

**AFRICACENTER OF EXCELLENCE FOR
WATER MANAGEMENT
(ADDIS ABABA UNIVERSITY)**



**ASSESSMENT OF WATER LOSS AND PERFORMANCE
EVALUATION OF DISTRIBUTION SYSTEM
(THE CASE OF HOSANNA TOWN, SNNPR, ETHIOPIA)**

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A thesis Submitted to the Africa Center of Excellence for Water
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of Masters of Science in Water Supply and Sanitation

Advisor: Andinet Kebede (Ph.D.)

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AFRICA CENTER OF EXCELLENCE FOR WATER MANAGEMENT
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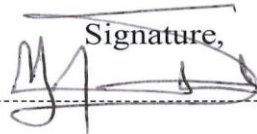


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DECLARATION

I hereby declare that this thesis, entitled by “**Assessment of Water Loss and performance evaluation of Distribution System**”, is my original work with the guidance of my advisor. The work contained here is my own, except where explicitly stated otherwise in the text, and that this work has not been submitted, in whole or in part, for any other degree or professional qualification.

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
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LIST OF ABBREVIATION

AWWA	American Water Work Association
AZNP	Average Zonal Night Flow
CARL	Current Annual Real Loss
CMI	Customer Metering Error
DMAs	District Metered Areas
EPS	Extended- Period Simulation
GTP-1	First Growth and Transformation Plan
HTWSSE	Hosanna Town Water Supply and Sanitation Enterprise
ILI	Infrastructure Leakage Index
IWA	International Water Association
JMP	Joint Monitoring Program
MDG	Millennium Development Goal
NRC	Non-Revenue Cost
NRW	Non-Revenue Water
RW	Revenue Water
SDHE	System Data Handling Error
SNNPR	South Nation Nationality People Region
UAP	Universal Access Program
UARL	Unavoidable Annual Real Loss
UC	Unauthorized Consumptions
UNICEF	United Nations Children’s Fund
UTM	Universal Transfer Mercator
WHO	World Health Organization
WSS	Water Supply and Sanitation

ABSTRACT

One of the biggest difficulties facing Ethiopia's urban water utilities is the reduction of excessive water losses. Water supply inconsistency and imbalanced distribution in Hosanna town is a major issue for the town's people. Despite the fact that the town has more than six sources of drinking water, considerable losses in the distribution system, along with an alarming increase in urbanization, have a significant impact on the supply shortfall. The major goal of this research was to determine the level of water supply coverage and distribution system losses. The hydraulic performance of the water supply distribution system was assessed using WaterGEMS. The existing distribution layout, Hosanna town administration master plan, and geospatial data were used as input data for WaterGEMS. The free water audit software from the American Water Works Association was used to assess the water loss. Financial and operational performance metrics, as well as the infrastructure leakage index, were used to assess total water losses and non-revenue water. The volume and cost of water lost and non-revenue water are reported in terms of volume and cost. The town's water supply covers 60% of the population, and the average daily per capita use is 29.02 liter. The data demonstrate that the GTP-2 aim of water supply coverage was not met. Water was lost from the system at a rate of 29.48 percent of total input water, including both apparent and real losses. The financial performance indicator for non-revenue water was found to be 30.73 percent of total generated water, including unauthorized use, apparent losses, and real losses. The infrastructure leakage index, which measures the efficiency of the distribution system, is 2.50. The hydraulic model was calibrated using observed pressure data as well, and the resulting coefficient of determination (R^2) was 0.997. According to the findings, the performance of Hosanna town's water supply distribution system is quite poor.

Keywords: WaterGEMS, water loss, distribution system, demand, water supply

1. INTRODUCTION

1.1 Background

A large number of people around the world lack access to basic sanitation and drinking water supplies (WSS). According to information gathered by the WHO/UNICEF, (2015), In 2010, according to the Joint Monitoring Program for water supply and sanitation (JMP), 783 million people continued to get their drinking water from unimproved sources. One of the Millennium Development Goals (MDG) of the United Nations is to reduce the proportion of people without access to safe drinking water and basic sanitation by half by 2015, using 1990 as a baseline year (Hutton, 2013).

In 1990, global levels of better-quality drinking water and sanitation facilities were 76 percent and 54 percent, respectively, with millennium development goal (MDG) targets of 88 percent and 77 percent by 2015. The obstacles were enormous, as global statistics obscure large gaps in coverage between nations, many of which were grappling with poverty, instability, and rapid population increase (WHO/UNICEF, 2015).

Despite falling short of the MDG objective, Sub-Saharan Africa had a 20% increase in the usage of improved drinking water sources. This means that during the MDG timeframe, 427 million people acquired access — an average of 47,000 people every day for 25 years. Over the same period, the Caucasus and Central Asia, as well as Oceania, saw only 2% and 5% increases, respectively, falling short of the aim (WHO/UNICEF, 2015). The biggest challenge that poor countries have in providing potable water to their inhabitants is a lack of resources. Furthermore, citizens' ability to pay for safe water that covers the entire cost is quite limited. As a result, most developing countries face significant challenges in extending facilities and rehabilitating existing old pipes.

The Ethiopian Ministry of Water, Irrigation, and Energy approved the Universal Access Program (UAP) in 2005, with the goal of providing safe water to all people of the country. In addition, the first phase of the Growth and Transformation Plan (GTP-1) was adopted in 2010. It covers the years 2011 to 2015. This is expected to raise rural, urban, and total water supply coverage to 98, 100, and 98.5 percent, respectively, while lowering the number of failing schemes from 20 to 10%. However, the total (government, corporate, and community)

sub-sectors' ability to meet and perform the expanding water supply demand in tandem with the country's development is insufficient. (Ministry of Water, 2015)

Because of the shortage of water in developing countries, water utilities cannot afford inefficient water distribution systems. The goal of reducing non-revenue water in the water delivery system is to ensure long-term water supply and management. In addition, developing countries face numerous obstacles in minimizing non-revenue water losses, complexity of water loss sources, multiple evaluation criteria, inherent uncertainties, and conflicting stakeholder aims and interests (Zyoud et al. 2016). And according to Ociepa *et al.*, (2018) studies Too many distribution system failures and associated water leaks are one of the most serious issues facing waterworks. Water losses in water supply distribution networks and systems account for a large percentage of the water that enters the system. As a result, completing a full analysis and evaluation of water losses should be the beginning point Modernization efforts aimed at lowering the costs of water production and distribution.

WaterGEMS was chosen from among the common water distribution system modeling packages for modeling pressure-dependent systems and coping with low-pressure instances. As a result, AWWA Free Water Audit Software and WaterGEMS were used in this study to examine water loss and the performance of the Hosanna town's distribution system model, respectively. Finally, the author stated that the hydraulic model WaterGEMS is an advanced model for analyzing the hosanna town water supply system's distribution system.

1.2 Statement of the Problem

Water loss, also known as Non-Revenue Water (NRW), refers to inefficiencies in water delivery and measurement activities, mostly in transmission and distribution networks, and can account for a significant fraction of total water output in some systems. Water loss occurs on all distribution systems; the only difference is the volume, which indicates the utility's ability to manage its network. To understand why, how, and where water is being wasted, authorities must assess the physical characteristics of the network as well as existing operational practices. Poor infrastructure, inappropriate management practices, network features, operational methods, technology, skills, and societal factors are all factors that contribute to water loss and cultural influences.

Water volatility and an unbalanced distribution of water supplies are typical in Hosanna town. However, the system is intermittent for three or four days, but consumers in most areas of the town can't obtain fourteen to fifteen days, and while the town has more than six sources of drinking water, the town's main problem is a lack of water supply coverage. According to Mulatu,(2016) A more thorough investigation should be carried out to determine the key causes of high water loss, which is a source of concern and must be reduced to an intermediate level (below 25%) by taking quick action. As a result, it was necessary to assess the overall water loss in the Hosanna municipal water supply distribution system as well as the distribution system's hydraulic performance.

1.3 Objectives

The main objective of this research was to investigate the loss of water in the distribution system in the case of Hosanna town using WaterGEMS.

The study aspires to pursue the following specific objectives:

- ✚ To estimate the water supply coverage and demand of the Town.
- ✚ To evaluate the hydraulic performance of the distribution system using WaterGEMS
- ✚ To estimate the total loss of water in the Town, performance of the system management, and causes of water loss.

1.4 Research Questions

By pursuing the above objectives, the research strived to answer:

- ✚ How much water do consumers get? How much water is needed for the customer?
- ✚ What does the hydraulic performance of the distribution system look like?
- ✚ How much water is lost in the entire town, compared with the produced water? How the system is managed? And what is the causes of water loss in the town?

1.5 Significance of the Study

The study's findings included information on the amount of water lost, the location of sub-systems with substantial water loss, and recommendations for corrective efforts. As a result, the study may aid the town utilities, as well as the general public, in finding a solution to the problem of fluctuation and imbalanced distribution. Future scholars who want to look into

comparable subjects in Hosanna or elsewhere in the country may find the study useful as a starting point for further investigation.

1.6 Scope of the Study

The scope of this research was limited to Hosanna Town's current water distribution network. In addition, the water coverage, the amount of water lost, hydraulic performance evaluation, and the sources of water loss from the distribution system were all assessed. It does not involve a review of the town's water quality or sanitation system.

2. LITERATURE REVIEW

2.1. Introduction

Rapid population increase, infrastructure failure, network features, water loss management problems, and other issues all contribute to the difficulty of providing or distributing water to consumers in developing countries. Aside from that, water loss in the distribution system has a substantial impact on the availability of water.

The steady-state analysis is an important part of determining the network's sufficiency in a water distribution system. For a given total discharge or total head loss, the hydraulic problem in relation to the pipe network entails determining the distribution of flow and water loss in the different elements. The supply may come from the service reservoir and/or pumps, or it may be defined as inflows or outflows at certain points in the system, and pressure or head losses across the distribution system are calculated using the known discharge. (Izinyon and Anyata, 2009).

2.2. Urban Water Demand Coverage

One of the measures used to compare coverage is the percentage of consumers with or without piped water. According to Desalegn, (2005), Many poor countries have very limited water supply coverage compared to developed ones, where water loss is fairly considerable.

In 87 of the 116 nations studied, overall coverage has improved, while the urban-rural discrepancy in access has decreased since 1990. Since 1990, urban drinking water supply coverage has been at or over 95% in 34 of these, and the reduction in disparities is mostly due to the leveling up of rural water coverage to urban coverage levels (WHO/UNICEF, 2013).

In most cases, the rate of expansion in clean water coverage in rural areas has been faster than in urban ones. As a result, the rural-urban difference in access to safe water on premises has narrowed in all areas over the millennium development goals (MDG) period, with the exception of Oceania, where neither urban nor rural coverage has altered. Urbanization has decreased by ten percentage points in Sub-Saharan Africa (WHO/UNICEF, 2015).

2.3. Urban Water Demand Management

The volume of water required by users to meet their demands is referred to as water demand. While most economists believe that prices are an efficient tool for limiting consumption during periods of insufficient water supply, others disagree that water demand is price flexible and hence an effective instrument for managing consumption. (Hoffmann *et al.*, 2006). The analysis took into account rapid population increase in accordance with municipal expansion instructions, as well as other relevant facts to aid in the minimizing of errors in determining future water supply demand (Cordeiro, 2013).

Water demand is mediated by three interacting elements, according to water resource management theories: technological breakthroughs, pricing levies, and individual behaviors and demographics. While these elements provide useful information for future water conservation measures, such as outreach and education campaigns, pricing structures are also important. Few studies look at the relationship between land use planning and water consumption, despite incentives geared at residential expansion (Shandas and Parandvash, 2010)

House connection and out-of-house connection are two types of urban water demand that differ from household water consumption. Swimming pools, garden watering, public standpipes for public use, and fountains are examples of in-house connection uses, whereas out-of-house connection uses include swimming pools, garden watering, public standpipes for public use, and car washing (Desalegn, 2005). The demand for urban water should be properly studied and broken down in order to establish an effective water policy (Kostas and Chrysostomos, 2006). Demand management measures that promote family water conservation are a no-regrets alternative to safeguarding future water supplies, especially when they result in long-term changes in attitudes and behavior. Furthermore, voluntary demand management measures can be used in conjunction with a variety of other beneficial strategies, such as legislation and water-efficient infrastructure (Fielding *et al.*, 2013).

2.4. Water Loss

Water loss in a distribution system is the difference between the total generated water or system input volume and the approved billed and unbilled water use. If there is a significant amount of water loss, it should be incorporated in the model as an "unreal" demand at the

next expected node. In a water distribution system, water loss is unavoidable. Water loss is divided into two categories: real losses and apparent losses. Physical water loss from the distribution system, such as pipe bursts, tank overflows, and leakage, is the real loss. "Paper" losses, billing errors, and meter inaccuracies are examples of apparent losses, and unauthorized use. Water loss results from numerous factors.

Main breaks, unexplainable pipe leaks, reservoir drainage for repair, fire hydrant cleaning, unauthorized use, unrecorded services, inaccurate and non-functioning meters, and on-site water plant consumption are among these factors. Because specific or isolated variables are difficult to establish unless the water loss is divided equally across all junctions, the water loss is normally distributed equally across all junctions measurements of region zones are taken throughout the distribution system. The use of system-wide district zone measurements allows for a more precise estimate of water loss. Some water utilities have employed leakage tests in sub-areas of the water distribution system for proportional division of water loss on other zones with similar characteristics to improve allocation accuracy, age of main, such as pipe material, and soil type (AWWA,2012).

According to Winarni,(2009) Non-Revenue Water can alternatively be defined as the sum of unbilled approved consumptions and water losses. It's crucial to distinguish between different types of water leaks because not all of them are caused by leaking pipes or bad infrastructure. There are two types of water losses: perceived losses (non-physical losses and management losses) and true losses (physical losses) (physical losses).

Other functional methods, as well as the water storage capability of each sector; the particular capacity of the wells; and the flexibility of the systems in emergencies, were analyzed in conjunction with the hydraulic model to improve the management of the water supply system and minimize water loss. The hydraulic model uses two main lines of action to reduce water loss over the course of the project: the first is to compensate for pressure in the distribution system, and the second is to optimize information accessibility and accuracy, as shown in the table: 2.1 (Cordeiro, 2013).

Table 2:1: IWA Water balance (AWWA, 2013)

Volume from own sources (corrected for known errors)	System input volume	Water exported (corrected for known errors)	Billed water exported				Revenue water
		Water supplied	Authorized consumption	Billed authorized consumption	Billed metered consumption	Revenue water	
Unbilled authorized consumptions	Billed unmetered consumption						
	Water losses	Apparent losses	Real losses	Unbilled metered consumption	Non-revenue water		
Unbilled unmetered consumption							
Water imported (corrected for known errors)				Customer metering inaccuracies			
				Unauthorized consumption			
				Systematic data handling errors			
				Leakage on transmission and distribution mains			
				Leakage and overflows at utility's storage tanks			
				Leakage on service connections up to the point of customer metering			

Revenue water (RW) has an impact on the System Input Volume components that are billed for metered and unmetered approved consumptions and generate revenue water (AWWA, 2013). Each component of the water balance must be stated in detail, and the water balance must be expressed in terms of volume per year. The three types of non-profit water are listed below. (Thornton, 2002):

1. Unbilled approved consumptions: the total volume of unbilled metered water consumed by registered consumers each year.
2. Apparent losses: all forms of billing mistakes, as well as unauthorized consumption such as theft or illegal use.

3. Real losses: Are the physical water losses of the pressurized distribution system, up to the point of customer meter.

2.5. Non-revenue water (NRW)

The loss of water without income is the total amount of real losses, apparent losses, and unlawful consumptions. Any water supply distribution system contains non-revenue water. Non-revenue water has a significant impact on water utility efficiency, as well as on consumers and the urban poor, and it reflects the company's performance. Before ten years, the average Non-Revenue Water report for different countries around the world was 36.6 percent, ranging from 70 percent in developing countries to less than 10% in highly industrialized countries, as illustrated in figure 2.1 (Makaya, 2015).

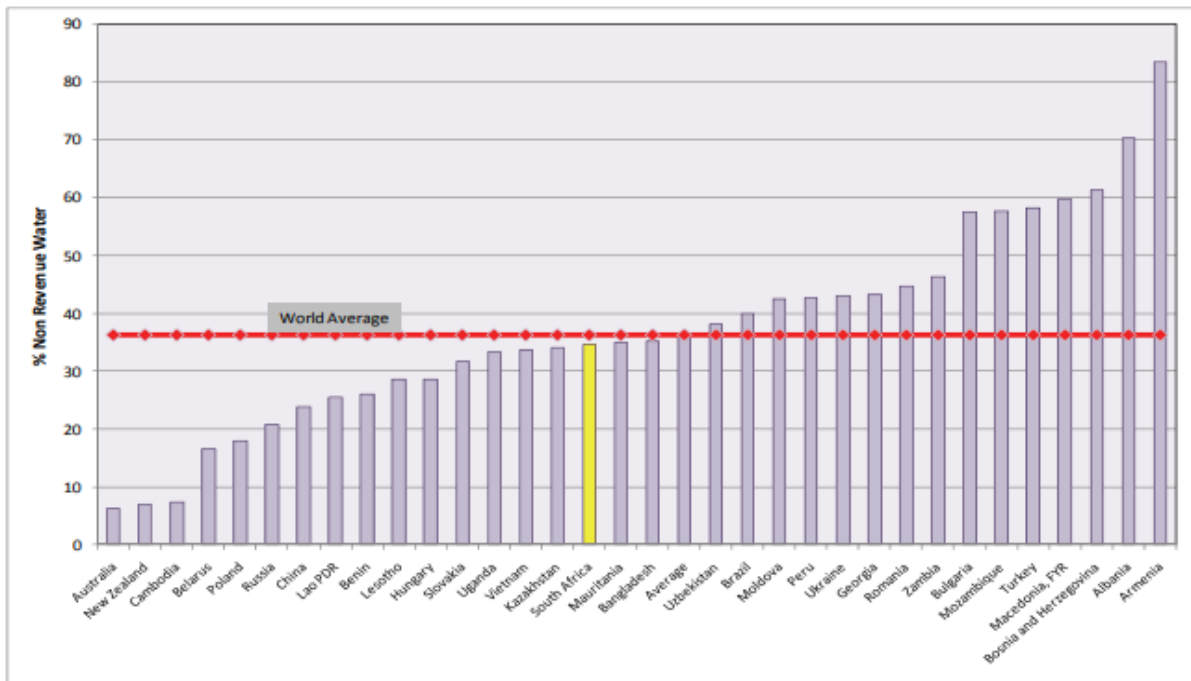


Figure 2:1: International percent of non-revenue water (Liemberger and Wyatt, 2019)

However, according to current studies, the global total volume of NRW is 346 million cubic meters every day, or 126 billion cubic meters per year. To put this in context, this annual amount is around 70% of the average flow of the Niger River, West Africa's most important river, and nearly half of the Ganges River's average flow is in India. But, more importantly, the overall amount of NRW accounts for 30% of global water system input quantities (Liemberger and Wyatt, 2019).

2.6. Water loss in developing countries

In poor nations, many water distribution facilities are run on a seasonal basis. As a result, the efficiency of these countries' water delivery systems is jeopardized. In addition to the issues connected with intermittent water supply system functioning, water losses in developing countries are extremely substantial and have reached alarming levels (Makaya, 2015).

Furthermore, one of the key issues facing various water utilities in most emerging municipalities, including Hosanna, is managing and decreasing water losses at all levels of a distribution system. Despite the fact that delivering adequate safe water is a growing management concern in Ethiopia, water loss from the distribution system is also on the rise, and there are just a few studies on the town's existing water utilities in terms of water loss and coverage (Gebrehiyot, 2015).

2.7. Pressure and Leakage

Even though the total volume of demand and the total volume of lost water can be easily determined in many water distribution networks, information about the possible effect of local pressure on demand is unfortunately lacking, making it difficult to assess and evaluate demand and water losses in distribution systems. On the one hand, the pressured distribution system exposes users to water shortages, resulting in water fluctuation and unequal distribution among consumers. Many water authorities devise a zoning system to address these issues, in which the entire water distribution network is separated into manageable components that can be readily metered and studied.

According to several research, the pressure of water in the distribution system and the rate of leakage are directly associated (Winarni, 2009). According to Zhou (2018), Pipe breakage, pipe bursts, and water leakage are the most common and obvious signs of urban water supply distribution system deterioration. The related performances include erratic water supply, low water pressure, and so on.

2.8. Pressure Management

The production of data to manage system pressure to a desirable level of services protecting sufficient and efficient water supply to legal uses or users is known as pressure management. According to Kanakoudis and Gonelas, (2014), The most efficient and encouraging effect on both actual losses and real consumption has been recognized as pressure management. It is a viable method for recovering a significant portion of non-revenue water. The main benefits of pressure management are not limited to lowering water losses. Lower pressure in the distribution system reduces mains and service connection burst rates, reduces pipe wear, resulting in longer pipe lifetimes, and generally extends the system's economic life.

2.9. Water Loss Management

In the face of a slew of water loss control difficulties, developing countries are battling to reduce water losses in their water distribution networks (Makaya, 2015). Actions to reduce urban water loss provide a number of advantages. Reduced water loss not only provides more safe water for the urban poor, but also lowers energy and treatment costs and delays the need for large capital investments in water delivery infrastructure (Sharma and Vairavamoorthy, 2009). As a result, the objectives of the development strategy of capacity could include gathering information on legal, technical, social, environmental, and financial cases connected to water loss reduction, depending on the target group (decision-makers, executive staff, and/or operators) (Gebrehiyot, 2015).

2.10. Reducing Water Loss from Leakage

Losses from detected and repaired leaks should be measured slowly to estimate the rate of water loss and the total amount of water lost throughout the leakage period. According to AWWA (2013), The objective is to choose an initial water loss (leakage) reduction target before approving the most effective strategy of the principal leakage control mechanisms listed below:

1. Identifying and measuring existing leakage amounts in the water utility transmission and distribution system, often by acoustic leak detection inspections and continuous flow checks into discrete zones or district metered areas (DMAs).

2. Improved leak repair activities: Ensures that leaks are repaired quickly and effectively.
3. Pressure management: By adjusting the operating pressure, water loss from pipe leakage can be prevented or eliminated.
4. System rehabilitation and renewal: All pipeline assets or distribution utilities will eventually approach the end of their design period or useful life and will need to be updated or replaced if they are to continue to provide service.

2.11. Distribution System Modeling

Models are excellent instruments for assisting operators with water audits and planning water loss control methods, but they must be utilized with caution and persistence. Models are not magical, rather they are the result of user interaction. They are only as good as the ideas they apply, the information they include, and the user's ability and experience. As a result, special effort should be made to ensure that the field data collected and the coefficients' actual conditions are as accurate as possible.

2.12. WaterGEMS

WaterGEMS is a modified version of WaterCAD that provides all of the features of WaterCAD as well as new tools. Model WaterCAD and Model WaterGEMS both use the same file format, therefore files saved in one version can be opened in the other. That is, if the model was saved in a lesser or equivalent version of the product, you can use both models to open it. Except for the tools that aren't available in WaterCAD, the user interface is identical (Bentley, 2014). As a result, WaterGEMS was the most appropriate recommendation for this study in terms of simulating water loss in the Hosanna Town water supply system's distribution system.

3. RESEARCH METHODOLOGY

3.1. Description of the Study Area

3.1.1. General

Hosanna town is located 235 kilometers from Addis Ababa in the Hadiya zone of Ethiopia's Southern Nation Nationality Peoples Regional (SNNPR). The settlement is around 168 kilometers southeast of Hawassa (the SNNPR capital) via Halabe-Angeca and 203 kilometers through Halabe-Wulbarag (Figure 3:1). The absolute geographic location of the town is from 7°53'00" to 7°55'00" North latitude and from 37°30'00" to 37°40'00" East longitudes.

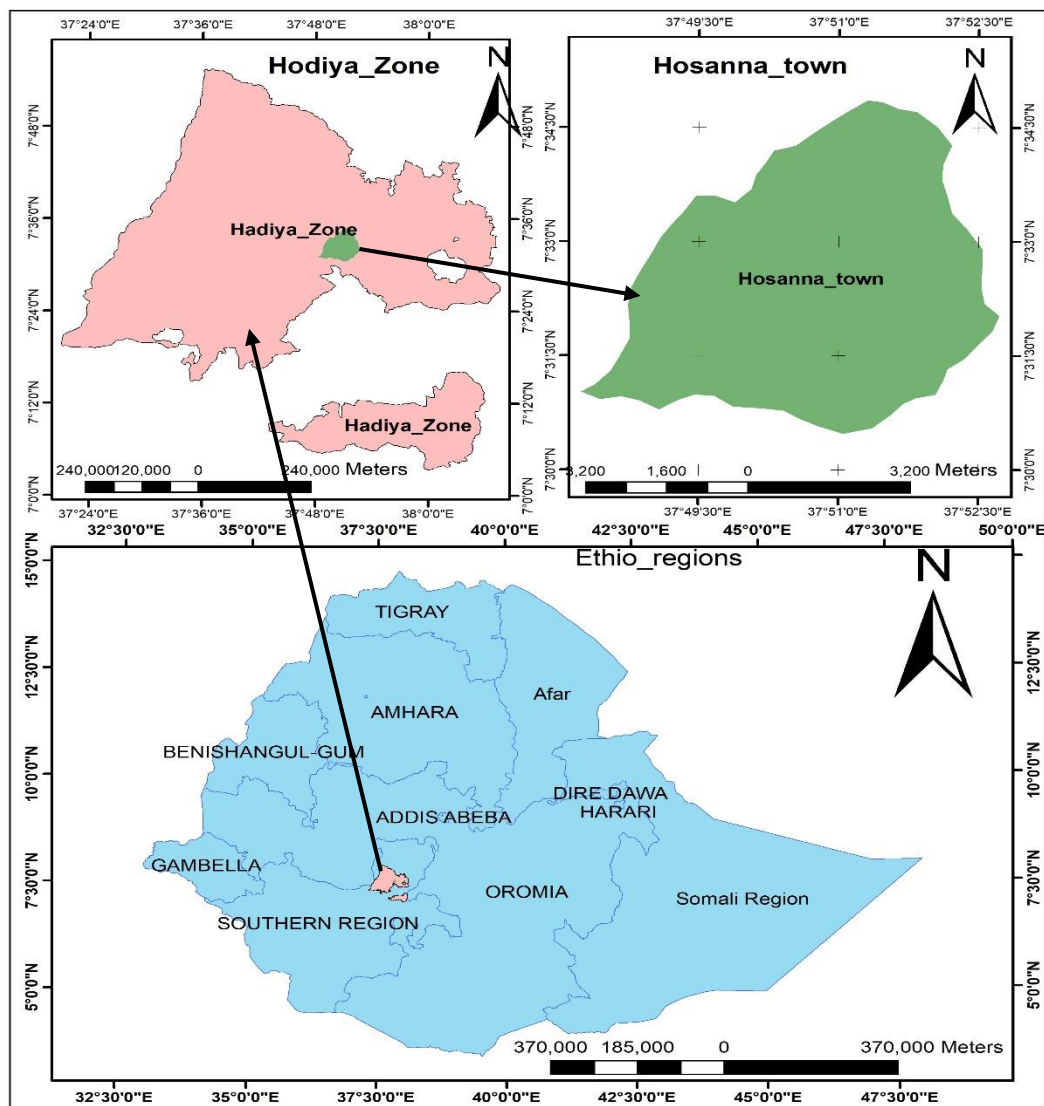


Figure: 3:1. Location map of the study area

3.1.2. Climate

The elevation varies between 2200 and 2404 meters above sea level. This indicates that the climate in the studied area is predominantly highland (Dega). In Hosanna town, there is only one meteorological station, which is located at 374900, 832800 UTM coordinates (Mulatu, 2016). The average monthly mean temperature ranges from a high of 200°C in April to June to a low of 170°C in December and January. The town receives an average annual rainfall of 1121.3mm. Bega (Dec, Jan, Feb), which delivers rainfall for a limited area of the town, Belg (March, April, and May), which is the little rainfall season, and Kiremt (June, July, and August), which is the main rainy season, are the three rainy seasons in the town. There are primarily two seasons based on this: rainy and dry seasons. (Hosanna Town Finance and Economic Development office 2014).

3.1.3. Topography

Physically, the Hosanna town spans 40.7 km² of land, with a topography that alternates between horizontal and vertical orientations. It has a number of ups and downs, as well as hills and plains. The drainage pattern of the town is from west to east, hence it is commonly asserted that the town is slanted largely from west to east. Approximately a quarter of the land is classified as having a slope of 4–7 percent. Hosanna's current topography owes its current surface to past volcano-tectonic activity, with minor modifications due to local thick soil development, soil erosion, and, to a lesser extent, valley creation. Hosanna is located on the physiographic region's western plateau, on the southern edge. Because of its high elevation, the town serves as a boundary between the Gibe Omo and Rift Valley lakes drainage basins. The town's elevation varies from 2,404 meters above sea level near Haile Bubamo primary school, now known as Hadiya Cultural Center, to 2,200 meters above sea level near Tekle-Haymanot Church. The average elevation above mean sea level is 2,300 meters. During the rainy season, Hosanna town is prone to flooding and soil erosion due to a high gradient from the hospital site to the low land of the open market area (Hosanna Town Finance and Economic Development office 2014).

3.1.4. Population

According to the census of 2000 E.C. (CSA, 2007), the town's population was 73,355, with a 2.9 percent annual growth rate. The town is currently divided into six administrative kebeles.

3.2. Existing water distribution system

The existing Hosanna water supply distribution system was finished in 1974 E.C., although most of the utilities in Hosanna town's existing water supply distribution system are ancient, and some of them are currently out of service. Field visits and secondary data were used to observe the system in various ways (AutoCAD sketch of the distribution system). The present hosanna town water supply system includes various utility units such as reservoirs, tanks, water sources, distribution system layout (pipe lines and junctions), and customer and water tariff numbers.

3.2.1. Water reservoirs

The reservoir data was gathered near the intersection of the town's main water networks. The reservoir's capacity in m³, building materials, and year of construction were all gathered. The distribution system has five concrete reservoirs, including the treatment facility. Two circular concrete reservoirs, each with a capacity of 150m³, are built side by side in Balewold and are operated by a common valve. Gorguade has one concrete reservoir with a capacity of 25m³. The remaining two circular concrete masonry reservoirs are placed in Gulit, each with a capacity of 2000 m³, and at the HWSSE office's treatment site, each with a capacity of 500 m³. Table 3:2 shows the details of the masonry circular reservoirs, one in the hospital with a capacity of 50m³ and the other in Ajo with a capacity of 50m³. Distribution tanks (Figure 3:7) are among those four, and they are further defined in WaterGEMS under the tank section. Because all of the tanks in the distribution system are cylindrical, the water supply office collects their dimensions data.

3.2.2. Distribution pipes

Material types in the existing distribution system include ductile iron (DI), galvanized iron (GI), and polyvinyl chloride (PVC) (PVC). Their diameters range from 53 to 350 inches, and there are 137 transmission and main pipes totaling 99.445 kilometers in length. Minor losses, omitting tee or elbow connections, are also included as part of pipes, as seen in figure 3:2.

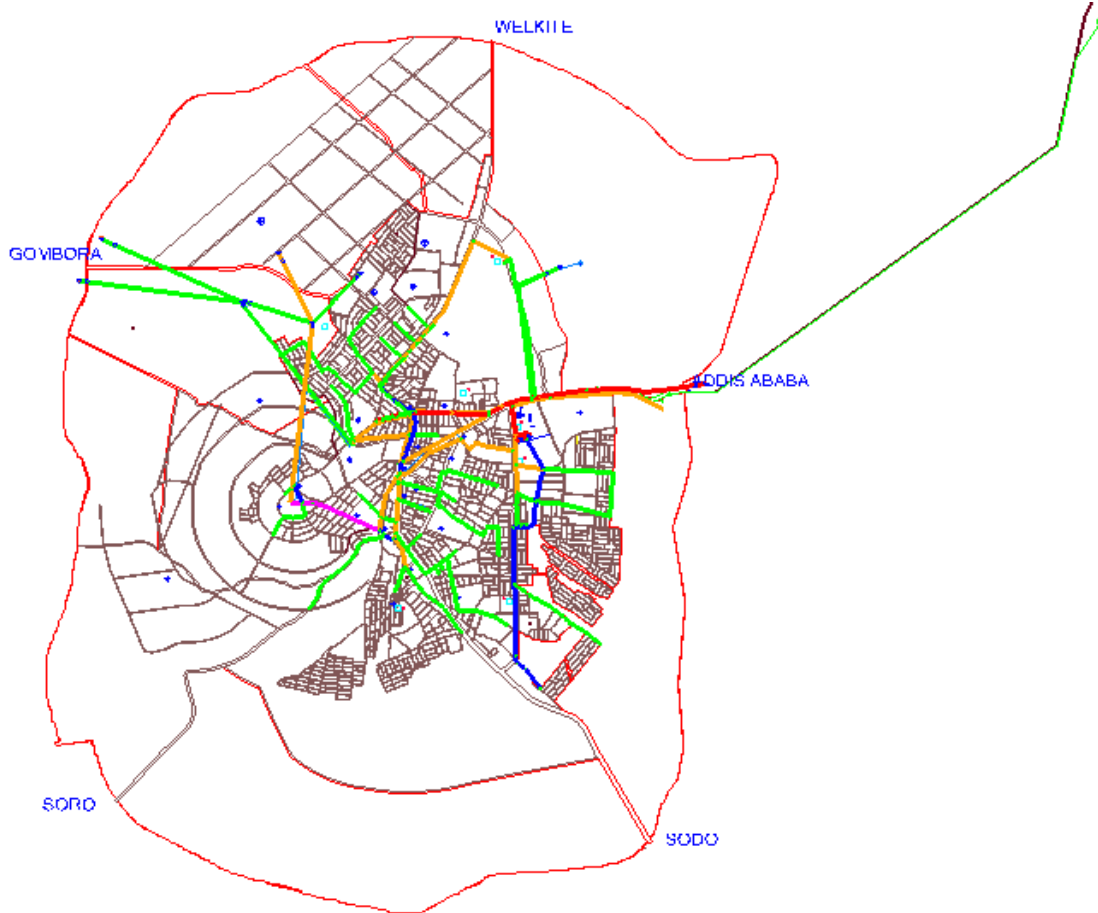


Figure 3:2. Existing (HTWSS) water distribution system layout

3.2.3. Junctions

Junctions are one of the node types, similar to tanks and reservoirs, which are connected by links such as pumps or valves and serve as flow input or output points, as well as fixed-grade nodes with static pressure and elevation, such as tanks and reservoirs. There are 113 junctions in the hosanna town water supply distribution system (Figure 3:3). A junction identification number, junction elevation, and junction demand are among the details linked with each junction node (Lingireddy et al. 2005). Depending on the needed demand and elevation (hydraulic grade line), the pressure in all connections varies (Figure: 3.3).

Table 3:1: Existing reservoirs

S.N	Reservoir	Capacity (M ³)	Material	Year of Construction
1	Gorguade treatment	25	Concrete	1970
2	Balewold 1 service	150	Concrete	1970
3	Balewold 2 service	150	Concrete	1989
4	Hospital service	50	Masonry	1998
5	Gulet service	2000	Concrete	2005
6	Treatment site (office)	500	Concrete	2005
7	Ajo treatment	50	Masonry	1998

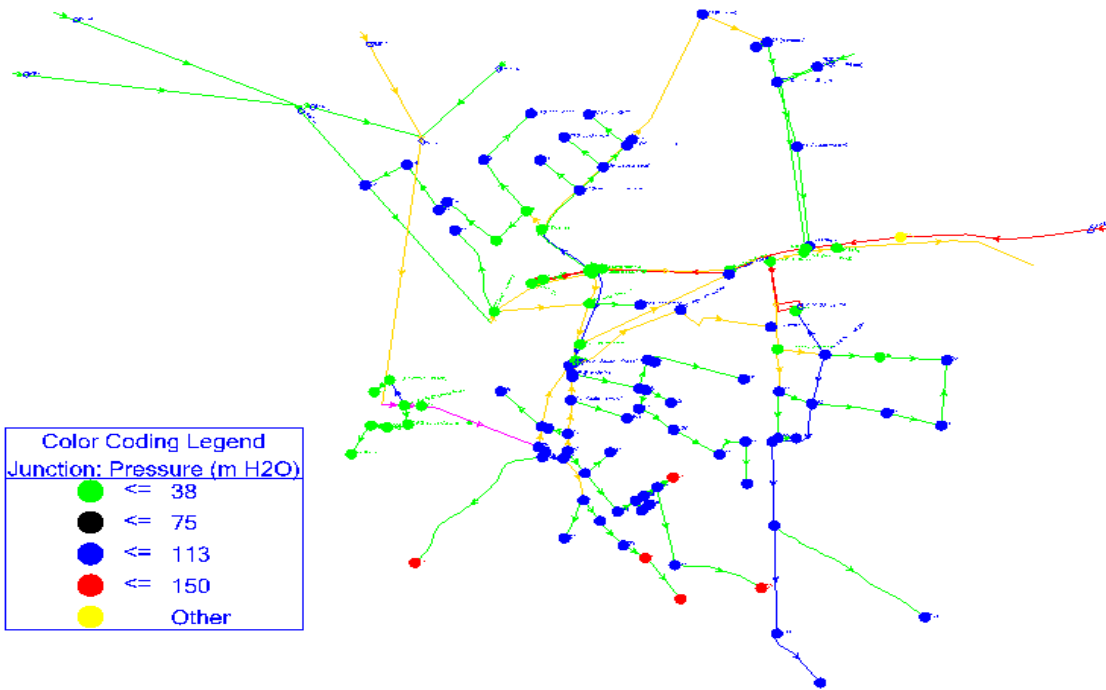


Figure 3:3. Junctions with various pressures

3.2.4. Water sources

The existing water supply distribution system was inspected by a representative from the Hosanna water supply service organization, who looked at the water production, treatment, transmission, and distribution networks. More than half of the town's water comes from a borehole constructed in 2005 at the Mosheshe and Shesher spring site, 45 kilometers northeast of Hosanna town (Table 3:3). The current output of the town water supply is 18

hours per day, with a total annual production of 1,879,102 m³/year. Groundwater is the primary source of supply for hosanna town.

Table 3:2: Existing water supply sources in Hosanna Town

S.N	Borehole	Average Current (L/S)	Working Hours/Days	Year Of Construction	Remark
1	Bobicho 1 (BH1)	5	16	1989	Functional
2	Bobicho 2 (BH2)	5	16	1989	Functional
3	Bobicho 3 (BH3)	3	16	1993	Not Working
4	Gombora 1 (BH5)	11	16	1998	Functional
5	Gombora 2 (BH6)	12	16	2008	Functional
6	Batena (BH4)	10	16	1998	Functional
7	Shesher Spring	70	24	2005	Functional
8	Mosheshe Spring	37.8	24	2005	Functional
9	Dam reservoir	6		1974	Not Working

3.3. Data collection

3.3.1. The town water supply networks

The town Water Supply and Sanitation Office provided the whole town water supply distribution layout and information. The length, diameter, material types, reservoir, and tank section are all included in this. The main and subsidiary pipes that make up the collected pipe network cover the majority of the town. During the site inspection, extension networks are added to the current network. The length of the entire network was grouped by diameter to determine the annual real loss that could not be avoided.

3.3.2. Pressure measurement

Throughout the day, pressure measurements were taken in the distribution system's customer taps at random junctions and zones. The intersections were chosen based on previous research's suggestions (Taylor, 2010; Lambert, 2010) and 6 points were selected in number and 5% of the junctions during the field visit, and each zones pressure data was used for model calibration as shown in annex I and the points were selected based on cluster sampling by dividing the total customer in three zones. After classifying the point selection was decided based on expertise recommendation.

Elevation readings were taken at the same site where pressure gauges were installed. While pressure gauges were being taken, critical times were chosen. These key times were determined based on the consumers' demand rate, which spans two-hour intervals (Annex

2.1). The study's pressure gauge was an analog pressure gauge that was used to measure the pressure on site (Figure: 3.4.).



Figure 3:4: Distribution system pressure measurement on customer tap

3.3.3. Consumption

The consumption data of each customer was acquired from the hosanna town water supply enterprise office to estimate the water loss in the supply distribution system of Hosanna town. According to published data, the entire town utilized over 1,301,581 m³ of water in 2011 E.C. The obtained consumption data is billed metered authorized consumption in this perspective. There was a considerable difference in consumption between consecutive months upon evaluating the data. This could be owing to metering inaccuracies caused by non-uniform meter readings.

3.3.4. Customers and water tariffs

The number and type of customers with the appropriate meter type were obtained from the town water supply enterprise office, with a total of roughly 13,500 customers in 2011 E.C to be utilized in the determination of real and apparent loss in water auditing analysis. The length of the service connection was also calculated because it was needed to calculate the real loss in the distribution system. As demonstrated in figure 3.5, the number of clients increased considerably from year to year.

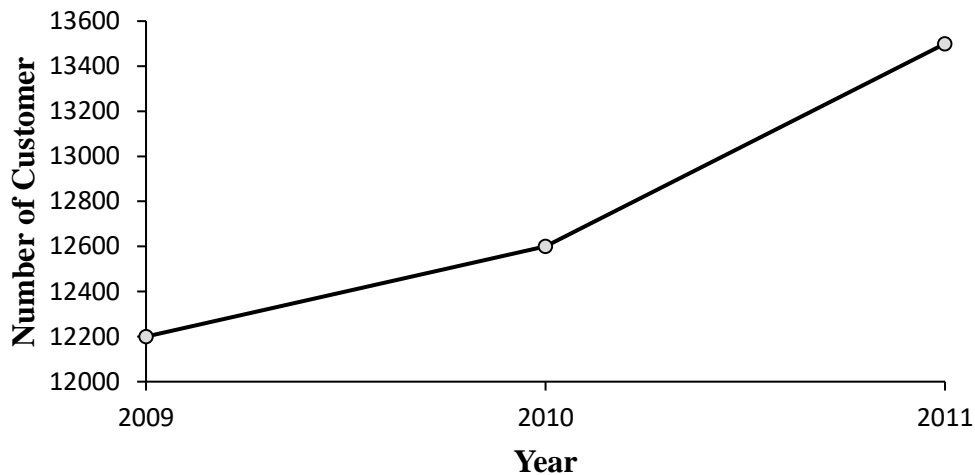


Figure 3:5. Number of customer versus a year

Currently, the unit cost of water or the tariff of Hosanna town water supply service is based on the consumption category given in Table 3.3.

Table 3:3: Block tariff being used in Hosanna town

Category	Unit Cost (ETB)	Measurement (m ³)
Category 1	6.27	0 to 5
Category 2	7.83	5 to 10
Category 3	9.40	10 to 30
Category 4	10.97	30 and above

3.4. Methodology

3.4.1. Water supply coverage

Statistical analysis was used to assess the town's water supply coverage based on average per capita use and the number of connections per family. Some system operators figure out

average day demand by dividing annual water production by the number of days in the year (365). This figure indicates the average yearly day output, which includes water lost due to distribution system leaks as well as other non-revenue water demands. The mean daily gross per capita water demand, or, more precisely, the mean daily gross per capita water demand, can be calculated by dividing this volume by the total population served by the system (Thornton, 2002).

$$\text{Average day demand} = \frac{\text{total annual water consumption}}{365} (\text{L/day}) \quad (1)$$

$$\text{Av. daily gross per capita consumption (L/C/D)} = \frac{\text{average day demand}}{\text{Population of the town in the year}} \quad (2)$$

3.4.1.1. Level of connection per family

The degree of connection per family is the best mechanism for knowing the coverage percentage and accessibility of water distribution in the system when evaluating the status of water supply coverage in the municipality. This level of connection per family was calculated by the ratio of total numbers of connections in the town by numbers of the population in the town divided by average family size who live in the town.

$$\text{Connection per family} = \frac{\text{Total numbers of water connection in the town}}{\frac{(\text{Number of population in the town})}{\text{Average family size}}} \quad (3)$$

3.4.1.2. Population forecasting

The population to be served is proportionally connected with the estimate of a town's water consumption. According to Ethiopian CSA data from 2007, the population of Hosanna town was around 73,388 people, which was utilized as the basis population for the current estimate. According to the CSA, the annual growth rate for the urban population at the regional level was 2.9 percent in 2011. The current (2011) projected population count for Hosanna town was shown in table 4.1 using the above CSA (2007) census reported population data as a base population and the geometric projecting method. The following are the basic assumptions for the geometric forecasting approach to be used:

- ✚ Growth rate is constant.
- ✚ Change is only experienced at the end of unit time.

✚ Compounding takes place at specified intervals.

$$P_{2011} = P_{2007} * e^{r*n} \quad (4)$$

Where: P_{2011} = Estimated population

P_{2007} = base population

r = Growth rate and,

n = Number of year

3.4.2. Distribution system modeling

The two essential concepts of distribution system hydraulics are mass and energy conservation, and the current distribution system pipeline in WaterGEMS was classified into six categories depending on pipe diameter (Figure: 3.6.). The Bernoulli equation asserts that the total of the elevation, pressure, and velocity heading between two places must remain constant in order to conserve energy. This equation does not hold in practice due to losses caused by friction during flow through the pipe. Head loss factors based on the Hazen-Williams, Chezy-Manning, or Darcy-Weisbach equations are used to account for frictional head loss. The following are some examples of head loss:

$$h_l = kQ^n \quad (5)$$

Where, “ h_l ” is head loss, “ k ” is the resistance coefficient, “ n ” is the flow exponent and “ Q ” is the flow rate.

Because of the law of conservation of mass, flows in series pipes must be equal, while flows in parallel pipes must be added. Head losses, on the other hand, are added for pipes in series and assumed to be equal at pipe-to-pipe connections. Loop and node equations are two types of equations. Mass continuity is expressed in loop equations as:

$$\Sigma Q_{in} - \Sigma Q_{out} = Q_e \quad (6)$$

Where “ Q_{in} ” is the inflow, “ Q_{out} ” is the outflow and “ Q_e ” is the external flow into or out of the system at each node.

Energy conservation is written as:

$$\Delta E = \Sigma hl - \Sigma ep \tag{7}$$

Where “ ΔE ” is the difference in energy grade, “ hl ” is losses considering pipe length, diameter, roughness, and minor losses, and “ ep ” is the pump head.

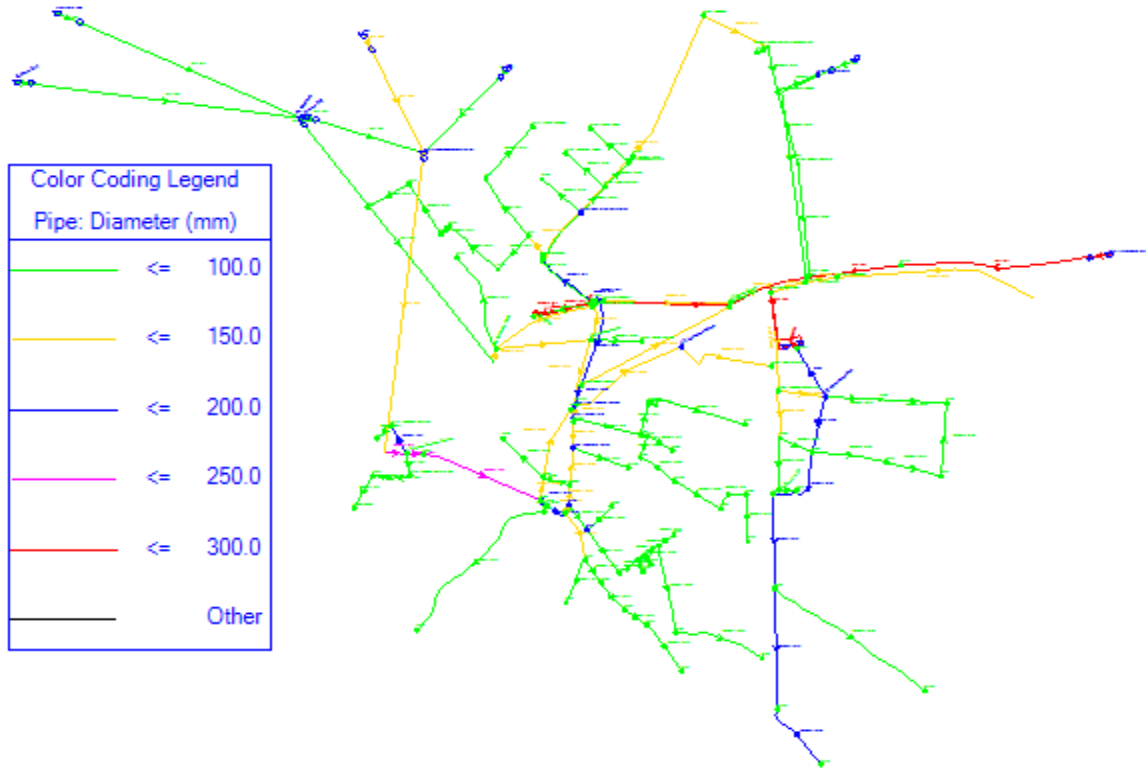


Figure 3:6: HTWS distribution system layout

3.4.2.1. Distribution tanks

In the entire municipality, including Wachemo University, there are four distribution tanks, which are further described in WaterGEMS under the section on tank hydraulic modeling. Because all of the tanks in the distribution system are cylindrical, the water supply enterprise office collects their dimensions data. The elevation of the tank is entered after the ID of the tank is entered into the section. Their starting water level is then used to determine their height (assuming full tanks); this height was calculated using the overflow to the outflow pipes, not the total height of the tank. The lowest and maximum levels are set to zero, and the maximum level is set to the same as the beginning level. No volume curve is chosen since all of the tank storage volumes vary linearly with height (Figure: 3.7.).

3.4.2.2. Distribution pipes

Pipes are linkages in WaterGEMS that connect two junctions. WaterGEMS' text or graphical interfaces can both be used to enter pipe information. It was suggested that the graphical interface be used in conjunction with the GIS map to demonstrate the distribution system's overarching logic through its placement. In addition, lengths surveyed were compared to compute lengths during the pipe-in process to ensure that field lengths were appropriately documented from the Hosanna town GIS plan. The length and diameter of the pipe, as well as the roughness, are next entered. A Hazen- William C coefficient used for Galvanized iron (GI), ductile iron (DI), and polyvinyl chloride (PVC) pipes were 120, 130, and 150, respectively.

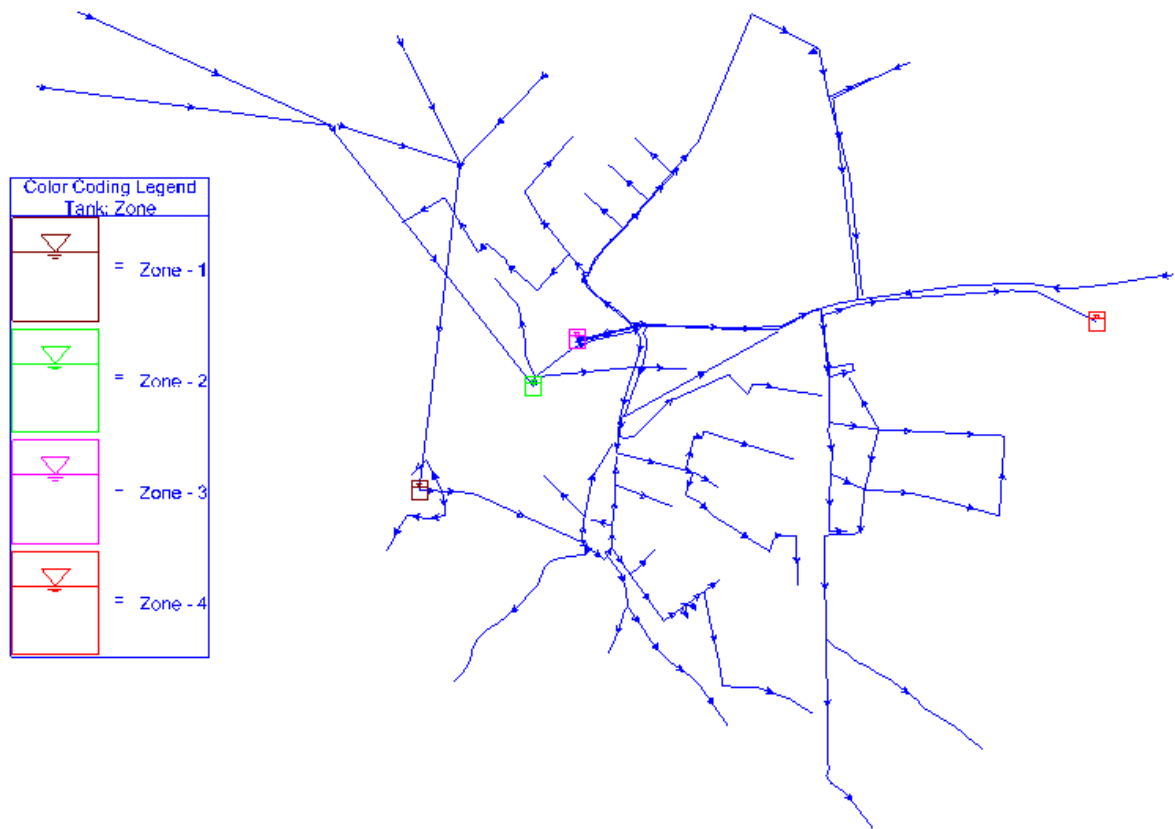


Figure 3:7. Existing distribution tanks

These minor losses were ignored and given an insignificant value because the errors in elevation were expected to outweigh the minor losses in such a way that the results would not be significantly affected if they were taken into account. When it came to the condition of pipes, they were usually left open by default. These were given the flow control valve (FCV),

which only allows water to flow from their first to second node. This option is critical to avoid backward flow from tanks or reservoirs with inlets that discharge above surface water, as well as emitter taps that would become sources if flow was not present.

3.4.2.3. WaterGEMS V8i model setup

Setting up certain necessary parameters, which describe the input values utilized by the software, was the initial step in launching the model. International System Units (SI units) were employed throughout the process. The user selects the SI flow unit from the tools option interface in WaterGEMS V8i to request the use of these units. In this work, liters per second were chosen as the unit of flow modeling, which also describes all other SI units. As a result, lengths, pressures, heads, and heights are measured in meters, whereas pipe diameters are measured in millimeters. For calculating head-loss, the Hazen-Williams equation was chosen. The next section goes over how to set up the interface for analysis in more detail.

The hydraulic modeling software WaterGEMS V8i was used to analyze the model under various conditions such as demand change, pressure variation, velocity, head losses, and overall systematic hydraulic performance of the water distribution system over time. Within the steady-state simulation and extended-period simulation, this comprises calibration and validation.

Steady-state simulation: Simulates the status of the system under the assumption that hydraulic demands and boundary conditions do not vary over time.

Extended-period simulation (EPS): determines the distribution system's quasi-dynamic character over time by assessing the status of the system as a series of steady-state simulations in which hydraulic demands and boundary conditions alter with time (Thomas M. Walski, 2017).

WaterGEMS V8i is selected for this study because it has the following additional programs or interfaces that WaterCAD lacks.

1. Pipe renewal planer

An asset management interface that ranks pipes based on their performance characteristics (pipe capacity, critical pipe segments, and pipe break history) as well as their facultative, property characteristics (material, location, year installed, and so on) to determine which pipes are the most critical to monitor for repairs.

2. Darwin designer

Entering hydraulic limitations such as permissible pipe widths and corresponding unit prices, as well as computation, can be done automatically or manually. Hundreds or thousands of design and rehabilitation options for systems are evaluated using the generic algorithm methodology.

3. Darwin calibrator

To determine the ideal value for a variety of model factors, such as pipe roughness, junction demands, and link operational status, that closely resembles the real-world state in the hydraulic system. Using a strong genetic algorithm optimization technique, the Darwin calibrator is effective in predicting the most likely areas of concealed water leakage hotspots.

4. Darwin scheduler

Find the best pump operations for fixed or variable speed pumps, optimize pumps to save energy in the system, and/or lower the cost of pump operations in the system.

5. Skelebrator

Skelebrator eliminates network or system complexity while maintaining connectivity, hydraulic equivalency, and collecting assigned needs according to specified parameters.

6. SCADA Connect

SCADA data can be directly integrated to the model, allowing for the calibration of an endless number of signals based on real-world conditions, the application of initial real-world conditions, and the computation of needs based on SCADA measured flow rates.

According to Bentley, (2014) the distribution layout system links and structures in a fully-scaled environment in the same design and drafting environment that was used to generate the engineering drawings are an advantage of using WaterGEMS (Figure 3:5). The existing

distribution system layout or CAD file was obtained from HTWSSE for these activities. Therefore, the model WaterGEMS V8i were selected to model Hosanna town water supply distribution system which is taken from Minister of Water, Irrigation and Energy of Ethiopia department of water supply and sanitation.

3.4.2.4. Model performance evaluation

The coefficient of determination was chosen in this study from among the various statistical approaches used to evaluate the performance of hydraulic models during calibration and validation of the results. The squared value of the correlation is denoted as the coefficient of determination R^2 . It was estimated as follows, using the "O" observed and "P" predicted system pressure values (Grillakis et al. 2010).

$$R^2 = \frac{(\sum_{i=0}^n (O_i - \bar{O}) * (P_i - \bar{P}))^2}{\sum_{i=0}^n (O_i - \bar{O})^2 * \sum_{i=0}^n (P_i - \bar{P})^2} \quad (8)$$

The coefficient of determination R^2 then fluctuates between 0 and 1, with higher values indicating better linear regression goodness-of-fit and lower error variance. According to Bahre, (2021) The degree of co-linearity between simulated and measured data is defined by the coefficient of determination (R^2). The coefficient of determination, R^2 , is a number that ranges from 0 to 1 and reflects how much variance in the measured data is explained by the model, with higher values suggesting less error variance.

Where,

n - The number of observations in the period under consideration

O_i , - is the i-th observed value,

\bar{O} , - is the mean observed value

P_i , - is the i-th model-predicted value and, \bar{P} - is the mean model-predicted value.

3.4.3. Total water losses assessment

Total water loss is the term used to describe the difference between the amount of water generated and the amount of water consumed. It's also known as "non-revenue water" or "unaccounted for water" (Farley, 2001).

Total water losses = water produced – water billed or consumed

Total water loss = physical (‘real’) losses + non-physical (‘management’ or ‘apparent’) losses.

$$\text{Total water loss (\%)} = \frac{\text{Total water produced} - \text{Total water billed}}{\text{Total water produced}} * 100 \quad (9)$$

Physical losses from distribution system leaks, bursts, and overflows from tanks and reservoirs up to the point of customer metering are referred to as real losses. While apparent losses include a variety of errors (inputs, outputs, and customer meters), as well as unlawful consumptions (theft, illegal use).

3.4.4. Non-revenue water

The discrepancy between the volume of water entered into a water distribution system and the volume of water billed to consumers is known as non-revenue water (NRW). NRW is made up of three parts: Unbilled permitted usage, physical losses, and commercial losses (Kingdom et al., 2006). The amount of non-revenue water (NRW) in a water supply distribution system is calculated by adding physical and commercial water losses, as well as unbilled allowed usage (for example, flushing mains or firefighting) (Fallis et al., 2011). The type of water that an authority puts into the distribution system that is not billed and thus does not generate money for the authority is referred to as NRW (Figure: 3.8). Unbilled Metered and Unbilled Unmetered Consumption, Apparent Losses, and Real Losses make up NRW (AWWA, 2013).

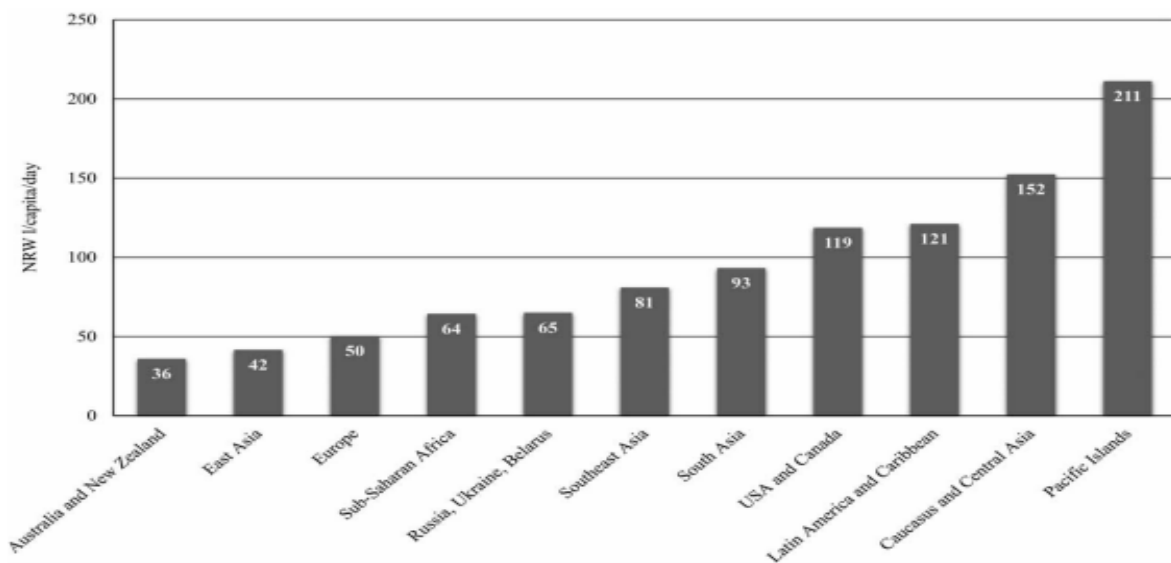


Figure 3:8: NRW in liters/capita/day (Source: Liemberger and Wyatt, 2019)

3.4.5. Water audit period

The selection of the audit study period is the first and most significant step in water audit assessment. The auditing period is determined by the most current availability of raw data, and 12 months (one year) is sufficient for analysis. Twelve months were chosen for this study based on Ethiopia's financial year, which runs from July 1 to June 30. Because it is recommended to use Ethiopia's budget year to eliminate the lag time while capturing data such as meter readings.

I. Water Audit

The water audit answers crucial issues such as: how much water is lost from the system? And how much does the water company lose as a result of these losses? The technique of water auditing is a useful instrument for authorities to assess consumption and water losses in the distribution system, as well as the water utilities' control systems. The AWWA Free Water Audit Software is the standard tool chosen by water utilities to prepare annual water audits for this auditing (AWWA, 2013). This technology enables the operator to determine where water is terminated along the water supply distribution system, as well as quantify consumption and lost water amounts. Drinking water agencies should use this procedure to conduct a water audit, according to AWWA the auditing process occurs at three levels, the selected process for this study is a top-down approach.

Top-down approach: - The top-down technique evaluates the entire water supply distribution system in a broad sense and can be gathered fast. The first step on the desktop is to acquire data from current records, procedures, data, and other information systems. As a result, the AWWA Free Water Audit Software was utilized in this study to measure overall water loss, as well as real and apparent loss, in the Hosanna municipal water supply distribution system.

II. Infrastructure Leakage Index

The Infrastructure Leakage Index (ILI) is a non-dimensional number that is calculated by dividing the Current Annual Real Loss (CARL) by the Unavoidable Annual Real Loss (UARL). An ILI close to 1 implies great performance in managing physical losses, but an ILI of 5, for example, signifies that current annual real losses are five times those expected for a

well-managed system with solid infrastructure, at the specified average pressure (Lambert, 2010) as shown in table 3.4.

$$ILI = \frac{\text{Current Annual Real Loss (CARL)}}{\text{Unavoidable Annual Real Loss (UARL)}} \quad (10)$$

Where, UARL is calculated by World Bank Institute Bands from the Night Flow Measurements equation.

$$UARL = (18 * L_m + 0.8 * N_c) * AZNF/24/1000 \text{ (m}^3\text{/hr.)} \quad (11)$$

Where: L_m = mains length (km)

N_c = number of service connection and AZNF = Average Zonal Night Flow (m)

In developing and developed countries, criteria 8 for evaluating the ILI based on the International Water Association (IWA), World Bank Index (WBI) Banding System, and American Water Work Association (AWWA) are shown in the table.

Table 3:4: Categories of water supply systems assessment according to ILI (Ociepa et al., 2019)

ILI Scope and Categories According To IWA	ILI Categories	ILI Scope according to WBI Banding System		ILI Scope According to AWWA
		Developing Countries	Developed Countries	
ILI ≤ 1.5 (Very Good)	Very Good	ILI ≤ 4.0	ILI ≤ 2.0	ILI ≤ 3
1.5 < ILI ≤ 2.0 (Good)				
2 < ILI ≤ 2.5 (Satisfactory)	Good	4 < ILI ≤ 8	2 < ILI ≤ 4.0	2 < ILI ≤ 2.5
2.5 < ILI ≤ 3 (Poor)	Poor	8 < ILI ≤ 16	4 < ILI ≤ 8	5 < ILI ≤ 8
3 < ILI ≤ 3.5 (Very Poor)				
ILI ≥ 3.5 Inadmissible	Inadmissible	ILI > 16	ILI > 8	ILI > 8

III. Financial performance indicators of non-revenue water (NRW)

Financial performance indicator can be expressed in terms of volume and cost.

Non-Revenue Water, expressed in %:

$$NRW = \frac{\text{Unbilled Volumes}}{\text{system input volumes}} * 100 \quad (12)$$

Unbilled volumes include unbilled authorized consumption and total water losses.

Non-Revenue Cost (NRC), expressed in%:

$$NRC = \frac{\text{annual cost real and apparent losses+unbilled authorized consumptions}}{\text{annual running cost of the supply system}} * 100 \quad (13)$$

The mean water sale price would be a suitable cost value for apparent losses. The unit costs (for treatment and operation) of producing and pumping water, or the cost of importing water, would be an adequate cost value for physical losses (bulk purchase). The difference between total annual costs and the capital costs of the complete supply chain is referred to as running costs (Farley, 2001).

4. RESULT AND DISCUSSION

4.1. Domestic Water Supply Coverage

The volume of consumed and generated water, as well as the population, are used to assess water supply coverage. Water consumption is translated to average daily per capita consumption using the population number to compute the amount of water.

4.1.1. Average daily per capita water consumption

The amount of water used for domestic purposes was totaled and reported to the town in order to determine the distribution of water supply coverage. Using the volume of usage to evaluate domestic water supply coverage may not allow for a distribution comparison between towns. As a result, using the town's population figure, the annual water consumption has been translated to average daily per capita water consumption (Table: 4.1)

$$\text{Average day demand} = \frac{\text{total annual water Consumption}}{365} \text{ (L/day)} \quad (14)$$

$$\text{Average day demand} = \underline{3,567,071.23 \text{ L/day}}$$

$$\text{Av. daily gross per capita consumption (L/C/D)} = \frac{\text{average day demand}}{\text{Population of the town in the year}} \quad (15)$$

$$\text{Average daily gross capita consumption (l/c/d)} = \underline{29.01 \text{ l/c/d}}$$

Table 4:1: Summary of average per capita water in Hosanna Town

Total Population	Total Production (m ³)	Total Consumption (m ³)	Consumption (l/c/d)	Production (l/c/d)
122,858	1,879,102	1,301,581	29.02	41.90

However, according to EBCS 9, the country standard for design purposes is 30 l/c/day to 60 l/c/day. In 2011, the town's average domestic water supply coverage was found to be 29.02 liters per capita per day. In comparison to national standards, this figure is quite low.

4.1.2. Level of Connection per Family

The degree of water connection in a town is a significant component in evaluating the level of water supply coverage, and it is the main focus of this section. On the other hand, it has a

direct impact on water loss, which is covered in more detail in the water loss analysis section. Within the town, there are around 14,359 connections or water meters. The total numbers of connections per junction are translated to connections per household using the town's population data to examine the distribution of water connections among the different zones. The average number of connections per family is calculated using a family size of 4.2, according to the 2007 census (Table 4.2). Up until June 30, 2011, the total number of water meters connected in the town was around 13,500. The average connection per household for the entire town is 0.12, similar to the per capita usage after accounting for outliers.

The water supply coverage in Hosanna town was assessed based on average daily per capita usage and the number of family connections. The water supply coverage in the town is low compared to the country standard of (30l/c/d to 60l/c/d) and the degree of connection per family is relatively excellent. According to Gebrehiyot,(2015); and Zewdu,(2014) Given the coverage of Debre Brihan and Axum towns, the degree of connection per family in Hosanna is higher in terms of water supply customers. However, the number of people who use piped water is also low, with an average daily per capita use of under 50% of the town's entire population. This means that the town's water supply coverage is significantly low when compared to the GTP-II plan's 70 percent yearly target for urban water supply coverage with the piped system in 2019 G.C (Assefa et al. 2018).

Table 4:2: Level of connection per family

Year	Pop	Average Family size	Number of connection	Level of connection
2009	104,409	4.2	12,200	0.49
2010	108,461	4.2	12,600	0.49
2011	112,669	4.2	13,500	0.50
2012	117,040	4.2	14,359	0.52

The low coverage of water supply in Hosanna town is owing to a rapid development in urbanization and informal settlement, which is putting pressure on the government's economic level. As WHO/UNICEF,(2014) reports Economic justifications remain extremely relevant to justify a further increase of WSS coverage in low- and middle-income countries, based on the findings of the study.

4.1.3. Population by mode of service

During the examination of the town's water supply coverage, the population's method of service in the water supply is critical. There are four major forms of services for domestic water consumers in Hosanna town, according to information from the Hosanna town water supply enterprise office. There are four types of connections: house connections (HC), private yard connections (YCP), shared yard connections (YCS), and public fountains (PF). Traditional source users, on the other hand, are individuals who are not served by any of these types of service (TSU).

According to the report, the majority of consumers (about 35.5%) acquire their water from a public tap (PF) outside their complex. A private yard connection (YCP) is used by 26.3 percent, a shared yard connection (YCS) is used by 30.6 percent, and a house connection is used by 6.1 percent (HC). The remaining 1.5 percent of the population uses traditional water sources (TSU) for their daily water needs (such as protected wells/springs, unprotected wells/springs, rivers, and ponds).

4.2. Hydraulic modeling

The entire water demand of the system in Hosanna Town exceeds the present water output due to high population expansion (high informal settlement) and significant water losses from the distribution network. Reduced system pressures are frequently used to restrict total demand and promote an equal allocation of available water supply. The water demand is calculated based on the greatest amount of water that can be collected during supply hours, rather than on diurnal fluctuations in demand. This is solely dependent on the network's available pressure heads (Figure: 4.1.).

4.2.1. Negative pressure

Situations that create negative pressures should be avoided at all costs. As a result, one of the causes of intermittent water delivery is pressure in the distribution system. The system was disconnected during peak demand period, and water was not reaching customers, according to all negative pressure reported in the appendices for this study. These were mostly caused by demand concentration (higher demand than the intended demand), insufficient pipe capacity (small diameter), and the availability of houses on the town's higher ground.

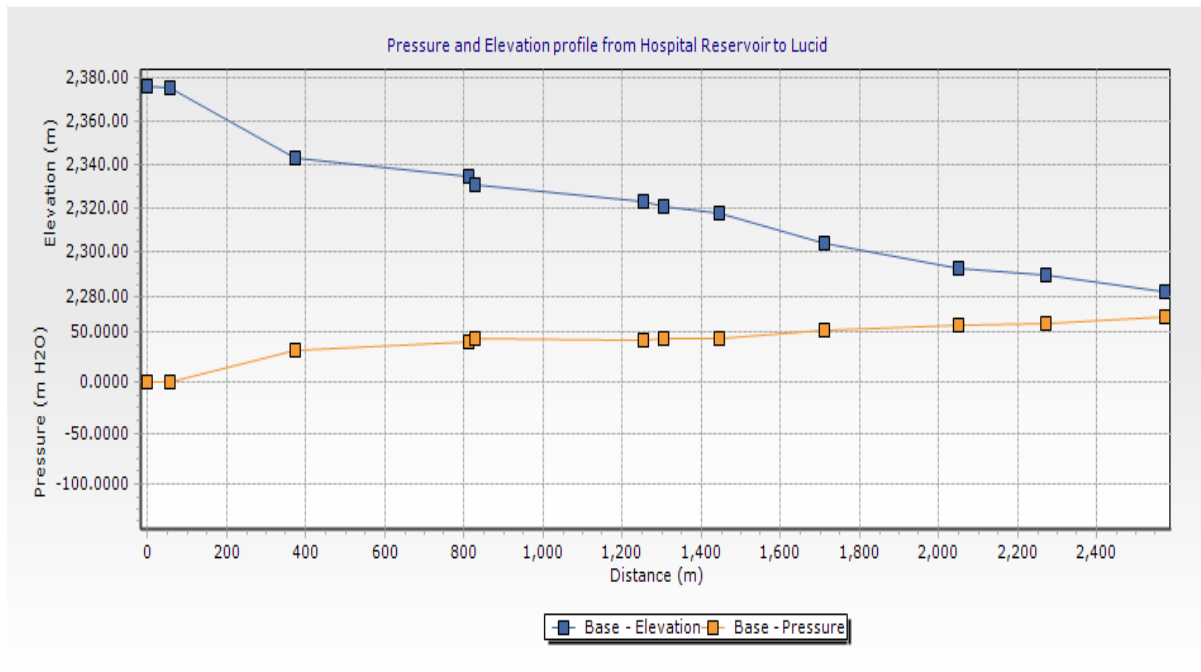


Figure 4:1. Pressure elevation profile from Hospital reservoir to Lucid

4.2.2. Simulation result

After that, single-period and extended-period simulations were run. To see the model in a snapshot state, a single period simulation has to be run at the start of the simulation. As a result, a single-performer preliminary model calibration was carried out. However, because the water distribution system is likely to encounter changes, it should not be used for network assessment. As a result, for the whole model calibration and model assessment effort, only extended period simulation was used. The demand patterns that were employed to simulate extended period simulations are shown in (Annex 4.1 and 4.2).

4.2.3. Model performance evaluation

4.2.3.1. Calibration

Calibration is an endeavor to better parameterize a model to a specific set of conditions in order to reduce uncertainty prediction. For comparing the results of model simulation with field data and applying modifications to anticipated values and field observations, hydraulic model calibration was computed. The usual comparison was carried out on pressure data gathered from chosen customer taps in the distribution system.

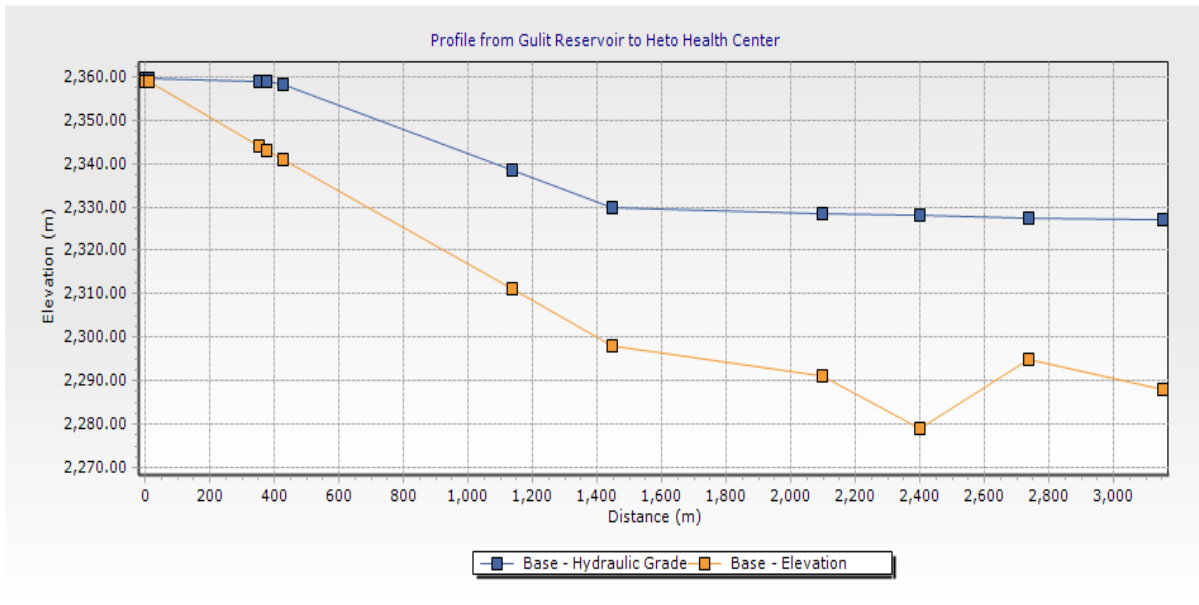


Figure 4:2 graph shows the profile of Hydraulic grade and elevation from Gulit reservoir to Heto health center

However, there are a variety of methods for assessing model calibration performance. The coefficient of determination (R^2) was calculated to determine the degree of co-linearity between simulated and measured data. As may be seen in figure 4.5, the coefficient of determination (R^2) was 0.9967. It refers to the percentage of variance in measured data that is explained by a model with lower error variance

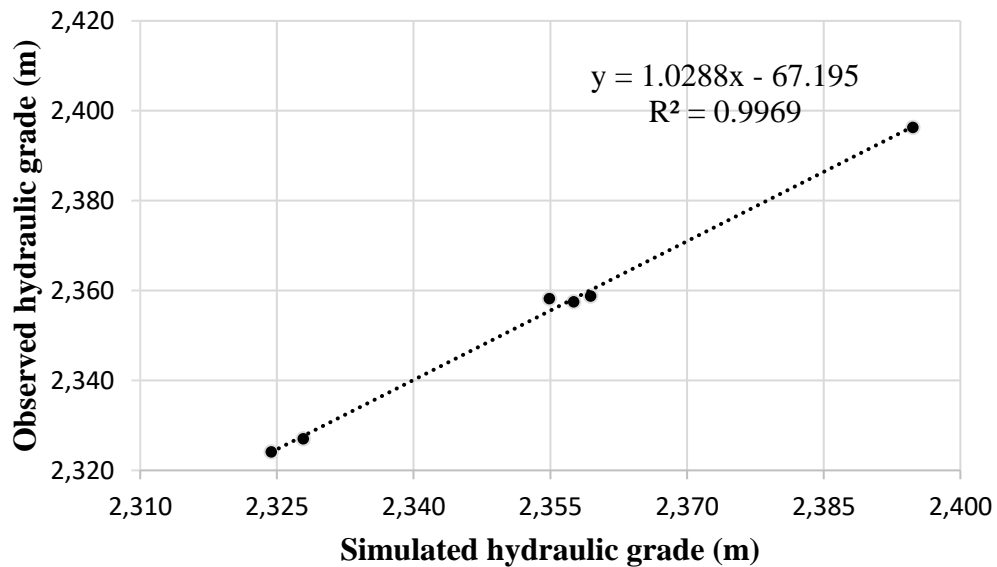


Figure 4:3: Correlation of observed and simulated hydraulic grade

4.2.3.2. Difference error

The level of accuracy varies based on the system's size and the amount of field data and testing the modeler has access to. The average pressure error from the table above pressure simulated to the observed value is around (+0.495) (Table 4.3).

As a result, the model is acceptable calibrated, as it meets the setting pressure calibration and validation criteria at an average level (1.5 m and a maximum difference of 5 m), indicating that the difference error value in this study is within the allowable range, indicating that the observed vs. simulated pressure data is good (Bahre 2021).

4.3. Water loss assessment

With rising demand and shifting weather patterns bringing droughts to many parts of the world, reducing and controlling water loss is becoming increasingly important. Many utilities have been working on different techniques to reduce water loss and its economic impact. Water is provided by the local authority in Hosanna. Hosanna Town Water Supply and Sanitation Enterprise is a company that provides water and sanitation to the residents of Hosanna (HTWSSE).

Table 4:3 Calibrated hydraulic head based on observed average working pressure and simulated pressure.

S.N	Junctions	Observed Hydraulic Grade (m)	Simulated Hydraulic Grade (m)	Difference error (m)
1	J-104	2,324.38	2,324.11	-0.27
2	J-72	2,354.90	2,358.26	+3.36
3	J-75	2,357.58	2,357.51	-0.08
4	J-95	2,327.92	2,327.05	-0.87
5	J-7	2,359.45	2,358.77	-0.68
6	J-38	2,394.81	2,396.32	+1.51

The total water produced annually and the billed water gathered from individual customer meter readings were combined to calculate the town's water loss. The water supply service's water production and consumption are evaluated using record data from the previous four years (2009–2012) and non-revenue water loss from the previous four years (Figure 4.6). The data for production come from the water meter installed at the source, while the figures for

consumption come from the water meters installed for customers and public taps. 2011 E.C collected data were used during the water loss assessment for AWWA free water audit software (Figure: 4.3.).

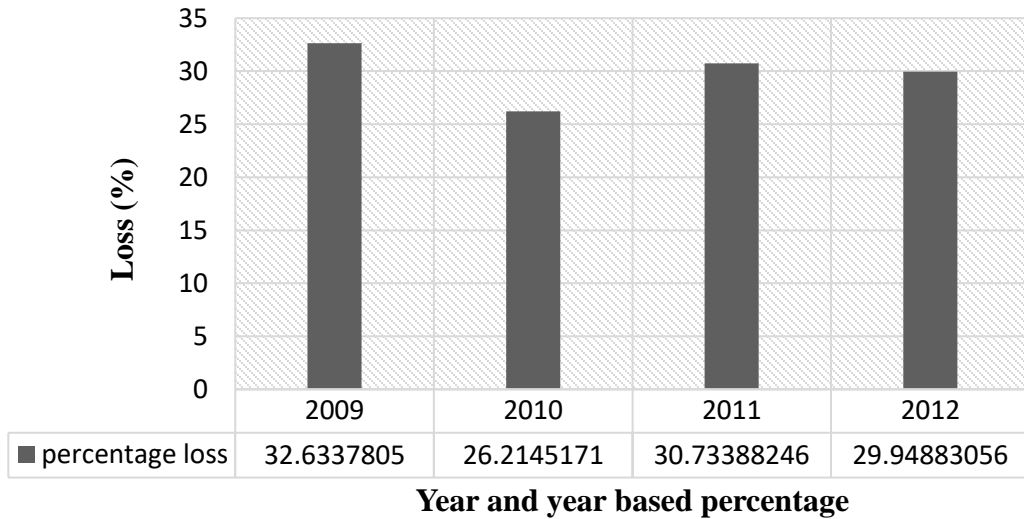


Figure 4:4. Last four years water loss status of Hosanna town

4.3.1. Apparent loss

According to AWWA's free water audit program, there are three categories of apparent losses. The first is unauthorized usage. Customer use that is not recorded due to metering mistake, inaccurate assumptions about unmeasured use, or unauthorized consumption are examples of apparent losses (Thornton 2002).

Because there is no documented evidence of unauthorized consumption, 0.25 percent default is used in water audit software. The second factor is mistakes in customer metering. Under this option, water utility management recognizes poor recordkeeping and meter oversight and allocates people and funding resources to organize improved recordkeeping and begin meter accuracy testing. To offer a superficial disposition of the meter population, existing paper records were acquired and sorted. Only when the consumer requests it, are customer meters verified for accuracy. Based on an interview with office professionals, this alternative was chosen since they do not have an annual inaccuracy testing program. The systematic data handling error is the third component. The option chosen for HTWSS is that they have a policy for activating new customer accounts and that they have oversight of billing data in place, but that it may be improved. Billing data is kept on paper records and electronic data

that isn't up to par. Only unstructured auditing work is done on a regular basis to ensure the billing data handling efficiency. The volume of unbilled water due to billing lapses is a guess.

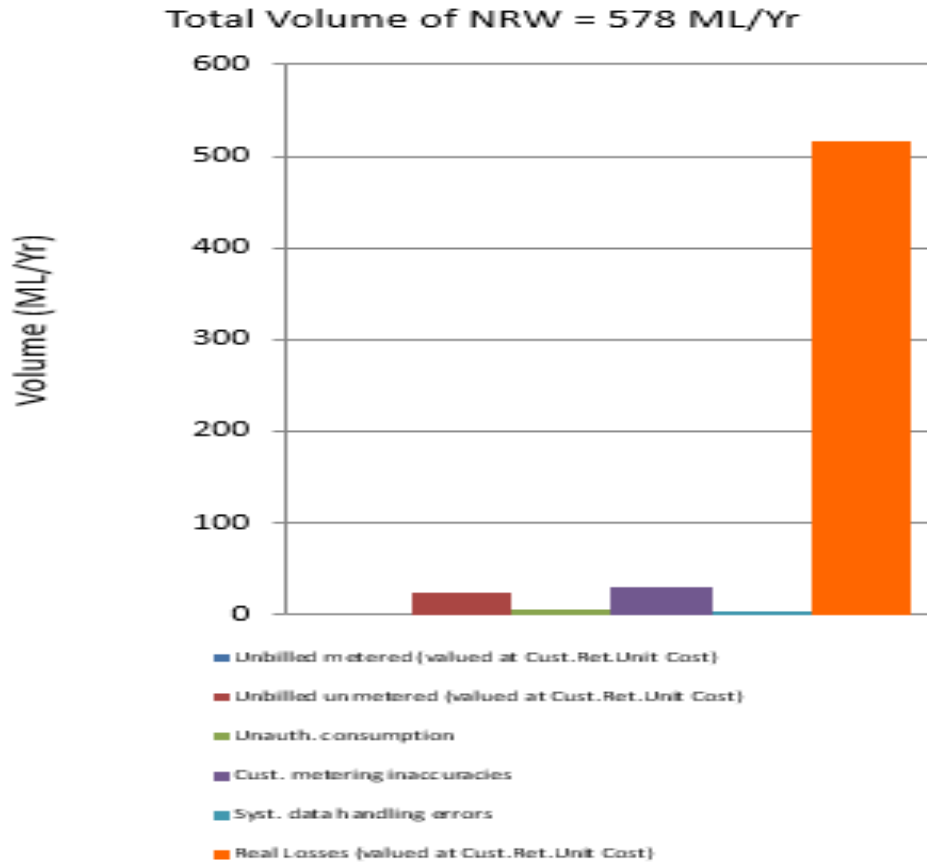
Therefore, apparent losses are the sum of unauthorized consumptions (UC), customer metering inaccuracies (CMI), and systematic data handling error (SDHE). The apparent loss breakdown is 4.698 million liters per year for UC, 30.096 million liters per year for CMI, and 3.254 million liters per year for SDHE, for a total apparent loss of 38.048 million liters per year, or 2.02 percent of the total water delivered to the system (Annex :2.2.).

4.3.2. Real losses

Physical water losses from leaks, burst pipes, and overflows of water from utilities up to the point of customer metering are considered real losses. The real loss in the HTWSSE is the difference between water loss and visible losses, as shown in annex 2.2. In HTWSSE, the true losses are far higher than the perceived losses. Because the firm doesn't have a clear cause, the huge amounts of water losses could be due to leakage and bursts from the transmission line, valves, and distribution pipes (Brian et al. 2007). Therefore, the real loss with unbilled authorized consumption of 1.25 percent is 515.985 million liters per year which are 28.71 percent of the total water production of the enterprise.

4.3.3. Non- revenue water (NRW)

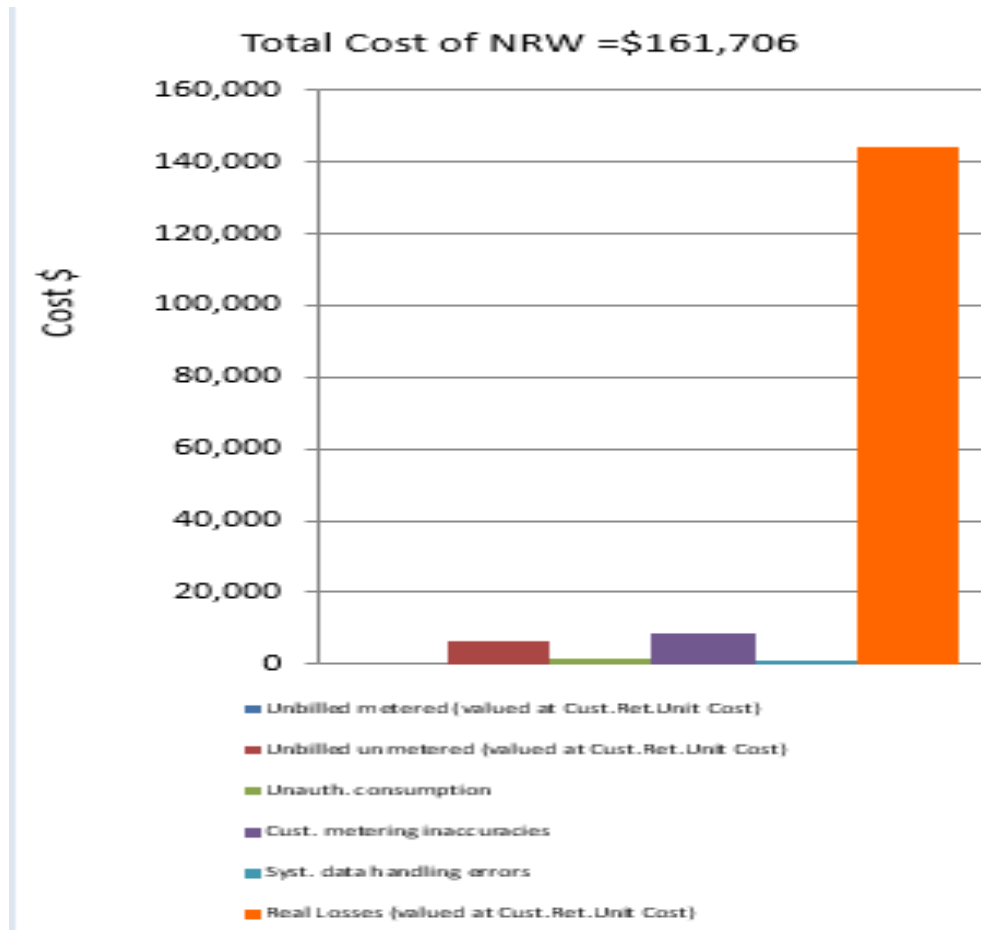
The gap between system input volumes and billed allowable water consumption is known as non-revenue water (NRW). The NRW is the sum of apparent losses, true losses, and unbilled allowed use, and it is also known as unaccounted for water. As a result, the NRW of the Hosanna Town Supply Distribution system is 577.521 million liters per year (about 578 million liters per year), or 30.73 percent of the total water input volume in the system (Annex: 2.3.). There are two ways to express non-revenue water (NRW). Figures 4.4a and 4.4b show the first one in terms of volume and the second one in terms of cost.



(a)

4.3.4. Financial performance indicators

The AWWA water audit program evaluates the entire system in two performance indicators when assessing water loss in the distribution system. Two financial performance indicators are included in the water audit approach, which can be used to examine a water utility's financial position in terms of water losses (AWWA, 2013). The first is the financial performance indicator in NRW, which is 30.7 percent by volume of water delivered (Figure 4.7 a) and 27.9 percent by percent cost of the operational system (Figure 4.7 b). The second is operational performance indicator, which is 7.72 liter/connection/day in apparent losses, 104.72 liters/connection/day in real losses, and 2.33 liter/connection/day/m in real losses per service connection per day per meter (head) pressure.



(b)

Figure 4.5. NRW in terms of volume and cost: (a) NRW in terms of volume and (b) NRW in terms of cost

4.3.5. Operational performance indicator

4.3.5.1. Infrastructure leakage index

This is a metric that measures how successfully a distribution system is managed (kept, repaired, and rehabilitated) in terms of preventing real (leakage) losses at the current operating pressure. It's the ratio of current annual real losses (CARL) to unavoidable annual real losses (UARL) in mathematics, or $ILI = CARL/UARL$. The present annual real loss (CARL) is 515.98 million liters per year, whereas the unavoidable real loss (UARL) is 206.79 million liters per year, according to this study. As a result, the system's infrastructure leakage index (ILI) is 2.50, as indicated in annex: 2.3. A low ILI value indicates that the

water utility has managed its leakage down toward the UARL, or the theoretical low limit of leakage technically achievable.

ILI is a leading benchmarking leakage performance measure utilized in worldwide performance comparisons because it is a dimensionless indicator (AWWA, 2016). Currently, the infrastructure leakage index is the most effective performance indicator measure for evaluating the efficiency of water distribution systems. As a result, the findings of this study are consistent with prior research, and the index level is excellent or good for IWA and AWWA, and very good for developing countries according to the WBI banding system. (Ociepa et al., 2019). Exhibition

4.3.5.2. Real losses as per service connection

The number of service connections (liters per service connection per day, l/c/d) is an appropriate measure of water loss in the distribution system, and it provides a more precise value than NRW as a percentage of input volume. According to the information acquired, the total number of service connections in Hosanna town was 13,500, and the volume of water loss per connection was calculated from the total real loss volume.

Loss per service connection = $\frac{\text{Annual real loss volume}}{\text{Total number of connection} \times 365}$ in liter per service connection per day is 104.72 liters per service connection. According to Farley, (2001), Hosanna town water loss per connection was judged to be in good condition as a performance indicator of the physical loss target matrix, which is about less than 145 liters/connection/day of loss

4.3.6. Causes of water losses

In the study of water losses in Hosanna town water supply distribution system the main causes of water losses are observed during field visit. Some of the cause are:

- ✚ In hosanna town the distribution system or pipe layout is not based on master plan of the town. Most of the pipelines are laid simply on road side and pipes are burst due to vehicles. Therefore, this is the main cause of water loss by leakage.
- ✚ The enterprise is not standby to maintain the burst pipes to reduce the water loss is also the main cause of water loss in Hosanna town (Annex 1).

- ✚ The data recording system of the enterprise is very poor. For example they don't have annual pipe burst frequency record that used to take strong measurement in controlling water loss.
- ✚ The policy of metering inaccuracy test is based on customer request.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Assessment of average water supply coverage and the town water distribution were proceeded based on the daily per capita consumption and level of connection per family using the population data of the town. The average water supply coverage of the town is found to be 41.9liters/person/day and the average per capita consumption is about 29.02 liters/person/day. The total population of the town is about 112,669 and the total number of piped water users was about 56,700 in 2011 E.C and the coverage of the water supply in the town is 50%. This average per capital consumption coverage of the water supply in the town is lower according to the countries GTP-II goal.

The performance assessment of hydraulic modeling of the Hosanna town water supply distribution system was conducted by using the WaterGEMS V8i. In this stage, the required data like the hosanna town administration master plan, the hosanna town water supply distribution layout, and the geospatial data are used. In the town, seven water supply sources are connected to supply the customers of the town. In the distribution system of the existing layout, the high pressure and low-pressure zone are identified. However, the burst frequency and other leakage information are not recorded, the high-pressure areas are highly vulnerable to burst and leakage of water.

The simulation of the hydraulic model to analyze the measured pressure was conducted by the Darwin calibrator analysis method. Hence, only extended period simulation was exclusively used for the entire model calibration and model assessment effort. Recorded pressure data was used in simulating extended period simulation of the model. As the result indicates that the observed and simulated pressure has a good correlation by -0.08 and $+3.36$ difference error and 0.997 value of the coefficient of determination.

Despite the low water coverage of the town, the total water loss is found to be high, the total water loss was computed by using AWWA water audit software by using the consumption (bill data), operation cost of the system, and the water production data of 2011 E.C. After computing the system the total water losses (Non-Revenue Water) of the town is 30.7% of total annual production in 2011 in the town level. The approaches non-revenue water

expressed as a volume and as a percentage of production. The performance indicators of the system are also important terms and are computed as a financial performance indicator, operational performance indicators (apparent losses per service connection per day, real losses per service connection per day, and real losses per length of main per day, and infrastructure leakage index (ILI)).

Finally, the result of the study in terms of the water loss level and some performance indicators shows that the system is good or satisfactory. But the water supply coverage is very low when compared to GTP-2 and other World Bank guidelines.

5.2. Recommendations

Based on the result of the study the following recommendations are made for Hosanna Town Water Supply Distribution System.

- ✚ In this study, the water supply coverage was done by considering the 2011 E.C fiscal year data of the town. However, the population growth rate of the town is forecasted as 2.9%, the population growth of the town due to informal settlement is beyond and the average per capita coverage of the town is 29.02 l/sec and the level of piped water users in a town is only 12%. This implies the coverage of the water supply is very low compared to the GTP-2 goal of the country. Therefore the town administration has to plan to achieve the target.
- ✚ The hydraulic model of WaterGEMS was used to analyze the system performance of the distribution layout. There is a limitation of important instruments in the enterprise like pressure gauge and GPS to collect the newly connected pipeline data. Resisting to improve the enterprise by technologies and basic instruments may lead to the loss of water as well as an economic crisis.
- ✚ The loss of water in the whole distribution system is high according to the results like water losses in percentage and performance indicators. The lost water from the distribution system 30.73% of volume from the input water and 27.9% of operating cost was also lost. Therefore, the enterprise has plan different technical management strategies to minimize the loss of resources.

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ANNEX 1: List of questions for discussion with office expertise

1. What are the town's primary water sources? Are there any sources of surface water?
2. Are there any water sources (now inactive sources) that are not part of the distribution system? If so, where and for how much?
3. Is it common for pipeline to burst? What zone are you in and where are you? How do you keep these pipelines in good working order, and do you have a maintenance team on standby?
4. What are the most common reasons for pipe failure? Do you have a plan in place to deal with pipe bursts that result in water being lost from the system?
5. Do you employ a specific type of distribution system? Is it better to be intermittent or constant? How long does it last if it's intermittent?
6. In 2011 E.C., what was the total annual operating cost of the water supply system?
7. Do you have a policy for water meter testing? If the answer is affirmative, how do you check for meter inaccuracy (once a year, annually)?

ANNEX 2: Measured pressure data table and AWWA water software results

Annex: 2.1: Measured Pressure Data from Selected Junctions

Time (hr.)	Junction	X	Y	Elevation	Observed Pressure	
					bar	m H ₂ O
08:00AM	J-104	374912	83533	2304	2	18
	J-72	373031	83631	2303	5	48
	J-75	374151	83707	2312	4	40
	J-95	375058	83423	2288	4	35
	J-7	372984	83562	2333	2	21
	J-38	374875	83271	2301	8	80
10:00AM	J-104	374912	83533	2304	2	20
	J-72	373031	83631	2303	5	47
	J-75	374151	83707	2312	4	42
	J-95	375058	83423	2288	4	39
	J-7	372984	83562	2333	3	24
	J-38	374875	83271	2301	9	86
12:00PM	J-104	374912	83533	2304	2	19
	J-72	373031	83631	2303	5	50
	J-75	374151	83707	2312	4	40
	J-95	375058	83423	2288	4	38
	J-7	372984	83562	2333	2	23
	J-38	374875	83271	2301	8	81
02:00PM	J-104	374912	83533	2304	2	20
	J-72	373031	83631	2303	5	50
	J-75	374151	83707	2312	4	43
	J-95	375058	83423	2288	4	40
	J-7	372984	83562	2333	3	26
	J-38	374875	83271	2301	9	89
04:00PM	J-104	374912	83533	2304	2	21
	J-72	373031	83631	2303	5	52
	J-75	374151	83707	2312	5	45
	J-95	375058	83423	2288	4	40
	J-7	372984	83562	2333	3	27
	J-38	374875	83271	2301	10	91
06:00PM	J-104	374912	83533	2304	2	21
	J-72	373031	83631	2303	6	53
	J-75	374151	83707	2312	4	41
	J-95	375058	83423	2288	4	37
	J-7	372984	83562	2333	3	25
	J-38	374875	83271	2301	9	90

08:00PM	J-104	374912	83533	2304	2	1718
	J-72	373031	83631	2303	5	51
	J-75	374151	83707	2312	4	40
	J-95	375058	83423	2288	4	39
	J-7	372984	83562	2333	3	26
	J-38	374875	83271	2301	9	84
10:00PM	J-104	374912	83533	2304	3	24
	J-72	373031	83631	2303	6	54
	J-75	374151	83707	2312	4	43
	J-95	375058	83423	2288	4	41
	J-7	372984	83562	2333	3	28
	J-38	374875	83271	2301	10	92
12:00AM	J-104	374912	83533	2304	3	25
	J-72	373031	83631	2303	6	55
	J-75	374151	83707	2312	5	50
	J-95	375058	83423	2288	5	45
	J-7	372984	83562	2333	3	30
	J-38	374875	83271	2301	10	95
02:00AM	J-104	374912	83533	2304	3	26
	J-72	373031	83631	2303	6	55
	J-75	374151	83707	2312	5	51
	J-95	375058	83423	2288	5	48
	J-7	372984	83562	2333	3	31
	J-38	374875	83271	2301	10	96
04:00AM	J-104	374912	83533	2304	3	26
	J-72	373031	83631	2303	6	56
	J-75	374151	83707	2312	5	52
	J-95	375058	83423	2288	5	48
	J-7	372984	83562	2333	3	30
	J-38	374875	83271	2301	10	98
06:00AM	J-104	374912	83533	2304	2	20
	J-72	373031	83631	2303	6	56
	J-75	374151	83707	2312	5	49
	J-95	375058	83423	2288	4	43
	J-7	372984	83562	2333	3	27
	J-38	374875	83271	2301	9	87

Annex: 2.2. Water balance of the system

		Water Audit Report for:		Hosanna (1245)		
		Reporting Year:		2021	7/2018 - 6/2019	
		Data Validity Score:		60		
	Water Exported 0.000	Billed Water Exported				
-	-	Authorized Consumption	Billed Authorized Consumption	Billed Metered Consumption (water exported is removed) 1,301.581	Revenue Water 1,301.581	
-	-		1,301.581	Billed Unmetered Consumption 0.000		
Own Sources (Adjusted for known errors)	-		1,325.070	Unbilled Authorized Consumption 23.489	Unbilled Metered Consumption 0.000	Non-Revenue Water (NRW) 577.521
-	-		Unbilled Unmetered Consumption 23.489			
1,879.102	-		Apparent Losses 38.048	Unauthorized Consumption 4.698		
-	Water Supplied	Water Losses		Customer Metering Inaccuracies 30.096		
-	-			Systematic Data Handling Errors 3.254		
-	1,879.102			Real Losses 515.985	Leakage on Transmission and/or Distribution Mains Not broken down	
-	-			Leakage and Overflows at Utility's Storage Tanks Not broken down		
Water Imported	-	554.032		Leakage on Service Connections Not broken down		
-	-					
0.000	-					
-	-					
-	-					

Annex: 2.3. The system performance indicators

<u>System Attributes:</u>	
	Apparent Losses: 38.048 ML/Yr
+	Real Losses: 515.985 ML/Yr
=	Water Losses: 554.032 ML/Yr
	? Unavoidable Annual Real Losses (UARL): 206.79 ML/Yr
	Annual cost of Apparent Losses: \$10,653
	Annual cost of Real Losses: \$144,476 Valued at Customer Retail Unit Cost
	Return to Reporting Worksheet to change this assumption
<u>Performance Indicators:</u>	
Financial:	Non-revenue water as percent by volume of Water Supplied: 30.7%
	Non-revenue water as percent by cost of operating system: 27.9% Real Losses valued at Customer Retail Unit Cost
Operational Efficiency:	Apparent Losses per service connection per day: 7.72 litres/connection/day
	Real Losses per service connection per day: 104.72 litres/connection/day
	Real Losses per length of main per day*: N/A
	Real Losses per service connection per day per meter (head) pressure: 2.33 litres/connection/day/m
	From Above, Real Losses = Current Annual Real Losses (CARL): 515.98 ML/year
	? Infrastructure Leakage Index (ILI) [CARL/UARL]: 2.50

* This performance indicator applies for systems with a low service connection density of less than 20 service connections/kilometre of pipeline

Annex: 2.4. The breakdown of the production and consumption data

AWWA Free Water Audit Software: Reporting Worksheet

WAS v5.0
American Water Works Association
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Water Audit Report for: **Hosanna (1245)**
Reporting Year: **2020** | 7/2018 - 6/2019

Please enter data in the white cells below. Where available, metered values should be used; if metered values are unavailable please estimate a value. Indicate your confidence in the accuracy of the input data by grading each component (n/a or 1-10) using the drop-down list to the left of the input cell. Hover the mouse over the cell to obtain a description of the grades.

All volumes to be entered as: MEGALITRES (THOUSAND CUBIC METRES) PER YEAR

To select the correct data grading for each input, determine the highest grade where the utility meets or exceeds the criteria for that grade and all grades below it.

WATER SUPPLIED

←----- Enter grading in column 'E' and 'J' ----->

Volume from own sources:	<input type="text" value="6"/>	<input type="text" value="1,879.102"/>	ML/Yr	Point:	<input type="text" value="2"/>	Value:	<input type="text" value=""/>	ML/Yr
Water imported:	<input type="text" value="n/a"/>	<input type="text" value="0.000"/>	ML/Yr					ML/Yr
Water exported:	<input type="text" value="n/a"/>	<input type="text" value="0.000"/>	ML/Yr					ML/Yr
WATER SUPPLIED:			1,879.102					

Master Meter and Supply Error Adjustments
Enter negative % or value for under-registration
Enter positive % or value for over-registration

AUTHORIZED CONSUMPTION

Billed metered:	<input type="text" value="8"/>	<input type="text" value="1,301.581"/>	ML/Yr	Point:	<input type="text" value="1.25%"/>	Value:	<input type="text" value=""/>	ML/Yr
Billed unmetered:	<input type="text" value="n/a"/>	<input type="text" value="0.000"/>	ML/Yr					ML/Yr
Unbilled metered:	<input type="text" value="n/a"/>	<input type="text" value="0.000"/>	ML/Yr					ML/Yr
Unbilled unmetered:	<input type="text" value="2"/>	<input type="text" value="23.489"/>	ML/Yr					ML/Yr
AUTHORIZED CONSUMPTION:			1,325.070					

Default option selected for Unbilled unmetered - a grading of 5 is applied but not displayed

WATER LOSSES (Water Supplied - Authorized Consumption)

554.032 ML/Yr

Apparent Losses

Unauthorized consumption:	<input type="text" value="5"/>	<input type="text" value="4.698"/>	ML/Yr	Point:	<input type="text" value="0.25%"/>	Value:	<input type="text" value=""/>	ML/Yr
Default option selected for unauthorized consumption - a grading of 5 is applied but not displayed								
Customer metering inaccuracies:	<input type="text" value="2"/>	<input type="text" value="30.096"/>	ML/Yr					ML/Yr
Systematic data handling errors:	<input type="text" value="2"/>	<input type="text" value="3.254"/>	ML/Yr					ML/Yr
Default option selected for Systematic data handling errors - a grading of 5 is applied but not displayed								
Apparent Losses:			38.048					

Real Losses (Current Annual Real Losses or CARL)

Real Losses = Water Losses - Apparent Losses: **515.985** ML/Yr

WATER LOSSES: **554.032** ML/Yr

NON-REVENUE WATER

NON-REVENUE WATER: **577.521** ML/Yr

= Water Losses + Unbilled Metered + Unbilled Unmetered

SYSTEM DATA

Length of mains:	<input type="text" value="4"/>	<input type="text" value="99.4"/>	kilometers
Number of active AND inactive service connections:	<input type="text" value="2"/>	<input type="text" value="13,500"/>	
Service connection density:	<input type="text" value=""/>	<input type="text" value="136"/>	conn./km main

Are customer meters typically located at the curbstops or property line? (length of service line, beyond the property boundary, that is the responsibility of the utility)

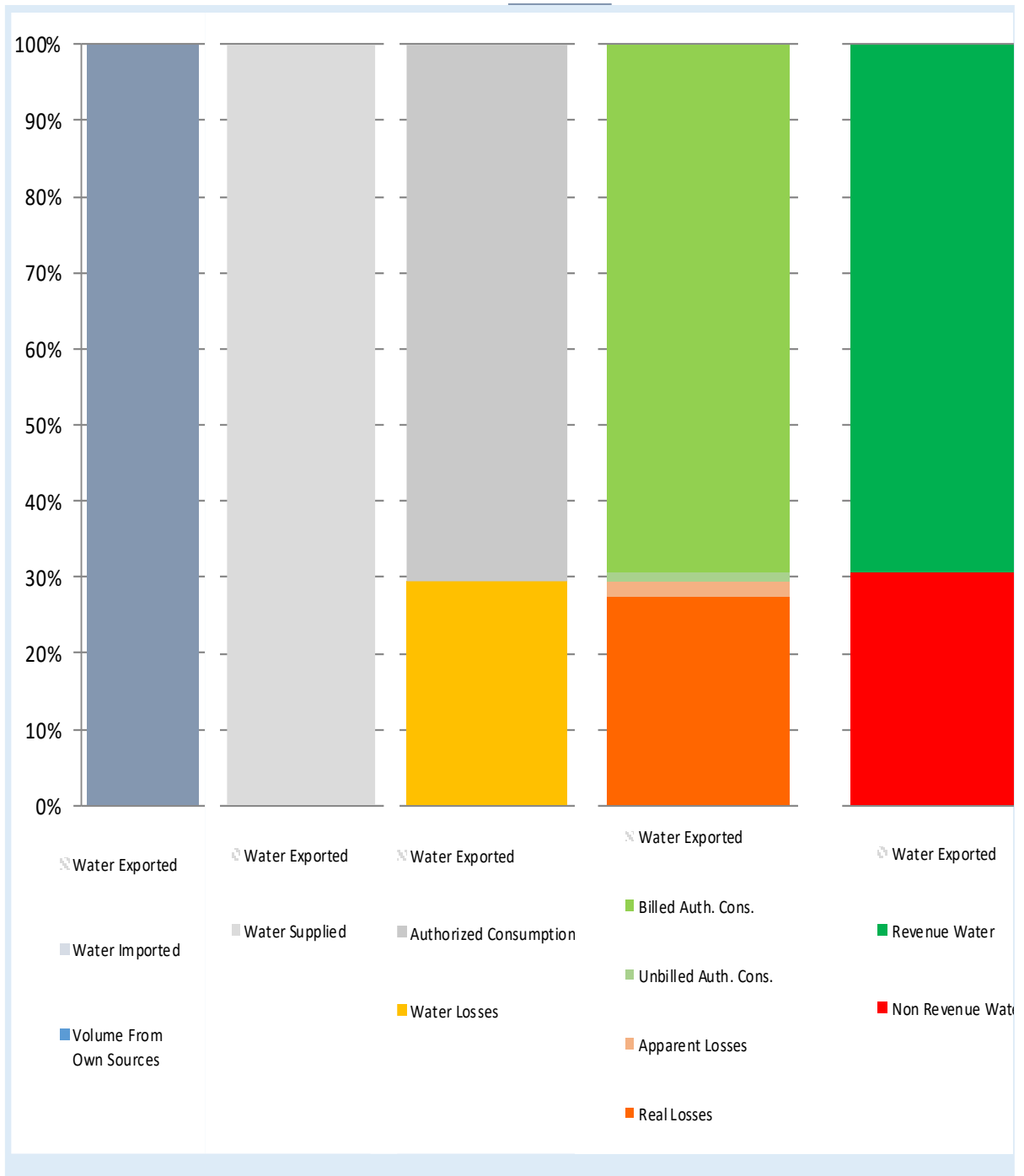
Average length of customer service line:

Average operating pressure: metres (head)

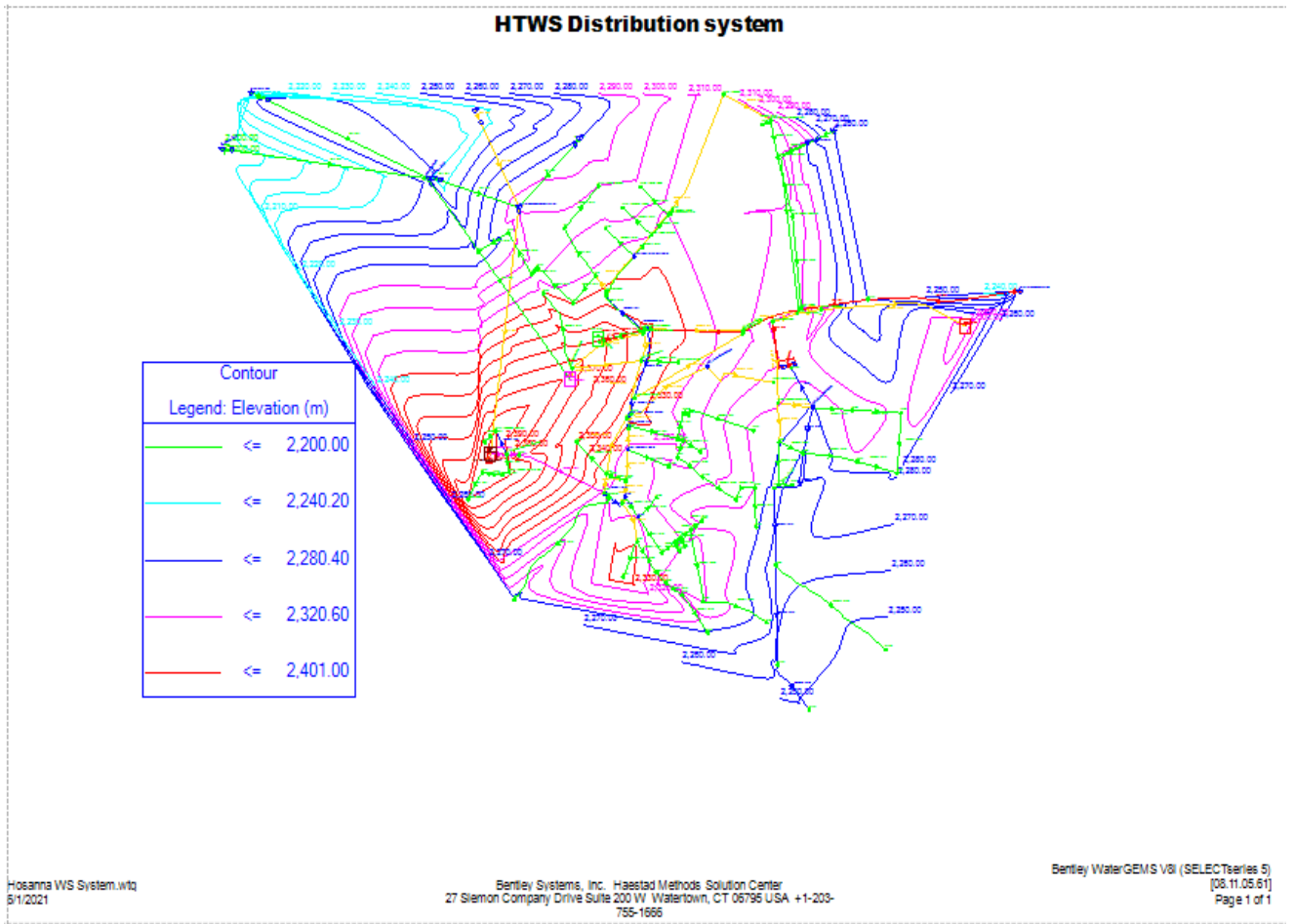
COST DATA

Total annual cost of operating water system:	<input type="text" value="4"/>	<input type="text" value="\$578,881"/>	\$/Year
Customer retail unit cost (applied to Apparent Losses):	<input type="text" value="4"/>	<input type="text" value="\$0.28"/>	\$/1000 litres
Variable production cost (applied to Real Losses):	<input type="text" value="4"/>	<input type="text" value="\$0.28"/>	\$/Megalitre <input type="checkbox"/> Use Customer Retail Unit Cost to value real losses

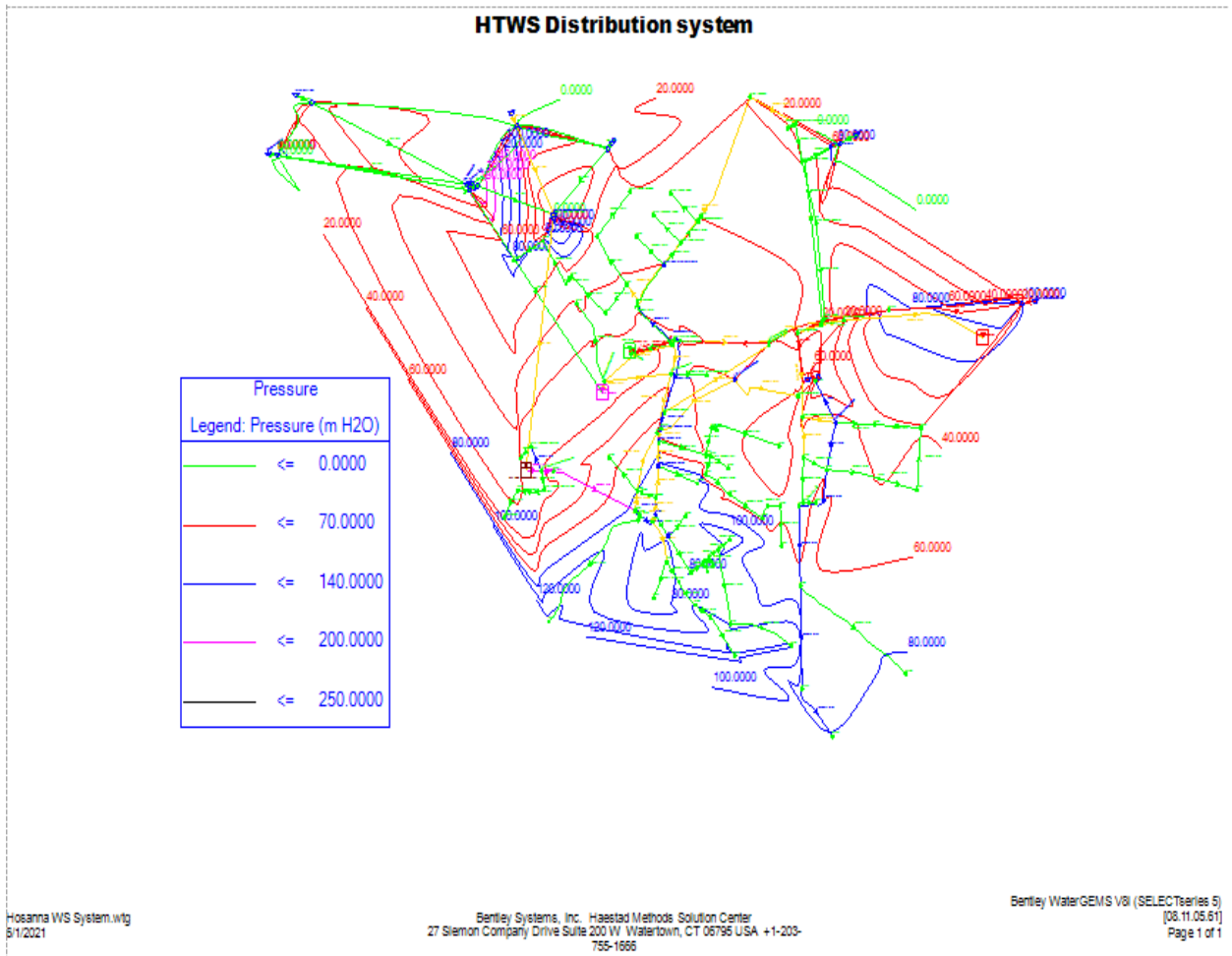
Annex: 2.5. Graphical representation water balance with bar height proportional to the volume the audit components



Annex: 2.6. Distribution layout in terms of contour



Annex: 2.7. Distribution layout in terms of pressure zone



ANNEX 3: Photograph during field visit



Figure A3: 0:1 Gulit reservoir with 2000m³ capacity



Figure A3: 0:2 Hospital reservoir with 50m³ capacity



Figure A3: 0:3 Field pressure measurement

ANNEX 4: Simulation results

Annex: 4.1. Extended Period Simulation Result of the System Pipe.

HTWS Distribution system										
ID	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C	Minor Loss Coefficient (Local)	Flow (L/s)	Velocity (m/s)	Head loss Gradient (m/m)	Length (User Defined) (m)
67	PMP-1	T-2	300	PVC	150	0	80	1.14	0.003	2,067
69	T-2	J-1	300	PVC	150	0	60	0.86	0.002	10
71	J-1	J-2	300	PVC	150	0	59	0.83	0.002	342
73	J-2	J-3	200	PVC	150	0	46	1.48	0.009	25
75	J-3	J-4	200	PVC	150	0	46	1.46	0.008	52
77	J-4	J-5	150	PVC	150	0	41	2.34	0.028	708
79	J-5	J-6	150	PVC	150	0	41	2.3	0.027	312
85	J-2	J-7	200	PVC	150	0	11	0.34	0.001	453
87	J-7	J-8	150	PVC	150	0	5	0.29	0.001	100
89	J-8	J-9	80	PVC	150	0	1	0.25	0.001	458
91	J-9	J-10	75	PVC	150	0	1	0.14	0	450
93	J-8	J-11	100	PVC	150	0	3	0.4	0.002	280
95	J-11	J-12	100	PVC	150	0	3	0.32	0.001	400
97	J-12	J-13	100	PVC	150	0	2	0.24	0.001	75
99	J-13	J-14	100	PVC	150	0	1	0.16	0	380
101	J-14	J-15	100	PVC	150	0	1	0.08	0	300
115	R-3	PMP-3	63	Galvanized iron	120	0	-9	2.88	0.172	700
117	R-3	PMP-2	150	Galvanized iron	120	0	-10	0.55	0.003	700
123	T-1	J-16	250	PVC	150	0	27	0.54	0.001	100
125	J-16	J-17	200	PVC	150	0	1	0.04	0	205

127	J-17	J-18	80	PVC	150	0	1	0.13	0	128
129	J-16	J-19	100	PVC	150	0	3	0.32	0.001	140
131	J-19	J-20	100	PVC	150	0	2	0.24	0.001	140
133	J-20	J-21	100	PVC	150	0	1	0.16	0	100
135	J-21	J-22	80	PVC	150	0	1	0.13	0	250
137	J-16	J-23	250	PVC	150	0	22	0.45	0.001	100
139	J-23	J-24	250	PVC	150	0	22	0.44	0.001	780
143	J-25	J-26	150	PVC	150	0	4	0.22	0	338
145	J-26	J-27	100	PVC	150	0	1	0.08	0	303
147	J-26	J-28	100	PVC	150	0	3	0.32	0.001	182
149	J-28	J-29	100	PVC	150	0	2	0.24	0.001	229
151	J-29	J-30	80	PVC	150	0	1	0.25	0.001	165
153	J-30	J-31	63	PVC	150	0	1	0.2	0.001	370
155	J-25	J-32	150	PVC	150	0	13	0.71	0.003	60
157	J-32	J-33	100	PVC	150	0	8	0.97	0.009	212
159	J-33	J-34	100	PVC	150	0	6	0.73	0.005	346
161	J-34	J-35	80	PVC	150	0	5	1.01	0.012	135
163	J-35	J-36	80	PVC	150	0	4	0.76	0.007	60
165	J-36	J-37	80	PVC	150	0	3	0.51	0.003	107
167	J-37	J-38	80	PVC	150	0	1	0.25	0.001	576
169	J-38	J-39	80	PVC	150	0	1	0.13	0	576
171	J-36	J-40	50	PVC	150	0	1	0.32	0.003	71
173	J-35	J-41	50	PVC	150	0	1	0.32	0.003	80
175	J-33	J-42	100	PVC	150	0	1	0.08	0	348
177	J-32	J-43	150	PVC	150	0	4	0.21	0	125
179	J-43	J-44	50	PVC	150	0	1	0.32	0.003	156
181	J-43	J-45	150	PVC	150	0	3	0.14	0	250
185	J-46	J-47	80	PVC	150	0	7	1.39	0.022	428
187	J-47	J-48	80	PVC	150	0	2	0.38	0.002	200

189	J-48	J-49	80	PVC	150	0	1	0.25	0.001	50
191	J-49	J-50	50	PVC	150	0	1	0.32	0.003	630
193	J-47	J-51	75	PVC	150	0	4	1.01	0.013	50
195	J-51	J-52	75	PVC	150	0	1	0.14	0	180
197	J-51	J-53	63	Galvanized iron	120	0	3	1.02	0.025	142
201	J-54	J-55	50	PVC	150	0	1	0.65	0.009	220
203	J-55	J-56	50	PVC	150	0	1	0.32	0.003	300
205	J-37	J-57	80	PVC	150	0	1	0.13	0	120
207	J-24	J-58	150	PVC	150	0	2	0.11	0	150
209	J-58	J-59	50	PVC	150	0	1	0.32	0.003	358
212	J-60	J-46	150	PVC	150	0	8	0.47	0.001	14
214	J-61	J-60	150	PVC	150	0	9	0.54	0.002	440
216	J-62	J-61	150	PVC	150	0	0	0.01	0	232
224	J-62	J-63	80	PVC	150	0	6	1.26	0.019	21
226	J-63	J-64	50	PVC	150	0	1	0.32	0.003	365
228	J-62	J-65	150	PVC	150	0	-7	0.4	0.001	670
229	T-3	J-65	150	PVC	150	1	19	1.07	0.008	58
231	J-65	J-66	90	Ductile Iron	130	0	1	0.1	0	661
233	J-63	J-67	80	PVC	150	0	5	1.01	0.012	827
235	J-67	J-68	50	PVC	150	0	1	0.32	0.003	325
237	J-67	J-69	80	PVC	150	0	3	0.63	0.005	224
239	J-69	J-70	50	PVC	150	0	1	0.32	0.003	325
241	J-69	J-71	50	PVC	150	0	2	0.97	0.02	215
243	J-71	J-72	50	PVC	150	0	1	0.32	0.003	325
245	J-71	J-73	50	PVC	150	0	1	0.32	0.003	60
247	J-7	J-74	150	PVC	150	0	5	0.29	0.001	1,860
249	J-74	J-75	150	PVC	150	0	4	0.25	0	450
251	J-75	J-76	100	PVC	150	0	1	0.08	0	75

253	J-75	J-77	100	PVC	150	0	3	0.4	0.002	300
255	J-77	J-78	63	PVC	150	0	1	0.4	0.003	275
259	J-77	J-79	100	PVC	150	0	1	0.16	0	485
261	J-79	J-80	63	PVC	150	0	1	0.2	0.001	727
266	J-81	J-82	150	PVC	150	0	1	0.04	0	749
268	J-61	J-83	50	PVC	150	0	1	0.32	0.003	313
273	J-24	J-85	200	PVC	150	0	19	0.6	0.002	52
274	J-85	J-25	200	PVC	150	0	17	0.54	0.001	150
276	J-85	J-86	100	PVC	150	0	1	0.16	0	44
278	J-86	J-87	100	PVC	150	0	1	0.08	0	1,169
280	J-6	J-88	150	PVC	150	0	11	0.61	0.002	650
282	J-88	J-89	150	PVC	150	0	3	0.16	0	312
284	J-89	J-90	80	PVC	150	0	1	0.25	0.001	600
286	J-90	J-91	80	PVC	150	0	1	0.13	0	110
288	J-89	J-92	80	PVC	150	0	1	0.2	0.001	500
290	J-92	J-93	200	PVC	150	0	-4	0.14	0	300
291	J-93	J-88	150	PVC	150	0	-7	0.41	0.001	300
295	J-93	J-94	63	PVC	150	0	1	0.36	0.002	339
297	J-94	J-95	63	PVC	150	0	0	0.16	0.001	415
299	J-95	J-96	63	PVC	150	0	0	0.05	0	476
301	J-96	J-97	63	PVC	150	0	-1	0.25	0.001	350
302	J-97	J-92	80	PVC	150	0	-1	0.28	0.001	469
304	J-92	J-98	200	PVC	150	0	3	0.1	0	470
306	J-98	J-99	200	PVC	150	0	3	0.08	0	600
308	J-99	J-100	200	PVC	150	0	1	0.04	0	780
310	J-100	J-101	200	PVC	150	0	1	0.02	0	470
312	J-99	J-102	75	PVC	150	0	1	0.14	0	1,156
314	J-6	J-103	150	PVC	150	0	29	1.66	0.015	200

317	J-103	J-104	150	PVC	150	0	29	1.62	0.014	200
329	J-4	J-105	200	PVC	150	0	4	0.12	0	500
333	J-105	J-84	150	PVC	150	0	1	0.04	0	1,050
364	BH5	PMP-7	100	PVC	150	0	17	2.16	0.039	158
368	J-107	R-1	300	Galvanized iron	120	0	112	1.58	0.009	687
369	PMP-7	J-107	100	PVC	150	0	17	2.16	0.039	1,550
374	J-53	J-108	63	Galvanized iron	120	0	3	0.82	0.017	265
375	J-108	J-54	50	PVC	150	0	2	0.97	0.02	340
377	J-45	J-109	50	PVC	150	0	1	0.32	0.003	371
378	BH1	PMP-10	100	PVC	150	0	10	1.25	0.014	60
379	PMP-10	R-3	100	PVC	150	0	10	1.25	0.014	698
380	BH2	PMP-2	150	PVC	150	0	10	0.55	0.002	100
381	BH3	PMP-3	63	Galvanized iron	120	0	9	2.88	0.172	50
382	R-2	PMP-5	100	PVC	150	0	13	1.63	0.023	25
383	BH4	PMP-4	100	PVC	150	0	13	1.65	0.024	150
384	PMP-4	R-2	100	Galvanized iron	120	0	13	1.65	0.036	1,500
385	BH 6	PMP-6	100	PVC	150	0	11	1.46	0.019	80
386	PMP-6	R-2	100	PVC	150	0	11	1.46	0.019	1,700
388	PMP-5	T-3	100	PVC	150	0	13	1.63	0.023	1,950
390	J-107	J-110	300	Galvanized iron	120	0	-95	1.35	0.007	45,000
394	J-104	T-4 WCU	150	PVC	150	0	28	1.59	0.014	1,275
402	J-110	PMP-9	300	Galvanized iron	120	0	-96	1.36	0.007	45
404	PMP-9	R-18	300	Galvanized iron	120	0	-96	1.36	0.007	100
405	J-65	J-61	150	PVC	150	0.28	11	0.6	0.002	315
407	R-3	PMP-8	150	Galvanized iron	120	0	26	1.49	0.018	20
408	PMP-8	T-1	150	Galvanized iron	120	0	26	1.49	0.018	1,928
420	R-1	PMP-1	300	Ductile Iron	130	0	80	1.14	0.004	15
422	J-93	J-106	200	PVC	150	0	1	0.02	0	500
431	J-58	J-111	150	PVC	150	0	1	0.04	0	514

433	J-45	J-112	150	PVC	150	0	1	0.04	0	245
436	J-105	J-113	200	PVC	150	0	3	0.08	0	100
437	J-113	J-81	150	PVC	150	0	2	0.11	0	774

Annex: 4.2. Extended period simulation result of the system junction

ID	Label	Elevation (m)	Zone	Demand Collection	Demand (L/s)	Hydraulic Grade (m)	Pressure (m H2O)	Pressure Head (m)
68	J-1	2,359.00	Zone - 3	<Collection: 1 items>	2	2,359.66	0.66	0.66
70	J-2	2,344.00	Zone - 3	<Collection: 1 items>	2	2,359.03	15.00	15.03
72	J-3	2,343.00	Zone - 3	<Collection: 1 items>	1	2,358.82	15.78	15.82
74	J-4	2,341.00	Zone - 3	<Collection: 1 items>	1	2,358.38	17.35	17.38
76	J-5	2,311.00	Zone - 3	<Collection: 1 items>	1	2,338.47	27.41	27.47
78	J-6	2,298.00	Zone - 3	<Collection: 1 items>	1	2,329.94	31.87	31.94
84	J-7	2,333.00	Zone - 3	<Collection: 1 items>	1	2,358.77	25.72	25.77
86	J-8	2,322.00	Zone - 3	<Collection: 1 items>	1	2,358.71	36.64	36.71
88	J-9	2,306.00	Zone - 3	<Collection: 1 items>	1	2,358.30	52.20	52.30
90	J-10	2,300.00	Zone - 3	<Collection: 1 items>	1	2,358.16	58.04	58.16
92	J-11	2,329.00	Zone - 3	<Collection: 1 items>	1	2,358.22	29.17	29.22
94	J-12	2,308.00	Zone - 3	<Collection: 1 items>	1	2,357.76	49.66	49.76
96	J-13	2,309.00	Zone - 3	<Collection: 1 items>	1	2,357.71	48.61	48.71
98	J-14	2,282.00	Zone - 3	<Collection: 1 items>	1	2,357.59	75.44	75.59
100	J-15	2,273.00	Zone - 3	<Collection: 1 items>	1	2,357.56	84.39	84.56
154	J-32	2,318.00	Zone - 3	<Collection: 2 items>	1	2,403.03	84.85	85.03
156	J-33	2,319.00	Zone - 3	<Collection: 2 items>	1	2,401.16	82.00	82.16
158	J-34	2,320.00	Zone - 3	<Collection: 1 items>	1	2,399.36	79.20	79.36
160	J-35	2,313.00	Zone - 3	<Collection: 1 items>	1	2,397.68	84.51	84.68
162	J-36	2,310.00	Zone - 3	<Collection: 1 items>	1	2,397.24	87.07	87.24
164	J-37	2,306.00	Zone - 3	<Collection: 1 items>	1	2,396.87	90.69	90.87

166	J-38	2,301.00	Zone - 3	<Collection: 1 items>	1	2,396.32	95.13	95.32
168	J-39	2,274.00	Zone - 3	<Collection: 1 items>	1	2,396.17	121.92	122.17
170	J-40	2,305.00	Zone - 3	<Collection: 1 items>	1	2,397.06	91.87	92.06
172	J-41	2,309.00	Zone - 3	<Collection: 1 items>	1	2,397.47	88.29	88.47
174	J-42	2,307.00	Zone - 3	<Collection: 1 items>	1	2,401.13	93.94	94.13
176	J-43	2,316.00	Zone - 3	<Collection: 1 items>	1	2,402.98	86.81	86.98
178	J-44	2,322.00	Zone - 3	<Collection: 1 items>	1	2,402.58	80.42	80.58
180	J-45	2,317.00	Zone - 3	<Collection: 2 items>	1	2,402.94	85.77	85.94
182	J-46	2,331.00	Zone - 3	<Collection: 2 items>	1	2,374.23	43.14	43.23
184	J-47	2,323.00	Zone - 3	<Collection: 1 items>	1	2,364.66	41.57	41.66
186	J-48	2,316.00	Zone - 3	<Collection: 1 items>	1	2,364.25	48.16	48.25
188	J-49	2,316.00	Zone - 3	<Collection: 1 items>	1	2,364.21	48.11	48.21
190	J-50	2,287.00	Zone - 3	<Collection: 1 items>	1	2,362.57	75.42	75.57
192	J-51	2,321.00	Zone - 3	<Collection: 1 items>	1	2,363.99	42.91	42.99
194	J-52	2,313.00	Zone - 3	<Collection: 1 items>	1	2,363.93	50.83	50.93
196	J-53	2,318.00	Zone - 3	<Collection: 1 items>	1	2,360.42	42.34	42.42
198	J-54	2,293.00	Zone - 3	<Collection: 1 items>	1	2,349.25	56.14	56.25
200	J-55	2,290.00	Zone - 3	<Collection: 1 items>	1	2,347.19	57.07	57.19
202	J-56	2,282.00	Zone - 3	<Collection: 1 items>	1	2,346.41	64.28	64.41
204	J-57	2,284.00	Zone - 3	<Collection: 1 items>	1	2,396.84	112.61	112.84
210	J-60	2,335.00	Zone - 3	<Collection: 2 items>	1	2,374.25	39.17	39.25
232	J-67	2,325.00	Zone - 3	<Collection: 2 items>	1	2,364.55	39.47	39.55
234	J-68	2,313.00	Zone - 3	<Collection: 1 items>	1	2,363.70	50.60	50.70
236	J-69	2,320.00	Zone - 3	<Collection: 1 items>	1	2,363.38	43.29	43.38
238	J-70	2,304.00	Zone - 3	<Collection: 1 items>	1	2,362.54	58.42	58.54
240	J-71	2,320.00	Zone - 3	<Collection: 1 items>	1	2,359.10	39.02	39.10
242	J-72	2,303.00	Zone - 3	<Collection: 1 items>	1	2,358.26	55.15	55.26
244	J-73	2,313.00	Zone - 3	<Collection: 1 items>	1	2,358.95	45.85	45.95
263	J-81	2,318.00	Zone - 3	<Collection: 2 items>	1	2,358.27	40.18	40.27

265	J-82	2,296.00	Zone - 3	<Collection: 1 items>	1	2,358.26	62.13	62.26
270	J-84	2,314.00	Zone - 3	<Collection: 1 items>	1	2,358.33	44.24	44.33
279	J-88	2,291.00	Zone - 3	<Collection: 1 items>	1	2,328.42	37.35	37.42
281	J-89	2,281.00	Zone - 3	<Collection: 1 items>	1	2,328.36	47.27	47.36
283	J-90	2,275.00	Zone - 3	<Collection: 1 items>	1	2,327.79	52.68	52.79
285	J-91	2,265.00	Zone - 3	<Collection: 1 items>	1	2,327.76	62.63	62.76
287	J-92	2,269.00	Zone - 3	<Collection: 1 items>	1	2,328.06	58.94	59.06
289	J-93	2,279.00	Zone - 3	<Collection: 2 items>	1	2,328.09	48.99	49.09
294	J-94	2,295.00	Zone - 3	<Collection: 1 items>	1	2,327.27	32.20	32.27
296	J-95	2,288.00	Zone - 3	<Collection: 1 items>	1	2,327.05	38.97	39.05
298	J-96	2,281.00	Zone - 3	<Collection: 1 items>	1	2,327.08	45.99	46.08
300	J-97	2,289.00	Zone - 3	<Collection: 1 items>	1	2,327.51	38.44	38.51
303	J-98	2,275.00	Zone - 3	<Collection: 1 items>	1	2,328.03	52.92	53.03
305	J-99	2,265.00	Zone - 3	<Collection: 1 items>	1	2,328.01	62.88	63.01
307	J-100	2,258.00	Zone - 3	<Collection: 1 items>	1	2,328.00	69.86	70.00
309	J-101	2,247.00	Zone - 3	<Collection: 1 items>	1	2,328.00	80.83	81.00
311	J-102	2,243.00	Zone - 3	<Collection: 1 items>	1	2,327.59	84.42	84.59
313	J-103	2,292.00	Zone - 3	<Collection: 1 items>	1	2,326.97	34.90	34.97
316	J-104	2,304.00	Zone - 3	<Collection: 1 items>	1	2,324.11	20.07	20.11
328	J-105	2,336.00	Zone - 3	<Collection: 1 items>	1	2,358.34	22.29	22.34
366	J-107	2,294.00	Zone - 3	<Collection: 1 items>	1	2,304.27	5.59	5.60
373	J-108	2,304.00	Zone - 3	<Collection: 1 items>	1	2,356.02	51.91	52.02
376	J-109	2,306.00	Zone - 3	<Collection: 1 items>	1	2,401.98	95.79	95.98
389	J-110	2,260.00	Zone - 3	<Collection: 1 items>	1	2,610.66	92.19	92.37
435	J-113	2,335.00	Zone - 3	<Collection: 1 items>	1	2,358.34	23.29	23.34
213	J-61	2,343.00	Zone - 2	<Collection: 1 items>	1	2,375.06	31.99	32.06
215	J-62	2,344.00	Zone - 2	<Collection: 1 items>	1	2,375.06	30.99	31.06
223	J-63	2,344.00	Zone - 2	<Collection: 1 items>	1	2,374.67	30.61	30.67
225	J-64	2,361.00	Zone - 2	<Collection: 1 items>	1	2,373.72	12.69	12.72

227	J-65	2,375.00	Zone - 2	<Collection: 1 items>	1	2,375.78	0.77	0.78
230	J-66	2,331.00	Zone - 2	<Collection: 1 items>	1	2,375.65	44.56	44.65
246	J-74	2,318.00	Zone - 2	<Collection: 1 items>	1	2,357.71	39.63	39.71
248	J-75	2,313.00	Zone - 2	<Collection: 1 items>	1	2,357.51	44.42	44.51
250	J-76	2,319.00	Zone - 2	<Collection: 1 items>	1	2,357.50	38.42	38.50
252	J-77	2,317.00	Zone - 2	<Collection: 1 items>	1	2,356.99	39.91	39.99
254	J-78	2,300.00	Zone - 2	<Collection: 2 items>	1	2,356.20	56.08	56.20
258	J-79	2,308.00	Zone - 2	<Collection: 1 items>	1	2,356.84	48.74	48.84
260	J-80	2,301.00	Zone - 2	<Collection: 1 items>	1	2,356.22	55.11	55.22
267	J-83	2,326.00	Zone - 2	<Collection: 1 items>	1	2,374.24	48.15	48.24
421	J-106	2,297.00	Zone - 2	<Collection: 1 items>	1	2,328.09	31.03	31.09
122	J-16	2,392.00	Zone - 1	<Collection: 1 items>	1	2,404.12	12.09	12.12
124	J-17	2,400.00	Zone - 1	<Collection: 1 items>	1	2,404.11	4.11	4.11
126	J-18	2,396.00	Zone - 1	<Collection: 1 items>	1	2,404.08	8.06	8.08
128	J-19	2,393.00	Zone - 1	<Collection: 1 items>	1	2,403.95	10.93	10.95
130	J-20	2,395.00	Zone - 1	<Collection: 1 items>	1	2,403.86	8.84	8.86
132	J-21	2,396.00	Zone - 1	<Collection: 1 items>	1	2,403.83	7.81	7.83
134	J-22	2,390.00	Zone - 1	<Collection: 1 items>	1	2,403.76	13.73	13.76
136	J-23	2,375.00	Zone - 1	<Collection: 1 items>	1	2,404.04	28.98	29.04
138	J-24	2,318.00	Zone - 1	<Collection: 1 items>	1	2,403.50	85.33	85.50
140	J-25	2,320.00	Zone - 1	<Collection: 1 items>	1	2,403.21	83.05	83.21
142	J-26	2,329.00	Zone - 1	<Collection: 1 items>	1	2,403.10	73.95	74.10
144	J-27	2,338.00	Zone - 1	<Collection: 1 items>	1	2,403.07	64.94	65.07
146	J-28	2,320.00	Zone - 1	<Collection: 1 items>	1	2,402.89	82.72	82.89
148	J-29	2,304.00	Zone - 1	<Collection: 1 items>	1	2,402.73	98.53	98.73
150	J-30	2,288.00	Zone - 1	<Collection: 1 items>	1	2,402.57	114.34	114.57
152	J-31	2,279.00	Zone - 1	<Collection: 1 items>	1	2,402.26	123.01	123.26
206	J-58	2,323.00	Zone - 1	<Collection: 1 items>	1	2,403.49	80.32	80.49
208	J-59	2,351.00	Zone - 1	<Collection: 1 items>	1	2,402.55	51.45	51.55

272	J-85	2,318.00	Zone - 1	<Collection: 1 items>	1	2,403.41	85.24	85.41
275	J-86	2,314.00	Zone - 1	<Collection: 1 items>	1	2,403.40	89.22	89.40
277	J-87	2,277.00	Zone - 1	<Collection: 1 items>	1	2,403.30	126.04	126.30
430	J-111	2,335.00	Zone - 1	<Collection: 1 items>	1	2,403.48	68.34	68.48
432	J-112	2,328.00	Zone - 1	<Collection: 1 items>	1	2,402.94	74.79	74.94