure 3.1 Location map of Yeka Abado Condominium

3.1.2 Existing Water Supply System Description

I. Design Period

For the water distribution system, the design horizon is set at 20 years. The year 2012 has been used as the starting point.

II. Source of water

The Addis Ababa Water and Sewerage Authority (AAWSA) is a government agency in Addis Ababa that is in charge of providing potable water to the Yeka Abado condominium. The condominium draws its water from the Legedadi deep wells field. Each well has a submersible pump that pumps water through DCI pipes to a 5,000 m3 reservoir at T2. T3 Reservoirs receive water from the T2 5,000m3 reservoir. Finally, gravity delivered water from the T3 reservoir to the condominium.

III. Collection pipe line

The collecting pipe lines' purpose is to transport water from the ten wells to the T2 collecting reservoir. The collection pipe line is 16.00 km long and has a DN of 250-800. DCI and PN 16 pipe and fittings are used in collector pipelines.

IV. Transmission pipe line

From the end of the wells field pipe line LLA-PW 4 junction to the last reservoir of the transmission system T2 at Bekele Resort to T3 reservoir, the transmission pipe line is the major water conveyance. The Transmission pipe line is 5.4 km long and has a diameter of 400 mm. DCI is the pipe material used in the transmission pipe line.

V. Distribution pipe line

The distribution pipe line extends from the T3 reservoir to Yeka Abado condominium. The pipe material is uPVC and DCI, HDPE type and DN 100,150,200,300,350 & 450. Ike total length of pipe is 13.26 km.

VI. Existing Reservoir

T3 reservoir is a 5,000 m3 capacity reservoir constructed at a hilly place near to Yeka Abado condominium. It collects chlorinated water from T2 reservoir through pumping and supplies water to Yeka Abado condominium sites through gravity.

Figure 3.2 Reservoir of Yeka Abado Condominium

VII. Pump Stations

Water supplied from the bore holes and stored in T_2 reservoir is pumped to T_3, 5,000m3 capacity reservoirs and distributed to Yeka Abado condominium,

Pumping station consists of two groups of pumps. The first group consists of three multi stage ring section pumps of capacity 92 l/s at 140 m head each and transfer 15,897.60 m3/day water to T3, 5000 m^3 reservoir. The total daily flow is achieved with two duties and one standby pumps over 24 hours.

The second group consists of two single stage pumps of capacity 100 l/s at 68 m head each and transfer 8640.00 m3/day to T1, 2000 m^3. The total daily flow is achieved with one duty and one standby pump over 24 hours.

Chlorination of the water pumped from the well field is performed at pumping station using gas chlorination system. The chlorine solution is dosed at a point on the inlet to T_2 reservoir. The dosing rate is proportional to the flow rate and the residual chlorine is measured from sample taken from the station discharge line.

3.2 Materials

In this research, different material was used for different purposes. Those are:

1. **Pressure gages**

This apparatus was used to measure the amount of pressure in various junctions in this study. The water pressure was measured in order to calibrate and validate the model. The pressure measurement is carried out with the assistance of GPS. During the pressure reading, the GPS device was utilized to obtain the requisite elevation data in order to pinpoint the exact location of the sample locations.

2. **Ultrasonic meter**

This equipment was used to measure the amount of water entering the system in this study. Water Balance EasyCalc program uses the measured value of water that enters the system as input data. This software was used to assess water loss and determine the Performance Indicator (PI) in the research region.

3. **WaterGEMS software**

This software was created by combining ArcGIS software with a Microsoft Excel worksheet for pressure analysis. WaterGEMS was used to determine the pressure at each connection and to lower the pressure. ArcGIS was used to create the shape file and calculate the polygon area. While Microsoft Excel was used to calculate demand at each junction, the data was then utilized to feed into the WaterGEMS software. Table 3.1 provides a more detailed summary of the items used.

Table 3.1 Summary of material used

No	Materials	Purpose
1	Pressure gauges	To measure Pressure
2	GPS	To measure (x,y,z) co-ordinate
3	Ultrasonic meter	To measure the amount of water entering the system
4	WB-EasyCalc software	To evaluate water loss
5	WaterGEMS software	To analysis pressure
6	ArcGIS	ArcGIS used for preparation of shape file and calculation of polygon area
7	Microsoft excel	To calculate demand in each junction and to prepare input data for WaterGEMS software

3.3 Data Collection

The data for this study was gathered using primary and secondary sources that were appropriate for the investigation. It was also gathered in response to a formal request from AAWSA, as well as other associated organizations, via physical communication, talks, and online sources.

To clarify the obtained data in light of the present circumstances and obtain data that was not available from the utilities, the information needed for water loss analysis, pressure analysis, and water supply coverage analysis was gathered through various measurements and site observations.

3.3.1 Primary data collection

1) Pressure measurement

Pressure gauges were used to measure pressures in the distribution system. Elevation readings were taken at the same site where pressure gauges were installed. The sample junctions were chosen depending on the pressure value. Low, high, and medium pressure junctions were chosen based on this.

2) System input volume measurement

The system input volume of water was measured by ultrasonic meter to quantify the level of NRW in the distribution system and for the input data of the model. At the intrusion of water from the reservior into the system, the volume of system input was measured.

Figure 3.3 Measuring input volume of water in the system using Ultrasonic meter

3.3.2 Secondary data collection

1) Yeka Abado condominium water supply networks data

The water supply network including their attribute like the length, diameter, material types, pressure capacity (PN) of the pipes, pumps characteristics, reservoir and tank data and number of connection was collected from AAWSA Gurd Shola branch office.

2) Water consumption and total number house

Billed approved usage and unbilled authorized consumption data were acquired from the Addis Ababa water and sewerage authority Gurd Shola branch office in order to assess water loss in the distribution system and provide input data for the hydraulic model. The total number of houses was gathered from the Yeka sub city administration office to estimate the number of people who live in the condominium. The water supply network layout has been collected in the form of an AutoCAD file.

3) Volume of water used for Firefighting purpose

The volume of water utilized for firefighting purposes was collected from the Addis Ababa Fire and Emergency Privatization and Rescue Authority, Semit branch office, in order to compute authorized usage.

3.4 Method of Analysis

3.4.1 Water supply coverage analysis

The condominium's water supply coverage was assessed based on average per capita use and the number of connections per family. The average per capita consumption was calculated using the annual use of each customer, which was gathered from individual water meters. Aside from the average per capita water use, the number of residential connections per family has also been assessed. The supply coverage was assessed using statistical analysis.

1. Average daily per capita consumption

To study the distribution of water supply coverage among different localities, the volume of water consumed for domestic uses was aggregated into the condominium. Using the population, the annual consumption data was translated to average daily per capita consumption. The following equation was used to calculate the average daily per capita consumption.

$$per\ capita\ consumption\ \frac{l}{person}/day = \frac{Annual\ consumption(m3)*1000L/m3}{population\ number*365} \ldots\ldots\ldots \text{Eq. 1}$$

2. Level of connection per family

The number of water connections is an important factor to consider when determining the extent of water supply coverage and the overall number of connections. The following equation was used to determine the level of connectedness within each household.

$$\text{Level ofconnecton per family} = \frac{\text{Total No of connection} \times \text{Average family size}}{\text{Total No of population}} \ldots\ldots\ldots \text{Eq. 2}$$

3.4.2 Water loss analysis

WB-EasyCalc V4.05 software was used to assess water loss in the condominium water supply distribution system. Water balancing software version 4.05 was also used to perform a detailed analysis of the water loss components (WB-EasyCalc). The system input volume data, metered consumption data, unmetered consumption data, unbilled meter consumption data, unbilled unmetered consumption data, unofficial consumption data, inaccurate data meters and data handling, data on the length of distribution and transmission pipes, official pipeline data, average pressure data, and unofficial consumption data were all needed to calculate the water loss in WB-EasyCalc software.

The program calculates losses, revenue, NRW, Apparent loss, Real loss, Real loss and commercial loss performance indicators, real loss performance indicator, and the detail water balance when data entries are completed. As a result, the obtained data were entered into the software, and the findings were compiled and displayed in a water balance sheet using internationally agreed-upon nomenclature. Below is a table that was created.

Table 3.2 Standard IWA Water Balance

<table>
<tr><td rowspan="9">System input volume</td><td rowspan="4">Authorized consumption</td><td rowspan="2">Billed Authorized consumption</td><td>Billed Meter Consumption</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized consumption</td><td>Unbilled Metered consumption</td><td rowspan="7">Non-Revenue water</td></tr>
<tr><td>Unbilled Unmetered consumption</td></tr>
<tr><td rowspan="5">Water Loss</td><td rowspan="2">Commercial loss</td><td>Unauthorized consumption</td></tr>
<tr><td>Customer meter inaccuracy</td></tr>
<tr><td rowspan="3">Real loss</td><td>Leakage on Transmission and distribution mains</td></tr>
<tr><td>Leakage and over flow at storage tanks</td></tr>
<tr><td>Leakage on service connection up to point of customer meter</td></tr>
</table>

Water Audit Study Period

The research time for the water audit was chosen to be lengthy enough to investigate and evaluate overall system water use. A 12-month or one-year study period beginning in July 2019 and ending in June 2020. The majority of water system records are organized by calendar or fiscal year.

3.4.3 Performance indicator (PI)

For assessing changes and evaluating water loss, a performance indicator (PI) is utilized to assess how successfully the network is managed in comparison to the reduction of NRW (Mengistu, 2016). Knowing the features of performance indicators is important for better understanding water losses, defining and setting improvement targets, measuring and comparing performance, developing standards, and prioritizing investments.

A performance indicator basically addresses the operational and financial aspect of NRW. IWA has developed universally accepted indicators for NRW that take the different characteristics of distribution systems and utilities in an account. The performance of Yeka Abado Condominium was evaluated based on:

- ❖ Water losses as a % of system input volume.
- ❖ Physical losses per house connection
- ❖ Physical loss expressed as the length of the main pipe
- ❖ Infrastructure Leakage Index (ILI) for physical loss performance indicator
- ❖ Commercial loss performance indicator

1. **Water losses as a % of system input volume**

Water losses are simply estimated and routinely cited as a percentage of system input, and they are by far the most common indicator. Equation 3 (Mckenzie et al., 2012) and WB-EasyCalc software were used to compute the percentage of water losses in the research region.

$$\%NRW = \frac{System\ input\ volume - (Billed\ consumpton + free\ basic\ water)}{System\ input\ volume} \times 100$$ ……...Eq. 3

2. Physical losses per house connection

Physical losses per number of service connections (liters per service connection per day, l/c/d) is one of the relevant indicators of water loss in the distribution system, and it provides a more exact figure than physical losses as a proportion of input volume (Bogale, 2016). Equation 4 and WB-EasyCalc software were used to calculate the physical loss per house connection.

$$Physical\ loss\ per\ house\ connection = \frac{Physical\ loss \times 1000L}{Number\ of\ connection \times 365 days}$$ …….Eq. 4

3. Physical loss expressed as the length of the main pipe

Water loss is also measured in terms of kilometer length of main pipelines, which is used to compare water loss. Equation 5 and the WB-EasyCalc software were used to calculate the physical water loss expressed as the length of the main pipe.

$$Physical\ water\ loss = \frac{Annual\ physical\ water\ loss \times 1000L}{Length\ of\ main\ pipe\ in\ km \times 365\ days}$$ ………..Eq. 5

4. Infrastructural leakage index (ILI)

The infrastructure leakage index (ILI) is a good indicator of actual loss since it considers how the network is administered. The ILI indicators are defined as a ratio of real losses (RL) to yearly actual losses that are unavoidable (UARL). It is a new indicator for water supply systems that expresses the system's technical condition in terms of water loss. The International Water Association (IWA) has proposed and supported this indicator (Lambert, 2002).

Real losses are impossible to completely eliminate. Unavoidable Annual Real Losses are the lowest theoretically feasible annual volume of real losses for well-maintained and well-managed systems (UARL). Equation 6 was used to compute the infrastructure leakage index in the research area (Liemberger & Farey, 2004).

$$ILI = \frac{CARL}{UARL}$$ … … … ..Eq. 6

UARL (litters/day) = (18xLm+0.8xNc+25xLp)

Where: Nc (number of service connections)

Lm (km) (the length of mains)

Lp (km) (the length of private pipes between the street)

P (m) (the average operating pressure)

The infrastructural leakage index was estimated using WB-EasyCalc software in addition to the equation. The infrastructural leakage index was calculated automatically once the data was entered into the free WB-EasyCalc software.

5. Commercial loss performance indicator

WB-EasyCalc software was used to calculate the performance indicator for the commercial loss. Commercial water loss was measured in percent of permissible consumption and liters per connection per day by the software.

3.4.4 Pressure analysis

The pressure in the distribution system of Yeka Abado condominium was measured using WaterGEMS V8i. WaterGEMS is a useful tool for assisting in the design and study of real-world losses, as well as numerous scenarios and options for determining pressure. It was utilized in the experiment to solve the pressures at each node and within the pipes, allowing for proper pressure management and water loss reduction.

Running the model at peak hour demand, low hour demand, and temporal fluctuations of demand with different scenarios provided an analysis of the present system's model. Both steady-state analysis and extended analysis were used in this study.

The model incorporates several features that are essential for pressure analysis, and some parts, such as valves and lower diameter pipes, can be excluded based on their significance. The creation of a hydraulic model is essential for visualizing the existing distribution network system and simulating it using actual flow parameters.

Steady-state analysis

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

Extended period simulation

Extended period simulation is a type of linked steady state run that tracks a system across time. Demand fluctuates throughout the day in this analysis. Because the system's operations change with time, it's necessary to execute the extended period simulation.

The Procedure of modelling to determine pressure

Different techniques are used by different researchers to build a model and determine the pressure using WaterGEMS V8i. The techniques and the procedure vary depending on the input file used for the model. In this research, the input file was an AutoCAD file. Therefore, to build a model and predict the amount of pressure in each junction, different steps were carried out. These steps are:

a. Preparing shape file

ArcGIS software was used to prepare the shape file. To prepare the shape file, the first step was to clip the network layout of Yeka Abado condominium from the Addis Ababa water supply network layout using the clip tool. After clipping as shown in figure 3.4, change to the shape file. Finally, using the attribute table in ArcGIS, add the necessary key label or fill in the necessary blanks. such as pipes, junctions, tanks, reservoirs, valves, and pumps that were essential to build the model.

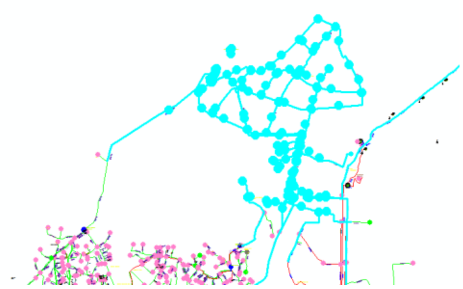

Figure 3.4 Clipping the water distribution layout of Yeka Abado from Addis Ababa's water network layout

b. Building a model

After clipping and changing in to the shape file as shown in figure 3.5, then build a model using the model builder tool in WaterGEMS V8i. The process starts by entering the necessary data in the dialog box of the model builder tool. After following the necessary steps, the model was built.

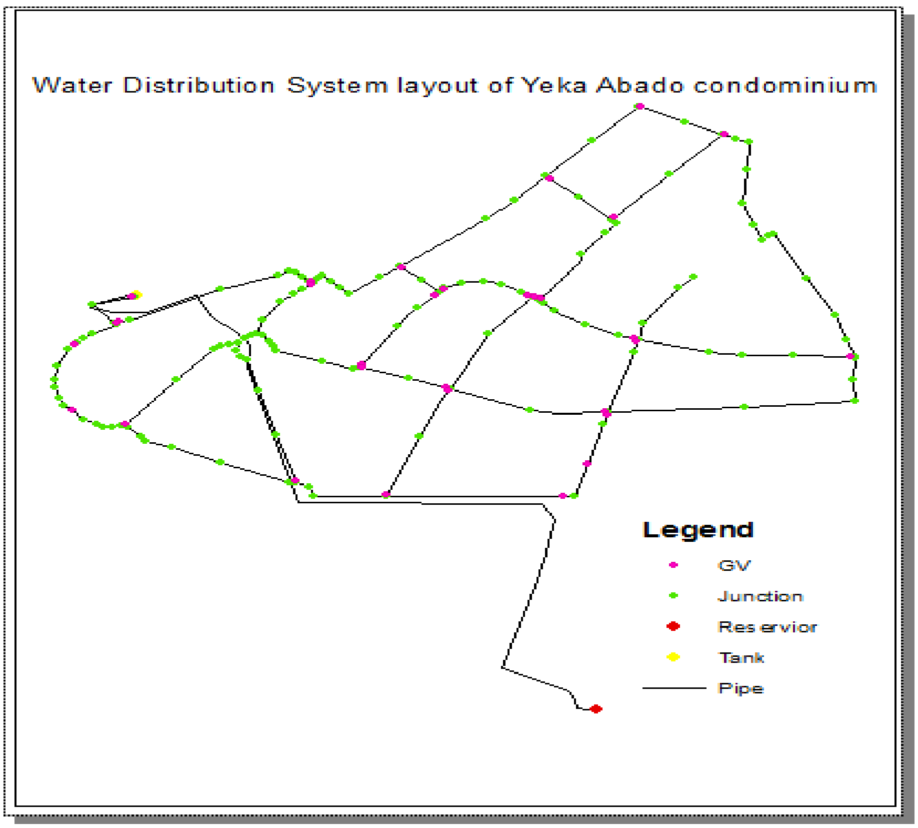

Figure 3.5 Shape file of the study area

Model Builder uses existing GIS assets to build a new WaterGEMS V8i model or update an existing WaterGEMS V8i model, according to (Bently WaterGEMS V8i Users Guidline V8i). Model Builder supports a wide range of data types, including simple databases (like Access and DBase), spreadsheets (like Excel), GIS data (like shape files), Bentley Map data, and high-end data stores (like Oracle and SQL Server). Map the tables and fields in the data source to the element types and attributes in the WaterGEMS V8i model using Model Builder. As a result, a

WaterGEMS V8i model is produced. Model Builder can be used in any of the WaterGEMS CONNECT platforms - Stand-Alone, Micro Station mode, AutoCAD mode, or ArcGIS mode.

c. Allocation of demand in each junction

The Thiessen polygon tool in WaterGEMS was used in the study area to create a polygon for each junction. Then the polygon area for each junction was calculated using ArcGIS. After that, demand for each junction was calculated using equation 7 (WaterGEMS V8i Users Guideline). The calculated demand results are presented in appendix A.

$$\text{Jed} = \left(\frac{\text{Jea}}{\text{JTa}}\right) * \text{Td} \ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. 7}$$

Where: Jed = Each Junction Demand

Jea = Each Junction Area

Jta = Total Junction Area

Td = Total Demand

The Dirichlet Tessellation is a Voronoi Diagram that is also known as the Thiessen Polygon. It defines a zone around each point given a set of points. A Thiessen polygon divides a plane by enclosing each point in a polygon and assigning the area to one of the points in the point set. Any point within a Thiessen polygon is closer to that polygon's point than any point outside of it. A Thiessen is created mathematically by connecting perpendicular bisector lines between all points. The Thiessen Polygon (Figure 3.6) Creator was created for water distribution modeling to quickly and effectively establish demand service zones (WaterGEMS V8i Users Guidline).

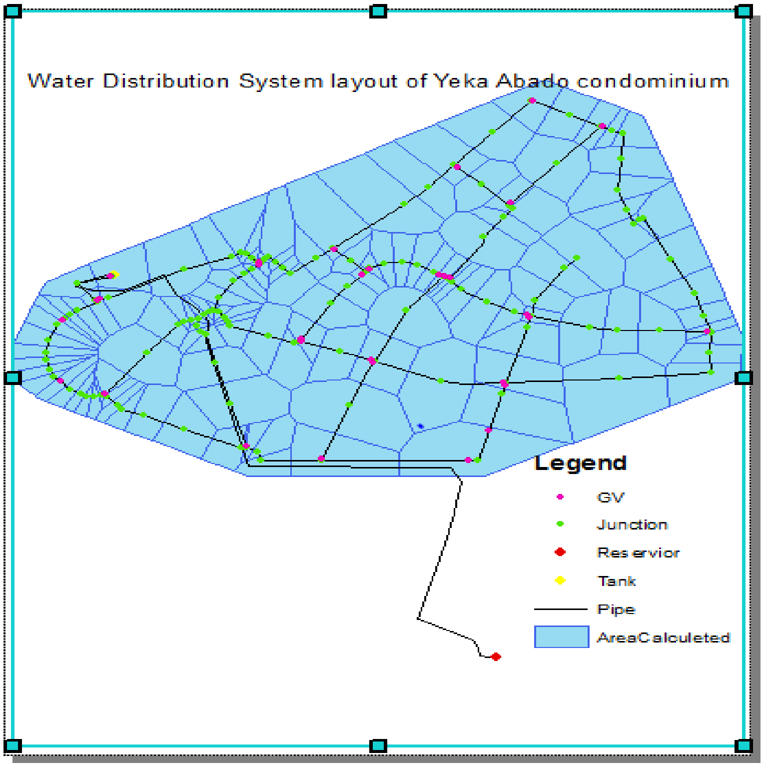

Figure 3.6 Thiessen polygon for each junction

d. Determination of elevation

The TRex wizard tool is used to determine the elevation at each junction. The elevation of the junction was determined by interring appropriate data in the TRex wizard tool.

The TRex Wizard automatically assigns elevations to selected nodes based on data from a Digital Elevation Model or a Digital Terrain Model, according to (WaterGEMS V8i Users Guideline). TRex can read elevation data from a variety of file types, including vector and raster files, and load it into model point features (nodes). The ArcGIS platform is required to use raster files as a data source. It is possible to use any platform with a vector data source. Either points with elevations or contours with elevations must be included in vector data. Understanding the resolution, projection, datum, units, and correctness of any source file used to load elevation data for nodes is critical.

e. Interring input data

Based on the information from the AutoCAD file, pipe data, valve data, pipe and tank data were entered using the flex table in Water GEMS. This information (Table 3.3) was helpful in running the model and determining pressure at each junction.

Table 3.3 Input Data

Element (Filled)	Type of Data Inter
Pipe	Diameter, Roughness coefficient, Types of Material
Tank	Initial elevation max elevation, Diameter
Valve	Diameter

Roughness coefficients for pipeline

Roughness coefficients are determined by the pipe's material. To account for frictional losses, Hazen-William roughness factors are utilized. Smoother pipes (with larger carrying capabilities) have higher C-factors, while rougher pipes have lower C-factors (Walski et al., 2003). In the research area, DCI and HDPE pipe are available. Table 3.4 displays the roughness coefficient that was chosen.

Table 3.4 Hazen - Williams coefficient Source (www.engineerungtoolbox.com

Material	Hazen-Williams Coefficient (c)
Cast iron asphalt coated	100
Cast-iron cement lined	140
Aluminium	130-150
Concrete	100-140
Polyethylene, PE,HDPE	140

Setting Pump data

Pump definition component is used to set pump data. The pump station consists of three multi stage ring section pumps of capacity 92 l/s at 140 m head each and transfer 15,897.60 m^3/day water to 5000 m^3 capacity reservoir and distribute to Yeka Abado condominium. The total daily flow is achieved with two duty and one standby pumps over 24 hours.

Assigning demand patterns

Water demand in a distribution system fluctuates over time. This variation in demand over time can be modelled using demand patterns. Demand patterns are multipliers that vary with time and are applied to a given base demand. The Components tab has an option called "Patterns", which opens the Pattern Manager window. This pattern manager creates water usage patterns based on daily, weekly and monthly use.

Each city has its own amount of utilization, which is determined by current weather conditions as well as the time of day. Demand is influenced by economic growth as well. Figure 3.6 depicts the demand pattern for the Yeka Abado condominium.

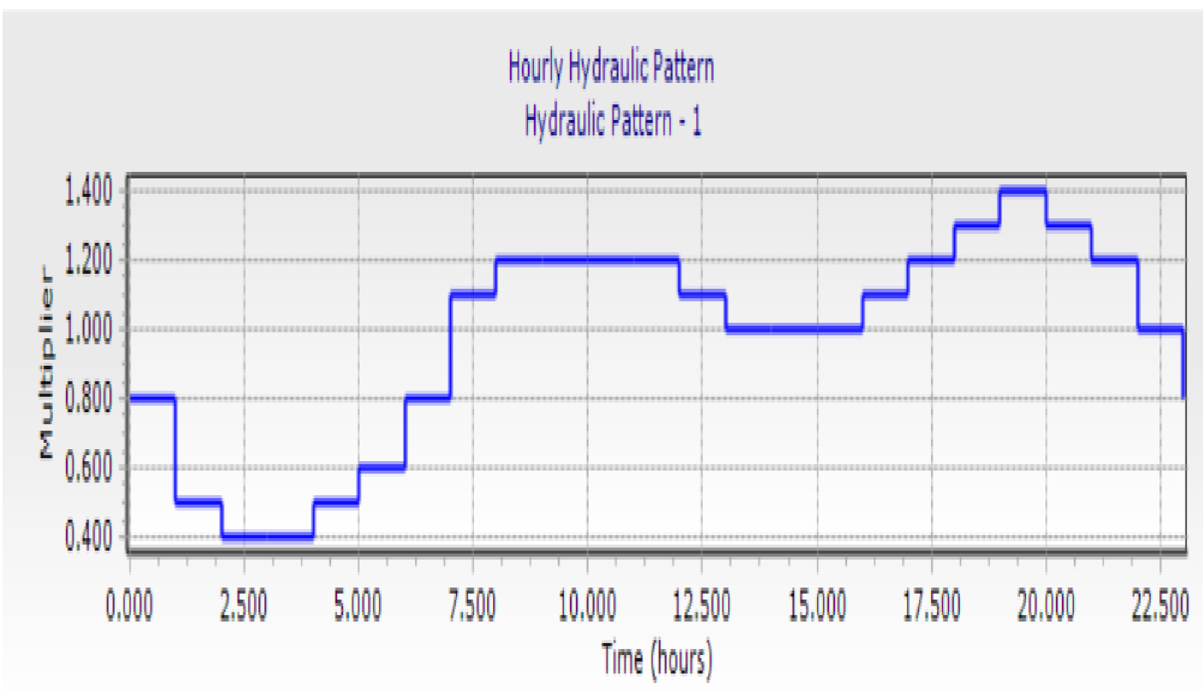

Figure 3.6 Variation of water demand during the day

A typical diurnal curve for a research region is shown in Figure 3.6. The usage is generally low at night when most people sleep, increases in the early morning hours as people wake up and prepare for the day, decreases in the middle of the day, and then increases again in the early evening as people come home.

3.5 Sample Size and Location

The calibration recommendations of the Engineering Computer Applications Committee (ECAC) (1999) were used to determine the number of sample sizes for pressure measurement. If modeling was used for operational purposes, the sample size for pressure measurement should be between 10% and 2% of the entire junction, according to the standards. The sample size in this study was 5% of the total junction in the system.

Sample size = 5% of total junction
= 0.05 × 131
= 6.55 which is approximately 7 junctions

As a result, seven representative samples for calibration and another seven representative samples for validation were taken. The calibration and validation samples were not the same. After simulating the computed model, knowing the pressure variation area, and reconnaissance of the condominium water distribution network, all sampling spots were chosen.

Due to the size of the pressure gauge accessible in this study, it was difficult to collect measurements at a direct connection to the water main nodes. As a result, samples were gathered from end-user water meters in areas with high, low, and medium pressure (Figure 3.7).

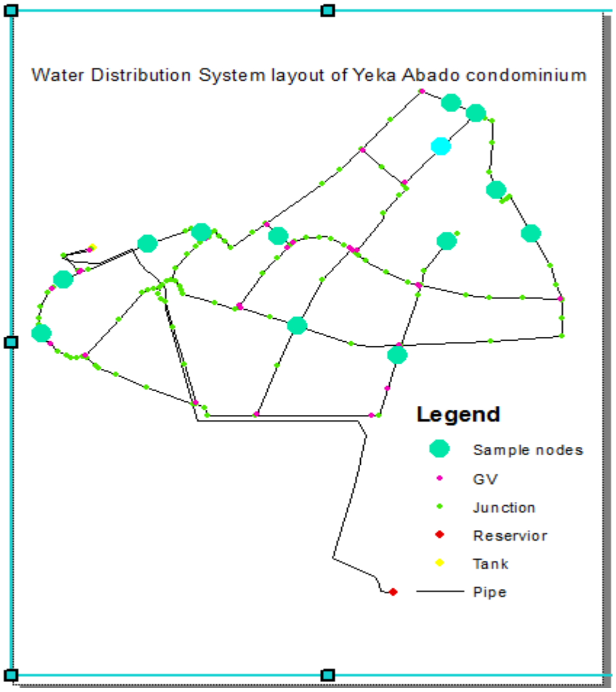

Figure 3.7 Location of samples site in distribution system

3.6 Model Calibration and Validation

Water utilities can now use hydraulic models to assess the state of their existing water delivery systems in the modern day. However, the computed model outputs were checked with the actual observed field circumstances of the study region to ensure the entered water distribution model inputs data accuracy.

Water pressure was measured at J-119 and J-5 in order to calibrate and validate the model output. J-87, J-78, J-37, J-44, J-122, J-87, J-78, J-37, J-44, J-122. Using pressure gauges, J-12, J-32, J-40, J-77, J-83, J-78, and J-131

Figure 3.8 Pressure reading measurement using pressure gauges

Data was acquired from field selected sample locations for model calibration and validation. This study's mandatory data collection included pressure. A total of fourteen representative pressure samples were taken at various connection points. Seven representative samples were used for calibration and seven representative samples were used for validation. The Darwin calibrator was used to calibrate the models.

Model calibration

Computer models, according to Walski et al. (2001), are substantial investments for water businesses. The model must be capable of accurately mimicking flow conditions encountered at the site in order to assure a good investment return and proper use of the models. The models are calibrated to achieve this. The process of modifying model traits and parameters so that the model's anticipated flows and pressures match actual observed field data to some desirable or acceptable level is known as calibration.

The Darwin calibrator was used in this study to calibrate the performance of model calibration. There are numerous techniques to calibrate the performance of model calibration. Darwin Calibrator is a technology for calibrating water distribution networks that is both quick and accurate. It allows you to: I handle field data in a flexible manner, (ii) pick calibration criteria,

(iii) weigh the importance and accuracy of field data results, (iv) establish roughness and demand groups, (v) perform multi-objective optimization, and (iv) examine results in real time. As a result, if appropriate data (field data, network setup) is provided, Darwin Calibrator can handle calibration difficulties quickly and produce reliable results with slight inaccuracies that can be overlooked (Apaydin, 2013).

Darwin Calibrator assesses millions of alternative solutions to enable users to quickly identify a calibration hypothesis that best fits recorded flows, pressures, and on/off state, allowing users to make confident judgments based on precise hydraulic simulation of the actual world.

Inserting the recorded pressure field data into the filed data snapshots tab begins the calibration procedure. Then, under the roughness group tab, group pipe into DCI and HDPE to limit the magnitude of the problem, making it easier to discover the best solution, and avoid instances where numerous similar pipes end up with drastically different roughness values due to field measurement discrepancies. Then, on the boundary overrides tab, enter the tank level from the pressure measurement. Then compute an optimized and manual run until the fitness number is lower and the discrepancy between the observed and simulated hydraulic grade value is reduced. Finally export the calibrated solution to scenario dialog box to apply the calibrated result to the created model.

Model validation

Model validation is a process that comes after calibration and involves using an independent field data set to ensure that the model is correctly calibrated. The calibrated model is run under settings different from those used for calibration in the validation step, and the results are compared to field data. The calibrated model is regarded validated if the model results (visually) substantially approximate the field findings for an adequate time period. Significant discrepancies suggest the need for more calibration (USEPA, 2005).

The model was validated using the difference error approach in this study. By comparing the observed and calculated pressure levels in the system, the degree of accuracy (error of difference) criteria is utilized to evaluate the calibration results. To verify the calibration results, the following criteria were used from (Bhave, 1998 quoted by James, 2002).

a) For a good data set, the difference between measured and simulated values should be 3.0m with a maximum difference of 10m, and b) For a - bad data set, the difference between measured and simulated values should be 3.0m with a maximum difference of 10m.

4. RESULTS AND DISCUSSION

4.1 Water Supply Coverage

In order to detect the problem, it is necessary to assess the distribution of the water supply. As a result, the existing water supply coverage was assessed based on average daily per capita use and the number of family connections. The annual water usage is translated to average daily per capita consumption utilizing the condominium's population data and customer consumption data in order to assess the amount of water consumed.

4.1.1 Average daily per capital consumption

To analyze the distribution of water coverage, the amount of water consumed for household purposes has been aggregated to the condominium. It's possible that evaluating residential water supply coverage based on consumption volume won't allow for a distribution comparison to be made. As a result, using the population, the annual consumption data has been transformed to average daily per capital consumption. The details can be found in Table 4.1.

$$\text{per capita consumption}\,\frac{\text{l}}{\text{person}}/\text{day} = \frac{1{,}620{,}172*1000L}{67{,}930*365}$$

= 65.3 l/capita/day

Table 4.1Water production and consumption of Yeka Abado Condominium

Year	Production m^3/year	Consumption m^3/year	Total Population	consumption l/person/day
2020	2,150,059.68	1,620,172	67,930	65.3

The condominium's per capita domestic water supply coverage was found to be 65.3 l/capital/day. When compared to the Addis Ababa Water and Sewerage Authority norm utilized for condominium design (110 L/capital/day), this per capita consumption is extremely low.

4.1.2 Level of connection per family

Knowing the amount of water connection is crucial to determining the extent of water coverage. According to the Gurd Shloa branch office of the Addis Ababa Water and Sewerage Authority, the total number of connections in the research area was around 3014. The average family size of 3.9 was used to calculate the average number of connections per family using the following equation based on the Central statistical Agency population prediction report 2013.

$$\text{Level of connection per family} = \frac{3014*3.9}{67,930}$$

$$= 17.3\%$$

The condominium's average connection per family was found to be 0.173. This means that on average, six families or twenty-three people share one internet connection. This means that clients will not receive water in the usual quantity.

The amount of water consumption is projected to be linearly related to the level connection in locations where water supply coverage is adequate. Water consumption is projected to be higher in areas with better connections because they may easily obtain it within their building or complex.

4.2 Evaluating the Distribution of the Water Supply Coverage

The condominium's water supply coverage was deemed to be inadequate in terms of both per capita use and level of connection. The volume of water usage is predicted to be linearly related to the level of connection in places where water supply coverage is adequate. Water consumption is projected to be higher in areas with better connections because they may easily obtain it within their building or complex.

While certain regions may have a higher level of connectivity, this does not always suggest that they are drinking more water, as the ability to receive water is dependent on the local area. According to Kabeto (2011), due to their topographic location, a number of localities receive minimal volumes of water. Because the city relies primarily on gravity for its supply, geography has a significant impact on per capita capital consumption. Water was distributed in the Yeka Abado condominium using a gravity distribution method. The distribution of water in low-elevation and high-elevation places varies as a result of this circumstance.

The elevation map of Figure 4.1 shows areas that have low elevation compared to the storage tank elevation, and those marked in green get more water because due to the topography of the area and the nature of the water. The area marked in red has a higher elevation than the storage tank elevation, and the water pressure is lower than the design standard, resulting in less water being delivered to the area. Areas having medium elevation compared to the elevation of the tank and marked by the yellow color get moderate water compared to the high elevation area.

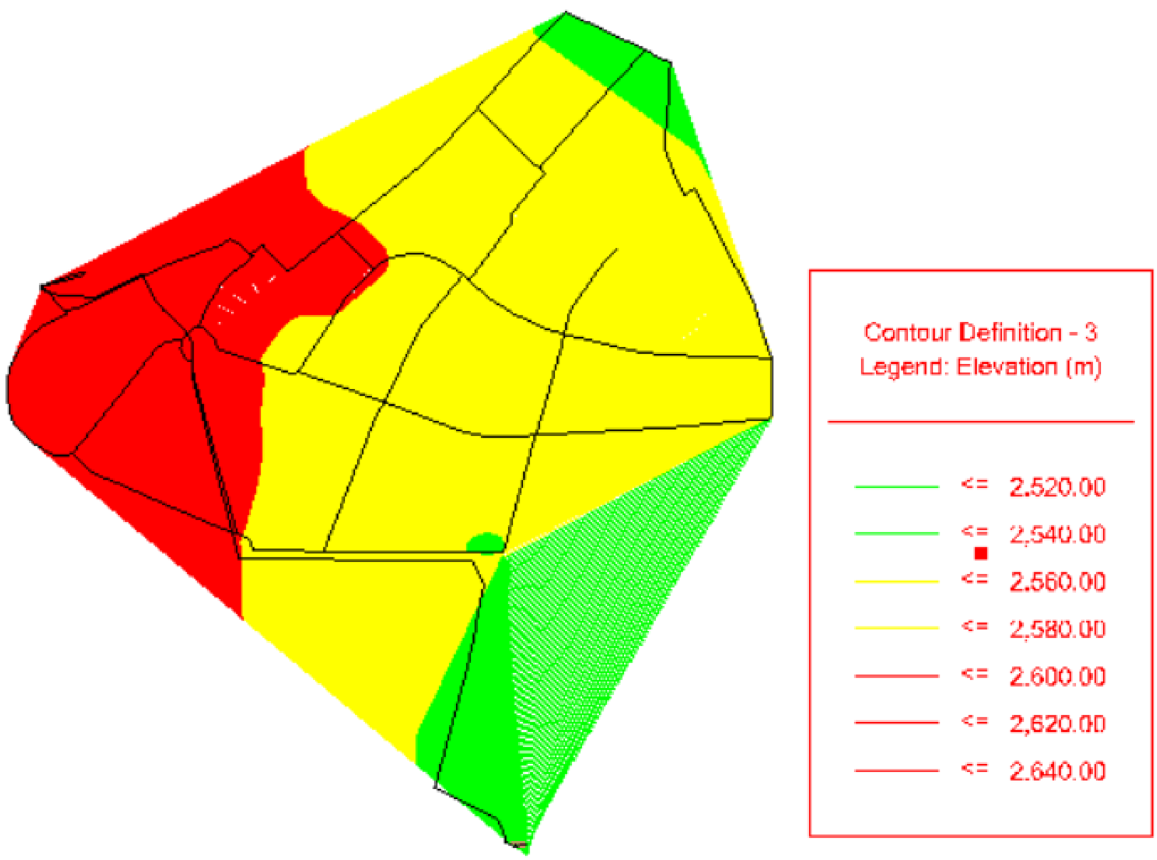

Figure 4.1 Elevation map

In addition to this, the coverage depends on the height of the building. The shortest building gets more water from the tallest one. In the study area, most of the buildings were seven stories, four stories or two stories. Among the three types of building that are found in the study area, the two-story buildings get more water. The main reason for this was the decrease in pressure with increasing height.

4.3 Water Loss Analysis

Water balancing software version 4.05 was used to calculate the amount of water lost (WB-EasyCalc). According to the volume of water, the values and percentages of water losses and NRW were calculated. The overall water loss from the system is 528,888 m3/year, or 24.6 percent of the system input volume, according to the analysis results.

Excessive water loss values are primarily related to genuine losses, inadequate water network management, and high operating pressure, according to the findings. This significant degree of water loss necessitates the implementation of a reduction program. Calculating the water balance and managing the water pressure are the first steps in a water loss reduction program. The following is a detailed water loss estimation for the Yeka Abado condominium water supply system:

Annual system input volume

The annual input volume of water provided to the Yeka Abado condominium was 2,150,060 m3 from July 2019 to June 2020. It was calculated using an ultrasonic meter, and the result was an average value.

Authorized consumption

Authorized consumption is the volume of metered and unmetered water taken by registered customers, laboratories, etc. For example, water used in fire hydrants and others. The Authorized consumption from July 2019 to June 2020 was 1,621,172 m^3/year.

Billed authorized consumption

This is the components of authorized consumption which are billed and produced revenue (also known as Revenue water). It is equal to billed Metered consumption plus Billed Unmetered consumption. In Yeka Abado condominium the total billed authorized consumption was 1,620,172 m^3/year.

Billed metered consumption

This consumption includes all groups of customers such as domestic, commercial, institutional and industrial. It also includes bulk water sale which is metered, billed and provide profit. Considering this concept, the billed meter consumption of Yeka Abado was 1,620,172 m^3/year.

Billed unmetered consumption

All invoiced usage that is not metered and is computed based on estimates or norms. In fully metered systems, this may be a minor component (for example, invoicing based on estimates for the time a customer meter is out of service), but in systems without universal metering, it can be a significant consumption component. This component could potentially contain unmetered but billed water transferred across operational borders (water exported). Furthermore, this sort of use includes the sale of water by car to another sub-city or water distribution system. However, there is no unmetered consumption invoiced at the Yeka Abado condominium.

Unbilled authorized consumption

Those components of unbilled authorized consumption which are legitimate but not billed and therefore do not produce revenue. This is equal to unbilled metered consumption plus unbilled unmetered consumption. The total unbilled authorized consumption in Yeka Abado was 1000 m^3/year.

Unbilled metered consumption

Water used for customers with installed meters but the company don't charge for collect water or free usage fees. At present, in the Yeka Abado condominium haven't unbilled metered consumption, so during July 2019 to June 2020 of unbilled meter consumption is 0 m^3.

Unbilled unmetered consumption

This component is utilized in water supply operations such as pipe washing, pipe testing, road cleaning, and firefighting, among others. The sole unbilled unmetered consumption in the Yeka Abado condominium was firefighting. According to statistics from the Semit branch office of the Firefighting Agency, the water used for firefighting purposes in the study area was 1000 m3/year.

Apparent or commercial loss

This encompasses all forms of metering irregularities, data handling issues (meter reading and invoicing), and unauthorized consumption (theft or illegal use). The apparent loss in the Yeka Abdo condominium was around 20,432m3/year.

Unauthorized consumption

An unlawful connection, meter bypass, or illicit use of a hydrant, for example, are all examples of unauthorized consumption. During the filled visit, an illegal connection was discovered. There were persons in the study area who built illegal buildings and did not have their own water supply system, so they had to rely on an illegal connection to acquire water. Unauthorized usage at the Yeka Abado water supply system was 805 m3/year, according to the WB-EasyCalc software results from July 2019 to June 2020.

Customer metering inaccuracies and data handling errors

These are apparent water losses caused by customer meter inaccuracies and data handling errors in the meter reading and billing system. Based on field observation and dissection with technician the water meters were good condition and good quality. However, there were a number of human errors associated with the processes of meter reading, recording and data entering.

According to the result of the software, Inaccuracy of meters and data handling in Yeka Abado condominium was 19,627 m^3 /year.

Physical losses

It is sometimes called ‘real losses’ are the annual volumes lost through pressurized system all types of leaks, bursts, and overflows in pipes, service reservoirs and service connection up to the point of the customer meter depends on frequency flow rate, and average duration of individual leak. Although physical losses after the point of customer use are excluded from the assessment of real losses, this does not necessarily mean that they are not significant or worthy of giving attention for demand management purposes. The calculated real loss of Yeka Abado condominium was 508,457 m^3/year. When changed in percentage, it was 23.65%. In the study area the main reason for this high physical losses were high pressure, poor maintenance of network and intermittent water scheduling.

Revenue water

This includes those components of Authorized consumption which are billed and produced revenue also known as Authorized consumption. This is equal to Billed metered consumption plus billed unmetered consumption. In Yeka Abado condominium the revenue water consumption was 1,620,172m^3/year.

Non- revenue water of Yeka Abado Condominium

This includes all water loss, components of system inputs which are not billed and do not produce revenue. In Yeka Abado Condominium water supply system non-revenue component is about 529,888 m^3 /year.

Non-Revenue water

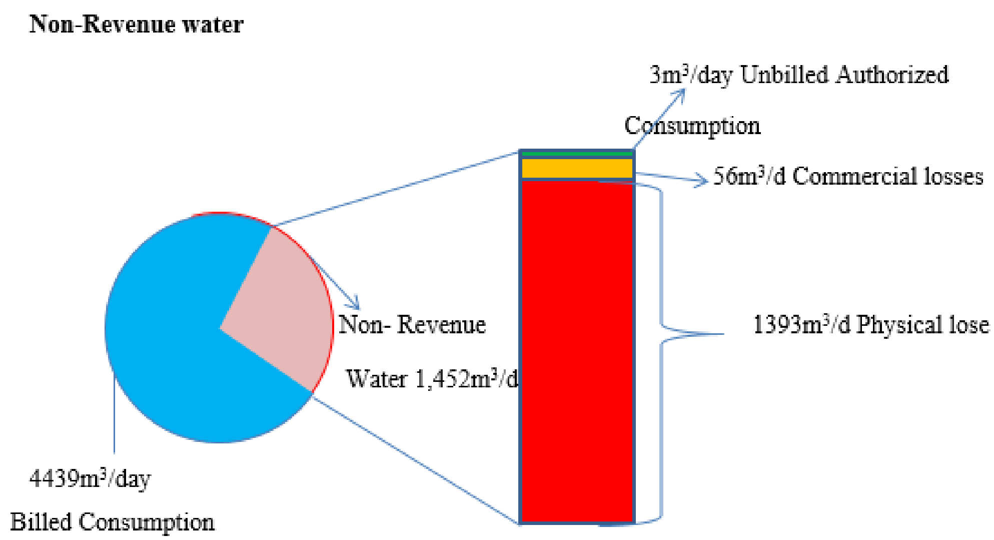

Figure 4.2 Non -Revenue water

The water balance in m^3/day and m^3/year shown in Table 4.2 and Table 4.3 respectively.

Table 4.2 Water balance in m^3/day

<table>
<tr><td rowspan="7">System input volume
5,847 m^3/d
Error Margin
[+-]=10%</td><td rowspan="4">Authorized consumption
4,429 m^3/d
Error Margin
[+]=0%</td><td rowspan="2">Billed Authorized consumption
4,439 m^3/d</td><td>Billed Meter Consumption
4,427 m^3/d</td><td rowspan="2">Revenue Water
4,427 m^3/d</td></tr>
<tr><td>Billed Unmetered
Consumption 0 m^3/d</td></tr>
<tr><td rowspan="2">Unbilled Authorized consumption
3 m^3/d
Error Margin
[+-]=10%</td><td>Unbilled Metered
consumption 0 m^3/d</td><td rowspan="5">Non-Revenue Water
1,452 m^3/ d
Error Margin
[+-]=40.6%</td></tr>
<tr><td>Unbilled Unmetered
consumption 3 m^3/d
Error Margin
[+-]=10%</td></tr>
<tr><td rowspan="3">Water Loss
1,449 m^3/d
Error Margin
[+-]=40.7%</td><td rowspan="2">Commercial loss
56 m.^{3}/d
Error Margin
[+-]=4.1%</td><td>Unauthorized consumption
2 m^3/d
Error Margin [+-]=10%</td></tr>
<tr><td>Customer meter inaccuracy and Data handling error
54 m^3/d
Error Margin [+-]=4.3%</td></tr>
<tr><td colspan="2">Physical Losses 1,393 m^3/d
Error Margin [+-]=42.3%</td></tr>
</table>

Table 4.3 Water balance in m^3/year

<table>
<tr><td rowspan="7">System input volume 2,150,060m^3/y Error Margin [+-]=10%</td><td rowspan="4">Authorized consumption 1,621,172m^3/y Error Margin[+]=0%</td><td rowspan="2">Billed Authorized consumption 1,620,172m^3/y</td><td>Billed Meter Consumption 1,620,172 m^3/y</td><td rowspan="2">Revenue Water 1,620,172m^3/y</td></tr>
<tr><td>Billed Unmetered Consumption 0 m^3/y</td></tr>
<tr><td rowspan="2">Unbilled Authorized consumption 1000 m^3/year Error Margin [+-]=10%</td><td>Unbilled Metered consumption 0 m^3/y</td><td rowspan="5">Non-Revenue Water 529,888m^3/y Error Margin [+-]=40.6%</td></tr>
<tr><td>Unbilled Unmetered consumption 1000 m^3/y Error Margin [+-]=10%</td></tr>
<tr><td rowspan="3">Water Loss 528,888m^3/y Error Margin [+-]=40.7%</td><td rowspan="2">Commercial loss 20,430m.^{3}/year Error Margin [+-]=4.1%</td><td>Unauthorized consumption 805 m^3/year Error Margin [+-]=10%</td></tr>
<tr><td>Customer meter inaccuracy and Data handiling error 19,627m^3/year Error Margin [+-]=4.3%</td></tr>
<tr><td colspan="2">Physical Losses 508,457m^3/year Error Margin [+-]=42.3%</td></tr>
</table>

The above table shows water loss analysis for the years from July 2019 to June 2020 for Yeka Abado condominium. The result from the water balance analysis, percentage of water losses is 24.6% with the composition of real losses 23.65 % and apparent losses of 0.95 %. So it is a matter of concern and action is required for water losses reduction.

The factor of commercial loss (Apparent losses) in Yeka Abado condominium caused by inaccuracies meter reading, illegal connection and data handling error. The greatest apparent losses caused data handling error.

4.3.1 Performance indicator

Performance indicators provided in the manual of best practice of IWA. Which are used to compare the performance of water losses management. The performance of Yeka Abado Condominium water supply system was evaluated based on: -

- Water losses as a % of system input volume.
- Physical losses per house connection
- Physical loss expressed as the length of the main pipe
- Infrastructure Leakage Index (ILI) for physical loss performance indicator
- Apparent loss performance indicator

1. Water losses as percentage of system input volume

Water losses as a percentage of system input, a traditional indicator, can be simply determined by dividing the amount of water lost by the total amount of water delivered to the system and multiplying by a hundred. As indicated in Figure 4.3, the percentage of water loss in Yeka Abado condominium is 23.65% physical loss, 0.95 percent commercial loss, and 75.35 percent revenue water.

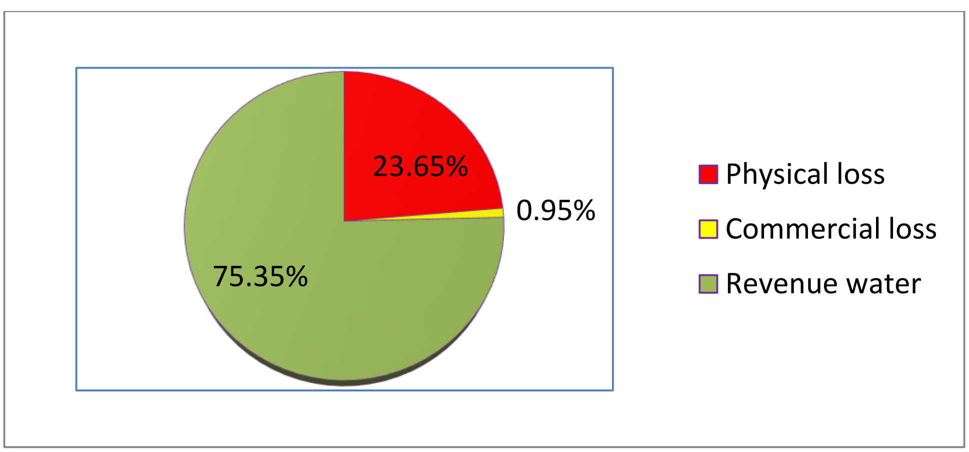

Figure 4.3 Water loss as percentage of input volume

Table 4.4 water loss in each months as percentage of input volume

Months	Water Distributed	Sold water or Consumption (m^3)	Unbilled Authorized consumption (m^3)	Total Consumption	Loss of water	
					m^3	%
July	190,200	137,620	70	137690	52510	23.15
August	190,150	124,127	65	124192	65958	34.69
September	179,160	160,094	90	160184	18976	10.59
October	170,145	135,898	90	135988	34157	20.1
November	160,171	126,991	85	127076	33095	20.6
December	190,200	112,156	90	112246	77954	40.98
January	175,145	131,844	80	131924	43221	24.7
February	170,245	143,082	92	143174	27071	15.9
March	175,213	127,138	88	127226	47987	27.39
April	190,155	139,665	80	139745	50410	26.5
May	180,105	146,938	100	147038	33067	18.36
June	179171	134,619	70	134689	55511	29.19

As shown in the above table, Percentage of system input value is certainly the most common indicator but it is influenced by water demand. When consumption decreases, seasonally or annually, or due to demand management measures, the percentage of real losses increases even if the volume of real losses remains unchanged. When consumption increases, the opposite effect occurs. In addition to this, performance indicator does not show what measure should be taken.

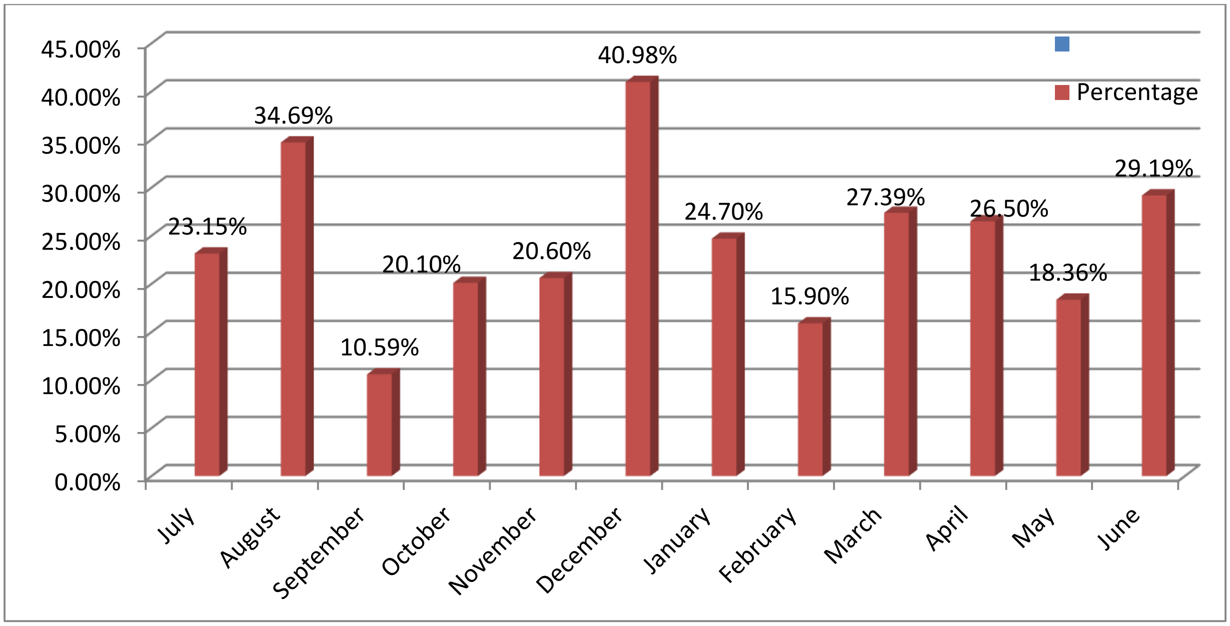

Figure 4.4 Individual months water loss as percentage input volume

According to McKenzie et al., 2012 study, the value of non-revenue water in Yeka Abado condominium was low and performed well, but because the system was new, it was expected to perform well. However, due of the high pressure, non-revenue water had a high value.

Table 4.5 Financial performance indictor

	Best Estimate	Error Margin [+/-%]	Lower Boundary	Upper Boundary
Volume of Non-revenue water expressed in% of system input volume	25%	41%	15%	35%
Value of Non-Revenue water expressed in% Annual operating cost	41%	41%	24%	57%
Liters per connection per day	481	41%	283	679

2. Physical losses per service connection

Considering that water losses as percentage of system input volume only shows water resources efficiency for the top management, and does not provide any information on management of distribution system, WA recommended operational PI per service connection (m^3/c/year).

The total number of service connection of Yeka Abado condominium was 3,014 which were obtained from Addis Ababa water and sewerage authority Gurd Shola branch office. The water loss per number of service connection was determined as 508,457m3/year x 1000L ÷ (3014 X 365 days) = 462.19 liters/connection/day.

According to Farley et al. (2008), the performance indicator of physical loss target matrix describes as a good condition system if water loss per service connection <150 liters/connection/day, average condition if between 150-450liters/connection/day and bad condition if >450liters/connection/day. In line of this, the condominium physical losses per service connection was 462.19 liters/connection/day, which shown as bad condition.

$$\text{Water loss as per number of connection} = \frac{\text{Physical water loss} * 1000\text{L}}{\text{number of connection} * 365\text{days}}$$

$$= \frac{508{,}457\text{m3/year} \times 1000\text{L}}{3014 * 365}$$

= 462.19 liters/connection/day

3. Physical loss expressed as the length of the main pipe

One of the best indicators of water loss in the distribution network system was determining physical loss as per length of the main pipe. According to AAWWSA Gurd shola branch office information, the total length of water distribution line was estimated around 13.2 km. The physical loss per kilometer length of main pipe was determined as 508,457 m3/year $\times 1000L$ ÷ (13.2 km×365days) =105,532.79 liters/km/day.

According to Farley et al. (2008), the performance indicator of physical loss target matrix describes as a good condition system if water loss per length of main pipe<10,000 liters/km/day, average condition if between 10,000-18,000liters/km/day and bad condition if >18,000L/km/day. In line of this, the condominium water loss per length of main pipe was 105,532.79 L/km/day, which shown as bad condition.

4. The infrastructure leakage index (ILI)

According to Peiris et al. (2008), the ILI is a real loss performance indicator which would allow international comparisons between systems with very different characteristics, e.g. intermittent supply situations, low and high pressure system, differences in consumption levels, etc. Based on the analysis of WB-EasyCalc software the ILI value for Yeka Abado condominium was 20. Additionally, the infrastructure leakage index was determined using equation as flows.

UARL (Liters/day) = (18x13.2Km +0.8x3014+25x12/1000)26m

=68876.6 L/d

CARL from water WB-EasyCalc software result was 1393m3/day=1393000L/d

Thus: ILI=1393000/68876.6

=20.2

This ILI value shows that the current annual real losses are assessed as being around 20 times as high as the unavoidable annual real loss for the system.

Based on Farley et al. (2008), the ILI value was greater than 16 so it is classified under category D. It indicated that the system is bad condition and the utility is using resources inefficiently and NRW reduction programs are imperative.

Table 4.6 Physical loss performance indicator WB-EasyCalc

	Best Estimate	Error Margin [+/-%]	Lower Boundary	Upper Boundary
Infrastructure Leakage index(ILI)	20	43%	11	29
Liters per Connection per day	462	43%	264	659
Liters per connection per day per meter pressure	18	43%	10	25
m^3/km mains per hour	4.18	44%	2.36	6

The above table shows the performance of indicators of physical loss such as liters per connection per day, liters per connection per day per meter pressure, and m^3/km mains per hour.

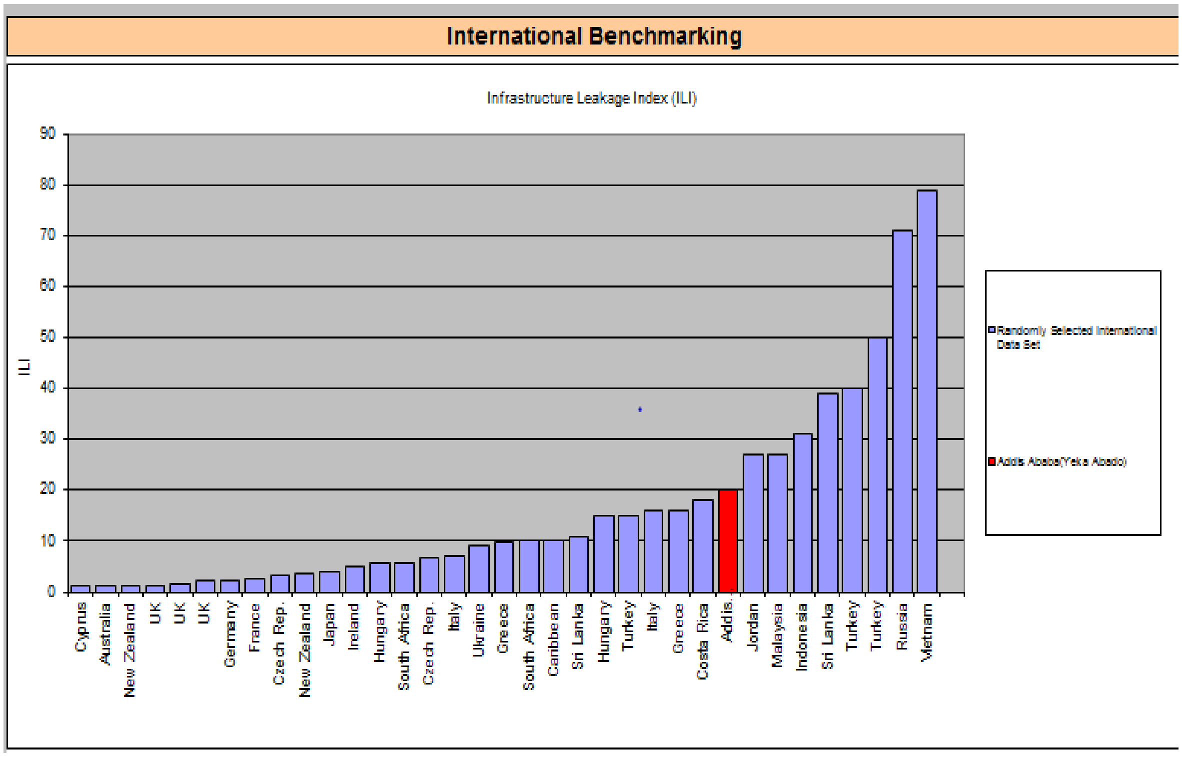

Figure 4.5 International Benchmarking

From Figure 4.5 it can be seen that the ILI values for Yeka Abado Condominium was high compared other counters like South African, Japan and others.

5. Commercial loss performance indicators

Currently, the best indicator is to measure commercial loss as percentage of authorized consumption. Based on the WB-EasyCalc software the result of commercial loss performance indicators was 1% of authorized consumption. which is acceptable and the management of the meters and customers is under control. The software also determines the commercial loss performance indicator in terms of service connection which is 18 l/c/d.

Table 4.7 Commercial loss performance indicator

	Best Estimate	Error Margin [+/-%]	Lower Boundary	Upper Boundary
Commercial water loss expressed in% of Authorized consumption	1%	4%	1%	1%
Liters/connection/day	18	6%	17	20

However, when the management of the meters and customers is under control, the ALI may be lower than one.

4.3.2 Cause of water loss in Yeka Abado condominium

The result from WB-EasyCalc software revealed that 23.65% of the water loss was real loss and 0.95% of water loss was a commercial loss. This indicates that most of the water loss causes in the Yeka Abado condominium because of real loss. This real loss was caused because of Intermittent water scheduling, poor pipe fitting connection, poor water loss management and high pressure. The least amount of water is caused by commercial (apparent) loss. Only data handling error and illegal connection was observed during in the study period.

1. High pressure

Using WaterGEMS software and field measurement using pressure gage, it was observed that there was the high-water pressure in the Yeka Abado Condominium water distribution system. High-pressure systems tend to cause more frequent pipe breaks and an increase in energy use and leakage.

The amount of pressure was high, even it exceeds up to 107m H_2O. The minimum and maximum operating pressure in the water supply distribution system network in Ethiopia was 15m and 60m respectively (MOWR, 2006a). It means the pressure in the condominium was not fulfilling the standard.

3. **Poor pipe fitting connection**

The loss of water is usually very high when unsuitable joints are used or incorrect piping is performed. At the time of the field visit, there was a poor pipe fitting connection observed. This situation creates a high amount of water loss. The water that was lost due to poor pipe fitting seems to be very little, but the truth was not. When it is not maintained immediately, it causes a lot of water loss.

Figure 4.6 poor pipe fitting connection

4. **Ineffective water loss management**

It was known that the water supply system of the Yeka Aabado condominium was a new system, but unmanaged water loss was observed. During the field visit, the fire hydrant was not protected. As shown in the following figure, the fire hydrant is not protected. As a result, these circumstances create favorable circumstances for the thief.

Figure 4.7 Fire hydrant without protection and unmanaged water loss

The above pictures show that the treated water flows on the rod because of poor water loss management. However, the authorities do not take any action or attention to solve this problem.

4. Intermittent water scheduling

Consumers in the study area have access to water four days a week. Due to the cyclic pressure condition generated by having the supply turned on and off, greater levels of leakage are observed as a result of stress being put on the pipes, causing them to break. The irony in this circumstance is that the water scheduling problem is caused by water shortages, which are largely due to leaking. A constant supply is not possible due to high levels of water loss, resulting in water schedules. The idea is to get rid of water scheduling.

5. Ineffective data management

In study area, the data for customer consumption was well recorded in proper manner. However, report of pipe leakage was not recorded properly. In addition to this, the authority has no information how much water used for firefighting purpose. Therefore, wrong water audit calculation was carried out.

6. Illegal connection

In Yeka Abado condominium water supply distribution system there are few illegal water utility users. These unauthorized consumers received water from the distribution system by informal connection, and they do not give payment tariff to the town water service office. This situation has been made worse by illegal house construction nearby, where people live near the condominium and farmers lived anciently before the construction of the condominium. The illegal connection was usually laid just near to the surface and the pipe material which was used for this purpose was easily gained and less expensive. As a result of this, the pipe was highly exposed to damage and water loss.

4.4. Hydraulic Model Calibration and Validation

4.4.1. Calibration

The credibility of a model is merely evident if a model results precisely reflects observed field values. Thus, to have a confidence on model result it needs to calibrate a model.

Calibration was accomplished by entering the measured pressure value into the Darwin calibrator. The pipes are then divided into two groups: high-density polyethylene and ductile pipe, with the roughness coefficients adjusted to obtain the best pipe friction coefficient in the system. In addition, the demand multipliers adjust dependent on the time of the filed pressure measurement to reduce model parameter uncertainty.

The Darwin calibrator find the optimal solution by adjusting C-factors While this attempt reduced the difference between observed and simulated value and the C-factor of DCI and HDPE pipes were lowered from 140 to 98, 126. As shown in figure 18 (New Optimized Run-8), All the values of observed and simulated hydraulic grade differences were between ±1.5m and ±5m depending on AWWA guideline.

Simulated Results

	Field Data Snapshot	Junction	Observed Hydraulic Grade (m)	Simulated Hydraulic Grade (m)	Difference (m)
1	Pressure Test - 1	J-12	2,641.27	2,638.74	-2.53
2	Pressure Test - 2	J-32	2,637.05	2,638.42	1.37
3	Pressure Test - 3	J-40	2,640.53	2,641.34	0.81
4	Pressure Test - 4	J-77	2,627.47	2,628.55	1.08
5	Pressure Test - 5	J-83	2,594.16	2,594.62	0.45
6	Pressure Test - 6	J-78	2,615.10	2,615.22	0.12
7	Pressure Test - 7	J-131	2,636.65	2,636.17	-0.48

Figure 4.8 Sniping shot of simulated results

According to (Bently WaterGEMS V8I User guideline), if the model was will calibrated, the points was appearing along the main diagonal on the diagnostic reability diagrams or calibration curves. The closer the more reliable the model. In addition to the calibration curve, a lower fitness indicates better calibration.

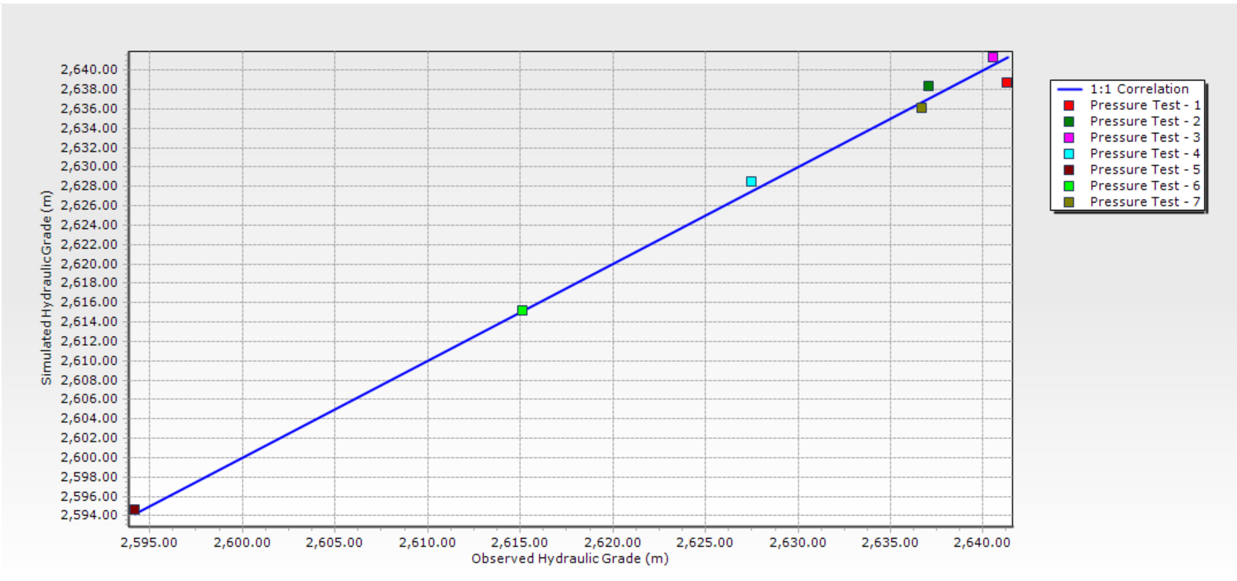

Figure 4.9 Correlation of observed and simulated HGL new optimized run-8

Aa shown in the above calibration curve, diagonal the simulated HGL have great agreement with the field data, the points were appearing along the main. This show that a model was well calibrated. Also the fitness value was 1. 029.It mean the model was will calibrated.

	Solution	Fitness
1	Solution 1	1.029

Figure 4.10 Fitness value

4.4.2. Validation

According AWWA (2012), Validation is a term often used to refer to the process of checking the results of a hydraulic model following an update process. Validation may also be used to refer to comparing the model to a different set of field data than that for which the model was calibrated.

Validation was done after calibration and uses an independent observed data set to verify that the model is represent the real water distribution system. Seven different samples have been taken to verify the model is well calibrated. The validation result shown in the following table.

Table 4.8 Pressure difference error

Sample No	Time (am)	Sample of Junction	Field measured pressure (mH2O)	Simulated Model Pressure (mH2O)	Pressure Difference Error (m)
1	7	J-119	57	55	2
2	8	J-5	17	14	3
3	9	J-87	65	67	-2
4	10	J-78	93.5	98	-4.5
5	11	J-37	55	57	2
6	12	J-44	50	47	3
7	13	J-122	85	89	-4

As shown in Table 4.8, All the difference error was between ±1.5m to a maximum of ± 5.0m which is satisfies the setting pressure calibration and validation criteria. this verify that, the model was representing the real system.

4.5. Summary of the Simulation Result

To examine pressure in the research region and take relevant measurements, a hydraulic analysis of the current WDS was performed. The pressure was measured using the WaterGEMS V8i program. To understand the condition of the distribution system, the software runs both long period and steady-state simulations.

Steady-state Analysis

The model has been performed in steady state run for the average daily demand, which is the demand at every node not changing throughout 24 hours of a day. The software simulates Steady- State hydraulic calculation based on mass and energy conservation equations principle. The system was initially checked for base flow conditions. Then extended period simulation was executed to evaluate variations in the system.

Extended Period Simulation

The system conditions have been computed over twenty-four hours with a specified time increment of one hour and starting model run time at 00:00 PM. The software simulates non-Steady-State hydraulic calculation based on mass and energy conservation principle.

The model can be simulated for every one-hour time setup in the twenty- four-hour duration. However, for the analysis the peak and minimum hours' demand has been simulated to identify the current problems of the system.

4.5.1. Pressure analysis

Pressure in water distribution system has to be maintained optimum; as to efficiently make water available to each demand category including at instances of firefighting (high withdrawal period) and as to reduce leakage as well as pipe breakage across the system.

The pipe system network was built and pressure analysis was performed in all junctions based on the supplied data. According to MoWR (2006), the recommended pressure for a safe hydraulic system was not less than 15m and not more than 60 m head at the distribution system. According to this guideline, certain junctions in the research region met or exceeded the recommended criteria, while others did not. Table 4.9 summarizes the pressure at pick hour demand, with Fig.4.11 showing the details.

Table 4.9 Pressure at pick hour demand

Pressure (mH2O)	**Junction (number)**	**Percentage (%)**
<15	13	9.92
16-45	71	54.20
46-60	28	21.37
61-75	10	7.63
76-90	7	5.34
91-105	2	1.53
Total	131	100.00

As depicted in Table 4.9, shows that 9.92 % of junction ware failed to satisfy desirable minimum criteria. On the other hand, 14.5 % of nodes exceed maximum allowable pressure of 60m. While 75.57 % of nodes are in the permissible pressure ranges of minimum 15m and maximum 60m.

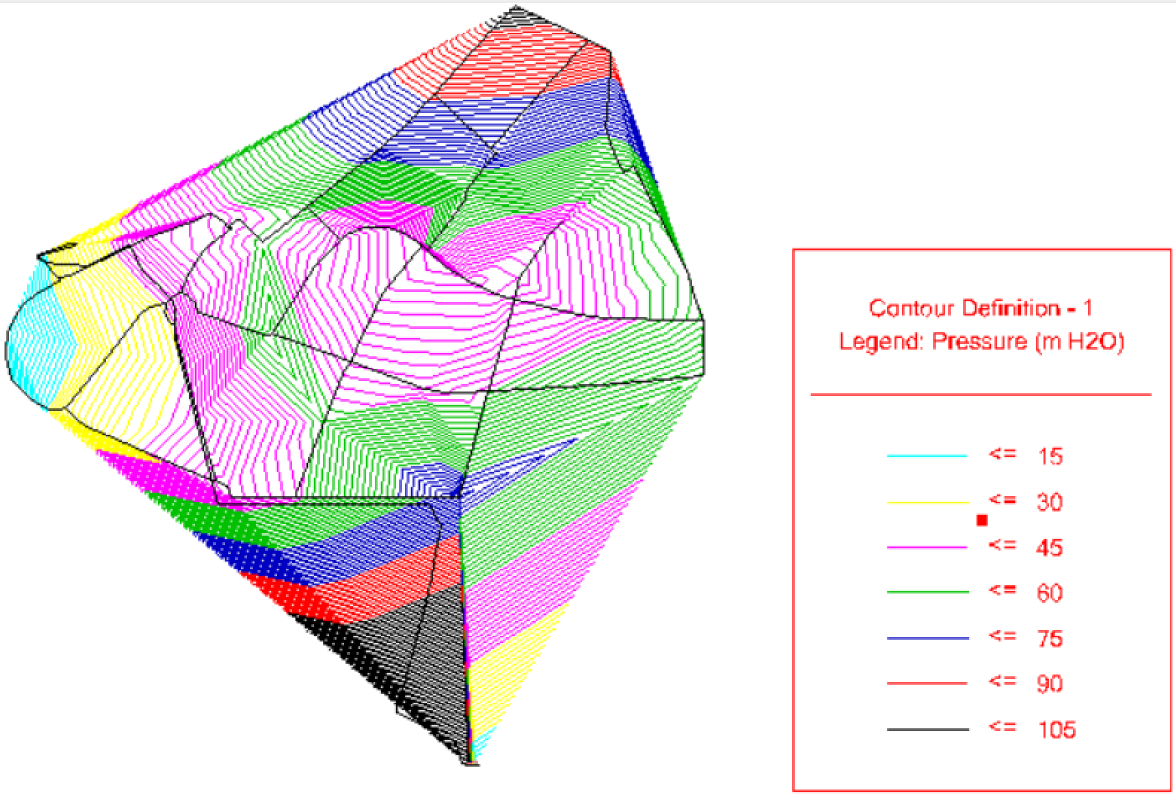

Figure 4.11 Pressure distribution contour map during peak hour demand

As shown in the figure 4.11 there are extreme high pressure throughout the system mainly due to the topography of the area and the elevation of the distribution reservoir. For example, some of the areas marked by black color and located at downstream part of the system receive high pressure.

Areas that found near to the tank and marked by light blue color receive low pressure because of small elevation difference between tank and junctions. However, Junctions that are found in middle of the network and marked by purple color receive optimum pressure. Generally, majority of areas located in relative perfect loop receive optimum pressure which does not violet minimum or maximum allowable pressure range.

On the other hand, at night time the consumer consumption was low as a result the pressure was high in most part of the network. This situation causes to stress the pipe and create leakages. The actual node pressure simulation during low hour demand distribution presented in Table 4.10 and Figure 4.12 in detail.

Table 4.10 Distribution of actual node pressure at minimum consumption hour

Pressure (mH2O)	**Junction (number)**	**Percentage (%)**
<15	12	9.16
16-45	23	17.56
46-60	38	29.00
61-75	24	18.32
76-90	19	14.50
91-105	10	7.63
106-120	5	3.82
Total	100	100.00

Extremely high pressure observed during low flow typically at mid-night when most of the customers are sleep and not using water. As shown in table 4.10 and detailed in appendix C, 44.27 % of junctions are liable to extremely high pressure and 9.16 % of junction observed minimum pressure in low hour demand. Only 46.56 % of nodes are received the water of optimum pressure at low consumption hour.

This implies that, Junction pressure at the minimum consumption hour, is very important rather than others peak and average water demand because, leakage and water quality is deter rioted very high in the system during this low consumption hour. Figure 4.12 as shown below the pressure distribution during low hour demand.

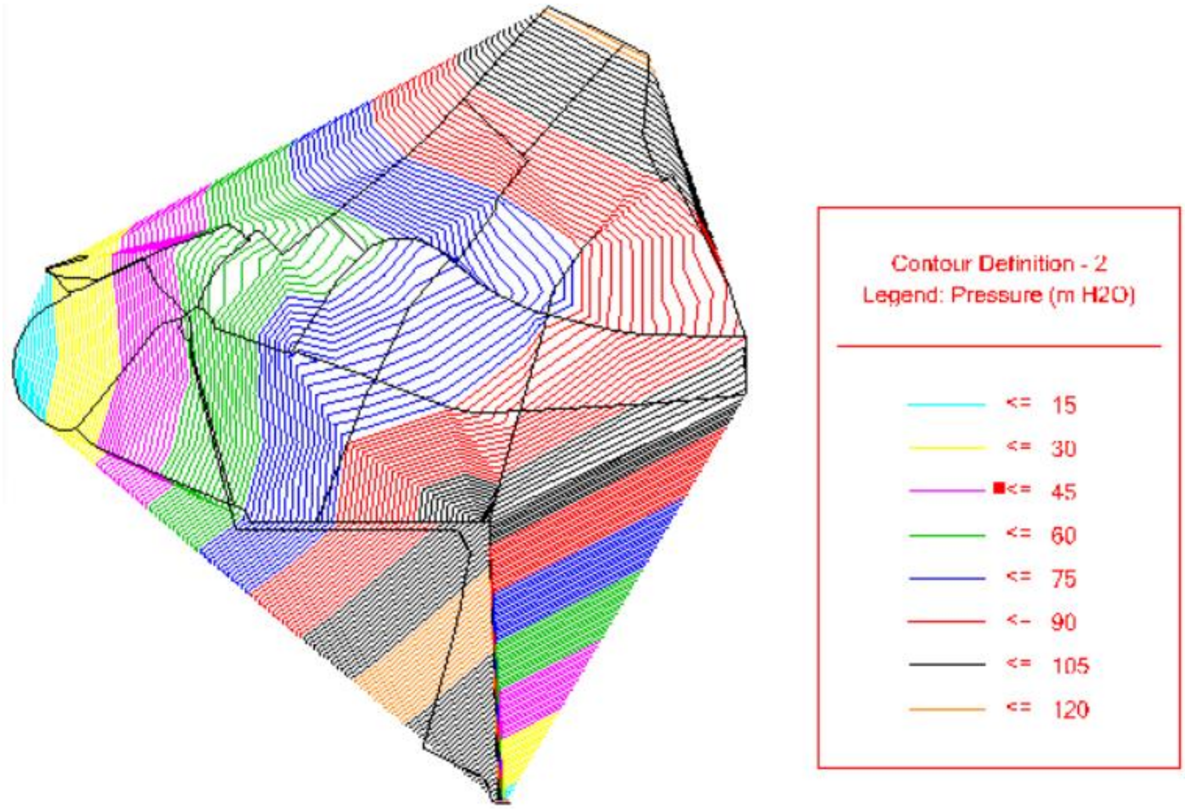

Figure 4.12 Pressure contour map of the distribution system at low hour demand

In general, lower pressure affects the capacity of water supply to the town that increases the redaction of quantities of water supplied to the consumer and entry of a contaminant or self-deterioration of water quality within the network itself severe damage to public health. On the other hand, at the night time (low hour demand) maximum pressure, maximum water residence time and minimum velocity and leakage rate expected to be high because at this time a minimum amount of water flow occurred at the customer taps.

4.6. Proposed Solution to Reduce Water Loss in the Study Area

According to the Ethiopian standard (MoWR,2006), the pressure at any given hour must be 15m to 60m of water. Unfortunately, pressure modelling indicated that the pressure in the water distribution system of Yeka Abado condominium was too high. Excess pressure was the main cause of pipe leakage. Based on the analysis results, there was high real loss in the study area. Generally, there are different reasons for high real losses. However, based on the results of the model and site observation, it was concluded that the main reason for this high water loss in the study area was high pressure. Therefore, it was decided to add pressure-reduced valves (PRV) at high pressure junctions to reduce pressure in the study area.

Reducing pressure will reduce the leakage flow rate as well as the possibility of pipe burst. High pressure are associated with higher frequency of new leaks. Research done in in Antalya city show that, pressure reduction up to about 3 bars using a pressure reducing valve (PRV) proved to be cost-effective to reduce water losses without receiving any complaints from the water subscribers.

WaterGEMS V8i was used to predict the changes of pressure before and after adding the PRV.The results obtained with PRV’s are shown in Table 4.11. It indicates that the reduction in pressure is achieved by adjusting the initial settings, keeping the status active, and adjusting the pressure setting of the PRV.

Table 4.11 Table pressure difference before and after addition of PVR

Junction	Pressure before Adding of PRV	Pressure After Adding of PRV
J-31	71	55
J-37	72	59
J-77	106	60
J-78	106	60
J-79	107	50
J-80	106	50
J-81	107	51
J-82	101	46
J-83	95	40

As shown in the above table, the junctions failed to satisfy the allowable maximum pressure before adding the pressure-reducing valve. However, after adding the pressure reducer valve, it fulfils the design criteria.

5. CONCLUSIONS AND RECOMMENDATION

5.1. Conclusion

The study was conducted to analyze hydraulic performance and water loss status using water balance software in the water supply distribution system of Yeka Abado condominium in Addis Ababa. The water loss status is evaluated using water balance software (WB-EasyCalcV 4.05). The result from the water balance analysis shows that the percentage of water losses is 24.6%, with the composition of real losses of 23.65% and apparent losses of 0.95 percent. In addition to this, water balance software is also used to determine the detailed water loss performance indicators. The water loss performance indicator is based on: water losses as a percentage of system input volume, physical losses per house connection, physical loss as the length of the main pipe, Infrastructure Leakage Index (ILI), and the apparent loss performance indicator.

Among these different types of performance indicator, the infrastructural leakage index is now widely accepted and used by practitioners around the world, as it best describes the efficiency of the real loss management of water utilities. The infrastructural leakage index value for Yeka Abado condominium was 20. It indicates that the system is in poor condition and the utility is using resources inefficiently, and non-revenue water reduction programs are imperative. Based on water loss as a percentage of system input volume performance indicator, the value of non-revenue water was low and good performance, but as we know the system is new, it is expected to have very good performance.

In the study area, both real and apparent losses were observed during the study period. Even so, most of the water loss in the Yeka Abado condominium was real loss. This real loss was caused because of poor pipe fitting connections, intermittent water scheduling, infective water loss management system and high pressure. However, the main reason for this real loss in the study area was the presences of high pressure in the network.

The amount of pressure in the network is determined by using WaterGEMS V8i. After calibration and validation, the software is used for decision purposes. Depending on the result of the model, some of the areas have excess pressure. This pressure is reduced by using a pressure-reducing valve. The prediction of pressure after adding the pressure-reducing value is also done by using WaterGEMS V8i. Pressure control by valve was a suitable method for optimal management and caused a significant reduction in network leakage.

Generally, it is important to establish a water management system, which would be able to develop the best management practices to further minimize the problems of water losses and NRW amounts.

In addition to the evaluation of water loss status and pressure, coverage is also determined based on average daily capital consumption and the level of connection per family. As a result, the average daily per capita capital consumption was 65.3 l/capital/day and the level of connection per family was 17.3%. The better per capita consumption and level of connection were indicators of better water supply coverage. However, some areas still have better levels of connection but less water supply coverage due to the topography of the area. The gravitational water supply system has an impact on water supply coverage.

5.2. Recommendation

Based on the findings and observations, the following recommendations are made:

- In high pressure areas, a pressure reduced valve is recommended to improve the water supply distribution system and regulate pressure variation.

- To make the assessment of water loss complete and in a reliable way, it is recommended that divide the existing network into sub-systems and district meter areas (DMA) for easy monitoring and managing the system and to use other water loss assessment approaches.

- Finally, it recommends carrying out water audits throughout the year. It helps with effective management of water supply network management, finding out the problem and taking action, and reducing water loss.

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APPENDIX

Appendix A Demand in each junction

Label	Demand	X (m)	Y (m)	Elevation (m)
J-1	0.01	484,737.90	1,002,200.66	2,619.12
J-2	0.01	484,627.27	1,002,170.22	2,628.71
J-3	0.02	484,686.31	1,002,100.09	2,623.98
J-4	0.02	484,693.40	1,002,091.66	2,623.41
J-5	0.02	484,626.35	1,002,056.39	2,629.30
J-6	0.02	484,601.15	1,002,037.72	2,631.54
J-7	0.03	484,582.07	1,002,020.61	2,633.24
J-8	0.03	484,560.84	1,001,995.49	2,635.17
J-9	0.03	484,529.28	1,001,930.86	2,638.16
J-10	0.03	484,522.88	1,001,873.85	2,638.96
J-11	0.04	484,524.74	1,001,846.74	2,638.92
J-12	0.04	484,534.64	1,001,803.20	2,638.28
J-13	0.05	484,545.73	1,001,774.91	2,636.33
J-14	0.05	484,568.65	1,001,752.46	2,633.53
J-15	0.06	484,602.97	1,001,719.37	2,629.35
J-16	0.06	484,636.32	1,001,699.38	2,625.71
J-17	0.07	484,657.53	1,001,689.23	2,623.49
J-18	0.07	484,681.30	1,001,685.96	2,621.27
J-19	0.07	484,703.73	1,001,691.38	2,619.47
J-20	0.07	484,711.95	1,001,693.95	2,618.83
J-21	0.07	484,719.75	1,001,686.15	2,617.87
J-22	0.08	484,756.30	1,001,649.50	2,613.37
J-23	0.08	484,772.70	1,001,635.77	2,611.45
J-24	0.08	484,841.77	1,001,607.48	2,604.36
J-25	0.09	484,973.10	1,001,548.73	2,594.28

J-26	0.09	485,164.42	1,001,468.24	2,582.14
J-27	0.10	485,174.53	1,001,467.25	2,581.57
J-28	0.10	485,180.39	1,001,466.82	2,581.24
J-29	0.10	485,216.18	1,001,449.18	2,578.91
J-30	0.11	485,227.52	1,001,416.80	2,577.61
J-31	0.12	485,428.13	1,001,413.48	2,566.60
J-32	0.12	485,942.28	1,001,412.62	2,540.25
J-33	0.12	486,020.77	1,001,701.71	2,556.60
J-34	0.12	486,034.94	1,001,745.42	2,556.55
J-35	0.13	486,104.60	1,001,985.48	2,561.01
J-36	0.13	486,115.66	1,002,033.35	2,563.37
J-37	0.13	486,131.67	1,002,101.03	2,564.37
J-38	0.13	486,229.07	1,002,239.85	2,560.60
J-39	0.14	486,269.77	1,002,277.90	2,558.73
J-40	0.14	484,725.82	1,002,108.68	2,620.57
J-41	0.14	484,975.96	1,002,230.01	2,598.89
J-42	0.15	485,132.42	1,002,287.08	2,594.41
J-43	0.15	485,160.30	1,002,302.81	2,593.81
J-44	0.15	485,179.08	1,002,295.99	2,593.24
J-45	0.16	485,199.02	1,002,281.18	2,592.58
J-46	0.16	485,217.21	1,002,260.73	2,591.52
J-47	0.17	485,221.25	1,002,258.11	2,591.30
J-48	0.17	485,229.37	1,002,256.97	2,591.10
J-49	0.17	485,197.88	1,002,230.74	2,590.76
J-50	0.18	485,175.12	1,002,214.65	2,591.16
J-51	0.18	485,138.21	1,002,180.30	2,590.11
J-52	0.19	485,093.18	1,002,109.67	2,591.05
J-53	0.19	485,072.46	1,002,056.66	2,592.71
J-54	0.20	485,058.47	1,002,050.49	2,593.73
J-55	0.20	485,039.38	1,002,035.16	2,595.13

J-56	0.21	485,026.32	1,002,020.76	2,596.11
J-57	0.21	485,002.30	1,002,015.34	2,597.83
J-58	0.21	484,975.16	1,002,008.81	2,599.77
J-59	0.22	484,955.09	1,001,996.25	2,601.50
J-60	0.23	484,855.96	1,001,871.99	2,610.52
J-61	0.24	485,019.65	1,001,991.64	2,596.69
J-62	0.25	485,029.82	1,001,968.30	2,596.06
J-63	0.26	485,050.85	1,001,952.08	2,594.63
J-64	0.27	485,079.83	1,001,834.58	2,593.02
J-65	0.28	485,127.24	1,001,657.64	2,588.18
J-66	0.28	485,239.57	1,002,276.47	2,591.38
J-67	0.28	485,254.63	1,002,286.92	2,590.97
J-68	0.29	485,276.33	1,002,264.00	2,590.20
J-69	0.29	485,301.57	1,002,237.27	2,588.77
J-70	0.30	485,325.80	1,002,211.77	2,586.95
J-71	0.30	485,412.86	1,002,281.48	2,586.10
J-72	0.31	485,467.88	1,002,324.23	2,583.70
J-73	0.31	485,702.74	1,002,511.60	2,565.78
J-74	0.31	485,777.63	1,002,581.60	2,560.56
J-75	0.32	485,867.11	1,002,677.82	2,553.81
J-76	0.33	485,990.07	1,002,818.05	2,544.18
J-77	0.33	486,118.10	1,002,952.26	2,534.66
J-78	0.34	486,246.49	1,002,893.13	2,533.27
J-79	0.36	486,346.93	1,002,844.02	2,532.30
J-80	0.36	486,386.43	1,002,822.84	2,532.00
J-81	0.36	486,418.63	1,002,809.13	2,531.60
J-82	0.36	486,414.06	1,002,706.12	2,536.08
J-83	0.36	486,401.23	1,002,568.39	2,542.27
J-84	0.38	486,431.65	1,002,484.71	2,544.87
J-85	0.43	486,459.48	1,002,427.68	2,547.20

J-86	0.46	486,474.70	1,002,440.48	2,545.73
J-87	0.47	486,488.19	1,002,450.83	2,544.59
J-88	0.48	486,580.10	1,002,273.69	2,548.86
J-89	0.49	486,656.12	1,002,126.28	2,548.62
J-90	0.49	486,684.34	1,002,030.63	2,547.76
J-91	0.50	486,708.11	1,001,965.04	2,546.69
J-92	0.50	486,710.36	1,001,959.04	2,546.49
J-93	0.51	486,707.80	1,001,873.07	2,544.36
J-94	0.53	486,709.25	1,001,792.98	2,539.95
J-95	0.53	485,090.35	1,002,048.72	2,591.48
J-96	0.54	485,111.49	1,002,027.16	2,590.07
J-97	0.55	485,118.72	1,002,010.87	2,589.62
J-98	0.55	485,124.96	1,001,992.10	2,589.24
J-99	0.57	485,254.97	1,001,948.12	2,580.22
J-100	0.60	485,341.42	1,001,918.55	2,574.22
J-101	0.60	485,355.67	1,001,925.82	2,573.18
J-102	0.61	485,459.20	1,002,085.35	2,580.11
J-103	0.61	485,514.79	1,002,159.79	2,580.81
J-104	0.61	485,572.27	1,002,220.27	2,581.34
J-105	0.62	485,587.93	1,002,236.92	2,580.92
J-106	0.63	485,636.29	1,002,256.26	2,579.32
J-107	0.64	485,695.78	1,002,260.74	2,577.35
J-108	0.65	485,741.37	1,002,252.29	2,576.02
J-109	0.70	485,798.51	1,002,221.37	2,574.63
J-110	0.75	485,826.92	1,002,203.11	2,573.73
J-111	0.76	485,858.09	1,002,174.43	2,572.72
J-112	0.76	485,886.98	1,002,147.39	2,571.78
J-113	0.76	485,971.71	1,002,091.40	2,568.42
J-114	0.82	486,066.17	1,002,047.58	2,564.97
J-115	0.86	486,309.68	1,001,986.45	2,557.32

J-116	0.86	486,403.16	1,001,973.85	2,554.65
J-117	0.86	486,543.97	1,001,970.56	2,550.99
J-118	0.92	485,490.08	1,001,879.61	2,570.56
J-119	0.93	485,602.33	1,001,839.59	2,567.91
J-120	0.94	485,824.24	1,001,755.50	2,562.36
J-121	0.94	486,411.20	1,001,766.30	2,545.47
J-122	0.94	486,202.68	1,002,686.91	2,543.28
J-123	1.01	486,043.68	1,002,506.32	2,555.69
J-124	1.07	486,060.55	1,002,491.45	2,555.81
J-125	1.13	486,028.93	1,002,456.20	2,558.25
J-126	1.14	485,963.58	1,002,372.96	2,566.46
J-127	1.42	485,844.23	1,002,187.11	2,573.17
J-128	1.44	485,705.51	1,002,055.53	2,572.31
J-129	1.60	485,519.27	1,001,648.48	2,562.65
J-130	1.67	485,952.75	1,002,591.96	2,554.83
J-131	1.84	485,524.01	1,002,266.98	2,582.76

Appendix-B

Pipe report

Label	Length (Scaled) (m)	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C
P-2	12	T-3	J-1	400	DCI	98
P-3	92	J-2	J-3	450	DCI	98
P-4	76	J-4	J-5	300	DCI	98
P-5	31	J-5	J-6	300	DCI	98
P-6	26	J-6	J-7	300	DCI	98
P-7	72	J-8	J-9	300	DCI	98
P-8	57	J-9	J-10	300	DCI	98
P-9	27	J-10	J-11	300	DCI	98
P-10	45	J-11	J-12	300	DCI	98
P-11	30	J-12	J-13	300	DCI	98
P-12	32	J-13	J-14	300	DCI	98
P-13	39	J-15	J-16	300	DCI	98
P-14	24	J-16	J-17	300	DCI	98

P-15	24	J-17	J-18	300	DCI	98
P-16	23	J-18	J-19	300	DCI	98
P-17	9	J-19	J-20	300	DCI	98
P-18	11	J-20	J-21	110	HDPE	126
P-19	52	J-21	J-22	110	HDPE	126
P-20	21	J-22	J-23	110	HDPE	126
P-21	75	J-23	J-24	110	HDPE	126
P-22	144	J-24	J-25	110	HDPE	126
P-23	208	J-25	J-26	110	HDPE	126
P-24	10	J-26	J-27	110	HDPE	126
P-25	40	J-28	J-29	110	HDPE	126
P-26	34	J-29	J-30	110	HDPE	126
P-27	201	J-30	J-31	110	HDPE	126
P-28	250	J-34	J-35	110	HDPE	126
P-29	70	J-36	J-37	110	HDPE	126
P-30	170	J-37	J-38	110	HDPE	126
P-31	56	J-38	J-39	110	HDPE	126
P-32	278	J-40	J-41	350	DCI	98
P-33	167	J-41	J-42	350	DCI	98
P-34	32	J-42	J-43	350	DCI	98
P-35	20	J-43	J-44	350	DCI	98
P-36	25	J-44	J-45	350	DCI	98
P-37	27	J-45	J-46	350	DCI	98
P-38	5	J-46	J-47	350	DCI	98
P-39	28	J-49	J-50	200	DCI	98
P-40	50	J-50	J-51	200	DCI	98
P-41	2,966	PMP-1	T-3	400	DCI	98
P-42	84	J-51	J-52	200	DCI	98
P-43	57	J-52	J-53	200	DCI	98
P-44	15	J-53	J-54	110	HDPE	126
P-45	24	J-54	J-55	110	HDPE	126
P-46	20	J-55	J-56	110	HDPE	126
P-47	25	J-56	J-57	110	HDPE	126
P-48	28	J-57	J-58	110	HDPE	126
P-49	24	J-58	J-59	110	HDPE	126
P-50	159	J-59	J-60	110	HDPE	126
P-51	30	J-56	J-61	110	HDPE	126
P-52	25	J-61	J-62	110	HDPE	126
P-53	27	J-62	J-63	110	HDPE	126
P-54	121	J-63	J-64	110	HDPE	126
P-55	183	J-64	J-65	110	HDPE	126
P-56	18	J-66	J-67	300	DCI	98

P-57	32	J-67	J-68	300	DCI	98
P-58	37	J-68	J-69	300	DCI	98
P-59	35	J-69	J-70	300	DCI	98
P-60	112	J-70	J-71	300	DCI	98
P-61	70	J-71	J-72	300	DCI	98
P-62	300	J-72	J-73	300	DCI	98
P-63	103	J-73	J-74	300	DCI	98
P-64	131	J-74	J-75	300	DCI	98
P-65	187	J-75	J-76	300	DCI	98
P-66	185	J-76	J-77	300	DCI	98
P-67	112	J-78	J-79	110	HDPE	126
P-68	35	J-80	J-81	110	HDPE	126
P-69	103	J-81	J-82	110	HDPE	126
P-70	138	J-82	J-83	110	HDPE	126
P-71	89	J-83	J-84	110	HDPE	126
P-72	63	J-84	J-85	110	HDPE	126
P-73	20	J-85	J-86	110	HDPE	126
P-74	17	J-86	J-87	110	HDPE	126
P-75	200	J-87	J-88	110	HDPE	126
P-76	166	J-88	J-89	110	HDPE	126
P-77	100	J-89	J-90	110	HDPE	126
P-78	70	J-90	J-91	110	HDPE	126
P-79	6	J-91	J-92	110	HDPE	126
P-80	86	J-92	J-93	110	HDPE	126
P-81	80	J-93	J-94	110	HDPE	126
P-82	20	J-53	J-95	200	DCI	98
P-83	30	J-95	J-96	200	DCI	98
P-84	18	J-96	J-97	200	DCI	98
P-85	20	J-97	J-98	200	DCI	98
P-86	137	J-98	J-99	200	DCI	98
P-87	91	J-99	J-100	200	DCI	98
P-88	16	J-100	J-101	110	HDPE	126
P-89	93	J-102	J-103	110	HDPE	126
P-90	52	J-105	J-106	110	HDPE	126
P-91	60	J-106	J-107	110	HDPE	126
P-92	47	J-107	J-108	110	HDPE	126
P-93	66	J-108	J-109	110	HDPE	126
P-94	40	J-111	J-112	110	HDPE	126
P-95	102	J-112	J-113	110	HDPE	126
P-96	104	J-113	J-114	110	HDPE	126
P-97	200	J-36	J-115	110	HDPE	126
P-98	94	J-115	J-116	110	HDPE	126

P-99	141	J-116	J-117	110	HDPE	126
P-100	237	J-119	J-120	110	HDPE	126
P-101	377	J-34	J-121	110	HDPE	126
P-102	299	J-121	J-94	110	HDPE	126
P-103	213	J-79	J-122	110	HDPE	126
P-104	22	J-123	J-124	110	HDPE	126
P-105	47	J-124	J-125	110	HDPE	126
P-106	106	J-125	J-126	110	HDPE	126
P-107	191	J-110	J-128	110	HDPE	126
P-108	239	J-128	J-119	110	HDPE	126
P-109	125	J-130	J-123	110	HDPE	126
P-110	67	J-131	J-104	110	HDPE	126
P-111	6	J-27	J-28	110	HDPE	126
P-112	8	J-47	J-48	230	DCI	98
P-113	219	J-60	TCV-1	110	HDPE	126
P-114	10	TCV-1	J-20	110	HDPE	126
P-115	5	J-1	TCV-2	450	DCI	98
P-116	110	TCV-2	J-2	450	DCI	98
P-117	12	J-3	TCV-3	350	DCI	98
P-118	29	TCV-3	J-40	350	DCI	98
P-119	4	J-3	TCV-4	450	DCI	98
P-120	7	TCV-4	J-4	450	DCI	98
P-121	7	J-7	TCV-5	300	DCI	98
P-122	26	TCV-5	J-8	300	DCI	98
P-123	2	J-14	TCV-6	300	DCI	98
P-124	46	TCV-6	J-15	300	DCI	98
P-125	191	J-65	TCV-7	110	HDPE	126
P-126	7	TCV-7	J-28	110	HDPE	126
P-127	243	J-129	TCV-8	110	HDPE	126
P-128	9	TCV-8	J-31	110	HDPE	126
P-129	482	J-31	TCV-9	110	HDPE	126
P-130	32	TCV-9	J-32	110	HDPE	126
P-131	133	J-32	TCV-10	110	HDPE	126
P-132	167	TCV-10	J-33	110	HDPE	126
P-133	204	J-120	TCV-11	110	HDPE	126
P-134	8	TCV-11	J-34	110	HDPE	126
P-135	37	J-33	TCV-12	110	HDPE	126
P-136	9	TCV-12	J-34	110	HDPE	126
P-137	42	J-114	TCV-13	110	HDPE	126
P-138	9	TCV-13	J-36	110	HDPE	126
P-139	40	J-35	TCV-14	110	HDPE	126
P-140	9	TCV-14	J-36	110	HDPE	126

P-141	158	J-117	TCV-15	110	HDPE	126
P-142	7	TCV-15	J-91	110	HDPE	126
P-143	110	J-118	TCV-16	110	HDPE	126
P-144	9	TCV-16	J-119	110	HDPE	126
P-145	6	J-119	TCV-17	110	HDPE	126
P-146	203	TCV-17	J-129	110	HDPE	126
P-147	24	J-109	TCV-18	110	HDPE	126
P-148	10	TCV-18	J-110	110	HDPE	126
P-149	6	J-110	TCV-19	110	HDPE	126
P-150	36	TCV-19	J-111	110	HDPE	126
P-151	214	J-126	TCV-20	110	HDPE	126
P-152	11	TCV-20	J-127	110	HDPE	126
P-153	226	J-122	TCV-21	110	HDPE	126
P-154	15	TCV-21	J-123	110	HDPE	126
P-155	7	J-79	TCV-22	110	HDPE	126
P-156	37	TCV-22	J-80	110	HDPE	126
P-157	10	J-101	TCV-23	110	HDPE	126
P-158	180	TCV-23	J-102	110	HDPE	126
P-159	9	J-101	TCV-24	110	HDPE	126
P-160	134	TCV-24	J-118	110	HDPE	126
P-161	68	J-103	TCV-25	110	HDPE	126
P-162	15	TCV-25	J-104	110	HDPE	126
P-163	16	J-104	TCV-26	110	HDPE	126
P-164	7	TCV-26	J-105	110	HDPE	126
P-165	7	J-46	TCV-27	300	DCI	98
P-166	20	TCV-27	J-66	300	DCI	98
P-167	8	J-72	TCV-28	110	HDPE	126
P-168	72	TCV-28	J-131	110	HDPE	126
P-169	12	J-75	TCV-29	110	HDPE	126
P-170	109	TCV-29	J-130	110	HDPE	126
P-171	8	J-77	TCV-30	110	HDPE	126
P-172	133	TCV-30	J-78	110	HDPE	126
P-173	9	J-48	TCV-31	200	DCI	98
P-174	32	TCV-31	J-49	200	DCI	98
P-297	9	PMP-2	PMP-1	450	DCI	98
P-298	14	R-12	PMP-3	600	DCI	98
P-299	12	PMP-3	PMP-2	600	DCI	98

Appendix-C

Low hour demand Pressure report

Label	Demand Base	Pressure (m H2O)	Hydraulic Grade (m)	Elevation (m)
J-1	0.01	24	2,642.68	2,619.12
J-2	0.01	14	2,642.57	2,628.71
J-3	0.02	18	2,642.48	2,623.98
J-4	0.02	19	2,642.48	2,623.41
J-5	0.02	13	2,642.43	2,629.30
J-6	0.02	11	2,642.41	2,631.54
J-7	0.03	9	2,642.39	2,633.24
J-8	0.03	7	2,642.37	2,635.17
J-9	0.03	4	2,642.32	2,638.16
J-10	0.03	3	2,642.29	2,638.96
J-11	0.04	3	2,642.28	2,638.92
J-12	0.04	4	2,642.25	2,638.28
J-13	0.05	6	2,642.24	2,636.33
J-14	0.05	9	2,642.22	2,633.53
J-15	0.06	13	2,642.20	2,629.35
J-16	0.06	16	2,642.19	2,625.71
J-17	0.07	19	2,642.18	2,623.49
J-18	0.07	21	2,642.17	2,621.27
J-19	0.07	23	2,642.16	2,619.47
J-20	0.07	23	2,642.16	2,618.83
J-21	0.07	24	2,642.05	2,617.87
J-22	0.08	28	2,641.61	2,613.37
J-23	0.08	30	2,641.46	2,611.45
J-24	0.08	37	2,640.99	2,604.36
J-25	0.09	46	2,640.22	2,594.28

J-26	0.09	57	2,639.31	2,582.14
J-27	0.10	58	2,639.27	2,581.57
J-28	0.10	58	2,639.25	2,581.24
J-29	0.10	60	2,639.01	2,578.91
J-30	0.11	61	2,638.82	2,577.61
J-31	0.12	71	2,637.93	2,566.60
J-32	0.12	97	2,637.06	2,540.25
J-33	0.12	80	2,636.69	2,556.60
J-34	0.12	80	2,636.65	2,556.55
J-35	0.13	75	2,636.34	2,561.01
J-36	0.13	73	2,636.30	2,563.37
J-37	0.13	72	2,636.27	2,564.37
J-38	0.13	75	2,636.23	2,560.60
J-39	0.14	77	2,636.23	2,558.73
J-40	0.14	22	2,642.42	2,620.57
J-41	0.14	43	2,641.97	2,598.89
J-42	0.15	47	2,641.70	2,594.41
J-43	0.15	48	2,641.65	2,593.81
J-44	0.15	48	2,641.62	2,593.24
J-45	0.16	49	2,641.58	2,592.58
J-46	0.16	50	2,641.54	2,591.52
J-47	0.17	50	2,641.54	2,591.30
J-48	0.17	50	2,641.52	2,591.10
J-49	0.17	50	2,641.35	2,590.76
J-50	0.18	50	2,641.24	2,591.16
J-51	0.18	51	2,641.06	2,590.11
J-52	0.19	50	2,640.76	2,591.05
J-53	0.19	48	2,640.58	2,592.71
J-54	0.20	47	2,640.53	2,593.73
J-55	0.20	45	2,640.47	2,595.13

J-56	0.21	44	2,640.44	2,596.11
J-57	0.21	43	2,640.48	2,597.83
J-58	0.21	41	2,640.54	2,599.77
J-59	0.22	39	2,640.60	2,601.50
J-60	0.23	31	2,641.16	2,610.52
J-61	0.24	44	2,640.30	2,596.69
J-62	0.25	44	2,640.19	2,596.06
J-63	0.26	45	2,640.11	2,594.63
J-64	0.27	47	2,639.82	2,593.02
J-65	0.28	51	2,639.49	2,588.18
J-66	0.28	50	2,641.50	2,591.38
J-67	0.28	50	2,641.48	2,590.97
J-68	0.29	51	2,641.44	2,590.20
J-69	0.29	53	2,641.40	2,588.77
J-70	0.30	54	2,641.36	2,586.95
J-71	0.30	55	2,641.24	2,586.10
J-72	0.31	57	2,641.16	2,583.70
J-73	0.31	75	2,641.03	2,565.78
J-74	0.31	80	2,640.99	2,560.56
J-75	0.32	87	2,640.94	2,553.81
J-76	0.33	97	2,640.92	2,544.18
J-77	0.33	106	2,640.90	2,534.66
J-78	0.34	106	2,639.83	2,533.27
J-79	0.36	107	2,639.11	2,532.30
J-80	0.36	106	2,638.71	2,532.00
J-81	0.36	107	2,638.43	2,531.60
J-82	0.36	101	2,637.76	2,536.08
J-83	0.36	95	2,637.01	2,542.27
J-84	0.38	92	2,636.61	2,544.87
J-85	0.43	89	2,636.39	2,547.20

J-86	0.46	90	2,636.34	2,545.73
J-87	0.47	92	2,636.31	2,544.59
J-88	0.48	87	2,636.07	2,548.86
J-89	0.49	87	2,635.96	2,548.62
J-90	0.49	88	2,635.93	2,547.76
J-91	0.50	89	2,635.93	2,546.69
J-92	0.50	89	2,635.93	2,546.49
J-93	0.51	91	2,635.94	2,544.36
J-94	0.53	96	2,635.97	2,539.95
J-95	0.53	49	2,640.54	2,591.48
J-96	0.54	50	2,640.49	2,590.07
J-97	0.55	51	2,640.46	2,589.62
J-98	0.55	51	2,640.43	2,589.24
J-99	0.57	60	2,640.23	2,580.22
J-100	0.60	66	2,640.10	2,574.22
J-101	0.60	67	2,639.85	2,573.18
J-102	0.61	59	2,639.63	2,580.11
J-103	0.61	59	2,639.55	2,580.81
J-104	0.61	58	2,639.51	2,581.34
J-105	0.62	58	2,639.24	2,580.92
J-106	0.63	59	2,638.71	2,579.32
J-107	0.64	61	2,638.21	2,577.35
J-108	0.65	62	2,637.88	2,576.02
J-109	0.70	63	2,637.52	2,574.63
J-110	0.75	64	2,637.38	2,573.73
J-111	0.76	64	2,637.13	2,572.72
J-112	0.76	65	2,636.95	2,571.78
J-113	0.76	68	2,636.61	2,568.42
J-114	0.82	71	2,636.38	2,564.97
J-115	0.86	79	2,636.03	2,557.32

J-116	0.86	81	2,635.96	2,554.65
J-117	0.86	85	2,635.93	2,550.99
J-118	0.92	68	2,638.60	2,570.56
J-119	0.93	70	2,637.78	2,567.91
J-120	0.94	75	2,637.13	2,562.36
J-121	0.94	91	2,636.21	2,545.47
J-122	0.94	96	2,639.27	2,543.28
J-123	1.01	84	2,639.54	2,555.69
J-124	1.07	84	2,639.52	2,555.81
J-125	1.13	81	2,639.48	2,558.25
J-126	1.14	73	2,639.44	2,566.46
J-127	1.42	66	2,639.41	2,573.17
J-128	1.44	65	2,637.49	2,572.31
J-129	1.60	75	2,637.81	2,562.65
J-130	1.67	85	2,640.17	2,554.83
J-131	1.84	57	2,640.19	2,582.76

Appendix-D

Pick hour demand Pressure report

Label	Damand (L/S)	Pressure (m H_2O)	Hydraulic Grade (m)	Elevation (m)
J-1	0.01	23	2,642.01	2,619.12
J-2	0.01	13	2,641.35	2,628.71
J-3	0.02	17	2,640.84	2,623.98
J-4	0.02	17	2,640.83	2,623.41
J-5	0.02	11	2,640.50	2,629.30
J-6	0.02	9	2,640.38	2,631.54

J-7	0.03	7	2,640.28	2,633.24
J-8	0.03	5	2,640.15	2,635.17
J-9	0.03	2	2,639.90	2,638.16
J-10	0.03	1	2,639.70	2,638.96
J-11	0.04	1	2,639.62	2,638.92
J-12	0.04	1	2,639.48	2,638.28
J-13	0.05	3	2,639.39	2,636.33
J-14	0.05	6	2,639.30	2,633.53
J-15	0.06	10	2,639.18	2,629.35
J-16	0.06	13	2,639.08	2,625.71
J-17	0.07	16	2,639.03	2,623.49
J-18	0.07	18	2,638.98	2,621.27
J-19	0.07	19	2,638.93	2,619.47
J-20	0.07	20	2,638.92	2,618.83
J-21	0.07	20	2,638.30	2,617.87
J-22	0.08	22	2,635.73	2,613.37
J-23	0.08	23	2,634.81	2,611.45
J-24	0.08	28	2,632.06	2,604.36
J-25	0.09	33	2,627.56	2,594.28
J-26	0.09	40	2,622.18	2,582.14
J-27	0.10	40	2,621.96	2,581.57

J-28	0.10	41	2,621.86	2,581.24
J-29	0.10	41	2,620.42	2,578.91
J-30	0.11	42	2,619.35	2,577.61
J-31	0.12	47	2,614.13	2,566.60
J-32	0.12	69	2,608.98	2,540.25
J-33	0.12	50	2,606.84	2,556.60
J-34	0.12	50	2,606.62	2,556.55
J-35	0.13	44	2,604.80	2,561.01
J-36	0.13	41	2,604.57	2,563.37
J-37	0.13	40	2,604.37	2,564.37
J-38	0.13	43	2,604.15	2,560.60
J-39	0.14	45	2,604.13	2,558.73
J-40	0.14	20	2,640.45	2,620.57
J-41	0.14	39	2,637.82	2,598.89
J-42	0.15	42	2,636.25	2,594.41
J-43	0.15	42	2,635.95	2,593.81
J-44	0.15	42	2,635.76	2,593.24
J-45	0.16	43	2,635.53	2,592.58
J-46	0.16	44	2,635.28	2,591.52
J-47	0.17	44	2,635.27	2,591.30
J-48	0.17	44	2,635.16	2,591.10

J-49	0.17	43	2,634.17	2,590.76
J-50	0.18	42	2,633.54	2,591.16
J-51	0.18	42	2,632.45	2,590.11
J-52	0.19	40	2,630.74	2,591.05
J-53	0.19	37	2,629.64	2,592.71
J-54	0.20	36	2,629.37	2,593.73
J-55	0.20	34	2,629.04	2,595.13
J-56	0.21	33	2,628.84	2,596.11
J-57	0.21	31	2,629.06	2,597.83
J-58	0.21	30	2,629.41	2,599.77
J-59	0.22	28	2,629.79	2,601.50
J-60	0.23	22	2,633.07	2,610.52
J-61	0.24	31	2,627.99	2,596.69
J-62	0.25	31	2,627.40	2,596.06
J-63	0.26	32	2,626.90	2,594.63
J-64	0.27	32	2,625.18	2,593.02
J-65	0.28	35	2,623.27	2,588.18
J-66	0.28	44	2,635.06	2,591.38
J-67	0.28	44	2,634.93	2,590.97
J-68	0.29	44	2,634.70	2,590.20
J-69	0.29	46	2,634.45	2,588.77

J-70	0.30	47	2,634.21	2,586.95
J-71	0.30	47	2,633.51	2,586.10
J-72	0.31	49	2,633.08	2,583.70
J-73	0.31	66	2,632.30	2,565.78
J-74	0.31	71	2,632.06	2,560.56
J-75	0.32	78	2,631.76	2,553.81
J-76	0.33	87	2,631.63	2,544.18
J-77	0.33	97	2,631.51	2,534.66
J-78	0.34	92	2,625.23	2,533.27
J-79	0.36	89	2,621.06	2,532.30
J-80	0.36	86	2,618.66	2,532.00
J-81	0.36	85	2,617.06	2,531.60
J-82	0.36	77	2,613.09	2,536.08
J-83	0.36	66	2,608.68	2,542.27
J-84	0.38	61	2,606.38	2,544.87
J-85	0.43	58	2,605.09	2,547.20
J-86	0.46	59	2,604.78	2,545.73
J-87	0.47	60	2,604.60	2,544.59
J-88	0.48	54	2,603.21	2,548.86
J-89	0.49	54	2,602.55	2,548.62
J-90	0.49	55	2,602.39	2,547.76

J-91	0.50	56	2,602.36	2,546.69
J-92	0.50	56	2,602.36	2,546.49
J-93	0.51	58	2,602.41	2,544.36
J-94	0.53	63	2,602.59	2,539.95
J-95	0.53	38	2,629.44	2,591.48
J-96	0.54	39	2,629.15	2,590.07
J-97	0.55	39	2,628.97	2,589.62
J-98	0.55	39	2,628.79	2,589.24
J-99	0.57	47	2,627.60	2,580.22
J-100	0.60	53	2,626.84	2,574.22
J-101	0.60	52	2,625.37	2,573.18
J-102	0.61	44	2,624.10	2,580.11
J-103	0.61	43	2,623.60	2,580.81
J-104	0.61	42	2,623.39	2,581.34
J-105	0.62	41	2,621.79	2,580.92
J-106	0.63	39	2,618.71	2,579.32
J-107	0.64	38	2,615.74	2,577.35
J-108	0.65	38	2,613.83	2,576.02
J-109	0.70	37	2,611.69	2,574.63
J-110	0.75	37	2,610.85	2,573.73
J-111	0.76	37	2,609.39	2,572.72

J-112	0.76	36	2,608.34	2,571.78
J-113	0.76	38	2,606.36	2,568.42
J-114	0.82	40	2,604.98	2,564.97
J-115	0.86	46	2,602.95	2,557.32
J-116	0.86	48	2,602.56	2,554.65
J-117	0.86	51	2,602.37	2,550.99
J-118	0.92	47	2,618.07	2,570.56
J-119	0.93	45	2,613.22	2,567.91
J-120	0.94	47	2,609.39	2,562.36
J-121	0.94	58	2,604.02	2,545.47
J-122	0.94	79	2,621.99	2,543.28
J-123	1.01	68	2,623.57	2,555.69
J-124	1.07	67	2,623.41	2,555.81
J-125	1.13	65	2,623.19	2,558.25
J-126	1.14	56	2,622.95	2,566.46
J-127	1.42	50	2,622.80	2,573.17
J-128	1.44	39	2,611.54	2,572.31
J-129	1.60	51	2,613.41	2,562.65
J-130	1.67	72	2,627.24	2,554.83
J-131	1.84	45	2,627.37	2,582.76