UNIVERSITY OF ZIMBABWE

Faculty of Engineering

Department of Civil Engineering

OPTIMIZATION OF NON REVENUE WATER MANAGEMENT FOR LIVINGSTONE TOWN-ZAMBIA: A CASE STUDY OF LIZUMA WARD

By

GOODSON MASHEKA

A thesis submitted in partial fulfilment of the requirements of the Degree of Master of Science in Integrated Water Resources Management

July, 2016

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In collaboration with

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MANAGEMENT FOR LIVINGSTONE TOWN-ZAMBIA:

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A thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Integrated Water Resources Management at the University of Zimbabwe

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Eng. Z. Hoko (University of Zimbabwe)

Dr E. Nyirenda (University of Zambia)

July, 2016

DECLARATION

I, **Goodson Masheka,** declare that this research report is my own work. It is being submitted for the degree of Master of Science in Integrated Water Resources Management (IWRM) at the University of Zimbabwe. It has never been submitted before for examination for any degree in any other University.

Signature: ____________________

Date: ________________________

DEDICATION

To my wife, Theresa, my daughters Mapesho and Taongo for enduring my long absence with strength.

To my Father, Simon Masheka, my Mother Beatrice Masheka and my sisters and brother for your encouragement and prayers during my study. Thank you for the support that has enabled me to be where I am today.

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LIST OF ABBREVIATIONS AND ACRONYMS

AZP	Average Zone Pressure
CARL	Current Annual Real Losses
CSO	Central Statistical Office (Zambia)
DMA	District Metered Area
ECONOLEAK	Economic Model for Leakage Management for Water Suppliers in South Africa
EPANET	Environmental Protection Agency Water Supply Model
ILI	Infrastructure Leakage Index
ISO	International Organization for Standardization
IWA	International Water Association
MNF	Minimum Night Flow
NRW	Non-Revenue Water
PRESMAC	Pressure Management Programme
RL	Real Losses
SADC	Southern Africa Development community
SANFLOW	South African Night Flow Analysis Software
SWSC	Southern Water and Sewerage Company Limited
SIDA	Swedish International Development Agency
TAPL	Total Apparent Losses
UARL	Unavoidable Annual Real Losses
WBI	World Bank Institute
WHO	World Health Organization
ZDA	Zambia Development Agency
ZNTB	Zambia National Tourism Board

ABSTRACT

Livingstone Town has a water supply service coverage of 81 % and has been experiencing a high Non-Revenue Water (NRW) which stands at 43 % compared to the recommended value of 23 % suggested for developing countries. The high NRW poses a threat to the sustainability of service provision as more resources are used compared to the revenue generated. Despite the town having a water audit team in place, high non-revenue water is still a challenge. It is from this background that a study was carried out in Livingstone Town in the period from December 2015 to March 2016. The objective was to determine the trends of NRW from 2008 to 2015, establish factors contributing to NRW and estimate real losses using a hydraulic model (EPANET). The study focused on Lizuma Ward. Historical data maintained by the water utility on volume of water supplied and billed from 2008 to 2015 was analysed to determine the NRW trends for Livingstone Town. Determination of billing and meter errors was done through an independent meter reading exercise and meter testing respectively in Lizuma Ward. The results showed that yearly minimum and maximum NRW for Livingstone Town from 2008 to 2015 was 43 % and 49 % respectively with an average of 45 %. The minimum and maximum NRW for Lizuma Ward was 62 % and 68 % respectively with an average of 65 % of which 85 % were real losses and 15 % were apparent losses. Statistical analysis performed on the NRW for the eight year period gave a coefficient of variation of 0.04 which showed low variability of NRW from year to year. The Mann-Kendall trend tests indicated that there was no distinctive trend observed for NRW during the period under investigation as the computed p-value (0.898) was greater than significant level (0.05). The study also established that apparent losses included under billing (18 %), over registering of meters by 3.1 % and unauthorized consumption (85.1 %). Unauthorized consumption was deduced from total apparent losses, billing and meter errors. The accuracy of EPANET for estimating real losses was determined by performing a t-test on simulated and measured inflow to the ward. The test gave a p-value of 0.852 suggesting that there was no significant difference in the means. The t-tests was also performed on the simulated and measured pressure on five different location in Lizuma Ward distribution network which gave p-values of 0.842, 0.18, 0.131, 0.247 and 0.66 which were higher than significant level (0.05). Therefore there was no difference in the means of simulated and measured pressure hence suggesting that EPANET could be used to estimate real losses. The study concluded that there was no distinctive pattern observed for NRW trend. The main contributing factor to NRW were the real losses (85 %) while the unauthorized consumption (85%) was the major contributing factor to apparent water losses. EPANET can be used to estimate real losses. The study recommends that Southern Water and Sewerage Company should consider using EPANET in estimating the real losses, replace old pipes and water audit team should investigate unauthorized consumption.

Keywords: Apparent water losses; EPANET; Lizuma Ward; non-revenue water; real losses; unauthorized consumption.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Water in adequate quantity plays a fundamental role in the health, hygiene and welfare of communities (Kamani *et al.*, 2012). The demand for water is increasing day by day in most parts of the world due to increase in population, urbanization, agricultural activities and industrialization (Mathur and Vijay, 2013). The increase in water demand coupled with Non-Revenue Water (NRW) is causing a challenge in meeting water demands for all competing uses for water utilities (Kamani *et al.*, 2012). Water resources are under stress due to growing population and climate change making a shift towards the implementation of non-revenue water reduction strategies in most countries worldwide (Kanakoudis and Muhammetoglu, 2014). It is expected that by 2030, 47 % of the world population will live in regions with severe water stress (González-gómez *et al.*, 2015). About 1.6 million children under the age of five years die every year due to contamination caused by the intermittent water throughout the world (WHO, 2003; UNICEF/WHO, 2006). Al-omari (2013), stated that reduction of NRW is one of the management tools in adapting to climate change in areas where the NRW is very high. The development and implementation of effective non-revenue water reduction strategies is very important for water utilities in meeting the water demand (Souza and Costa, 2014). According to predictions done by the Organisation for Economic Co-operation and Development (OECD) in 2008, the world water usage will rise from 4,085 km^3 as at 2000 to 6,275 km^3 in 2050 (González-gómez *et al.*, 2015).

Water loss occurs in all water networks, but the volume of water loss varies, depending on the characteristics of the pipe network and other local factors (WHO, 2001). Non-revenue water is defined as the difference between net water inputs in the distribution system and billed authorized consumption. A typical range for NRW in Europe is between 7 % – 30 % while in most of developing countries this is generally high ranging from 20 % - 90 % with Lagos, Nigeria having the highest NRW at 90 % (Jayaramu and Kumar, 2014). According to studies carried out by Al-omari (2013), NRW was estimated at 15 % of the system input volume in developed countries while for developing countries it was about 35 %. Globally, the total cost to water utilities caused by NRW can be conservatively estimated at US$141 billion per year, with a third of it occurring in the developed world (Kingdom *et al.*, 2006). Kanakoudis *et al.* (2015) stated that globally, one-third of the total water volume abstracted from the water resources and used as drinking water is lost in the distribution networks due to pipe leaks and bursts.

According to Kanakoudis *et al.* (2015), about 30 x 10^6 m^3/d of water globally delivered to the customer is not invoiced due to water theft, corruption by the employees and lack of metering. Most developing countries face challenges in the management of the non-revenue water because of lack of good NRW management strategies (Mathur and Vijay, 2013). Water supply in most of the African cities is unsatisfactory due to high water losses and inefficiencies in the management system (Sharma and Vairavamoorthy, 2015). High NRW increases the operation and maintenance costs and low revenue collection affect the financial viability of water utilities in Africa (Dighade *et al.*, 2015).

Zambia is a developing country located in the Southern part of Africa and its capital city is Lusaka. There are eleven water utility companies in Zambia mandated to supply water in the country (NWASCO, 2014). According to NWASCO (2015), the NRW in Zambia ranges from 32 % - 71 %. There is limited understanding on the management of NRW in most of the water utilities in Zambia which has caused an increase in the NRW (Nyirenda, 2015).

Southern Water and Sewerage Company Limited (SWSC) is a utility company which provide water and sewerage services to Livingstone Town and the rest of 20 towns in Southern Province. SWSC's average NRW is estimated at 35 % while for the Livingstone Town only, which makes up half of the company's customer base, NRW is at 43 % (NWASCO, 2015). The total number of water connections in Livingstone is approximately 21,210 and the service coverage is at 81 % (SWSC, 2015). The high NRW means that almost half of the water produced is not billed, hence posing a threat to the sustainability of the service provision as more resources are used in production process compared to the revenue generated.

1.2 Problem Statement

Livingstone Town has been experiencing a high NRW which stands at 43 % compared to the recommended value of 23 % suggested by Tyanan and Kingdom (2002). This has contributed to SWSC not to meet the current water demand (SWSC, 2014). Despite the town having a water audit team in place, high non-revenue water is still a challenge (SWSC, 2014). Sharma and Vairavamoorthy (2015) stated that water supply in the African cities is unsatisfactory due to high water losses and inefficiencies in the management system. A crude figure of NRW is normally reported by most of African utilities hence there is no proper reduction strategies planned for NRW (Kingdom *et al.*, 2006). Mutikanga *et al.* (2011a) stated that in the absence of adequate data and a proper methodology, most developing countries use default values or rules of thumb in determining components of NRW. They use 0.5 % of the total system input for computing unauthorized consumption and 2 % of metered consumption for computing meter under registration which does not give the true picture for component computation of apparent losses. Motiee *et al.* (2006) stated that it is so expensive to measure real losses in large distribution network. It is therefore more practical and economical to utilize modelling in estimating losses in water distribution system. According to Dighade *et al*. (2015) reduction of NRW can only be achieved once real and apparent losses are quantified. It is from this background that a study was carried out using a hydraulic model in estimating real losses and to partition NRW into various components. This will help to target investment to specific areas in Livingstone Town, thereby reducing NRW to acceptable levels.

1.3 Justification

The average NRW for Livingstone Town stands at 43 % (2015) which is high compared to the recommended values of 23 % suggested by Tyanan and Kingdom (2002) and 20 % for good performing water utility company in Africa (Mugabi *et al.*, 2007). The National Water and Sanitation Council of Zambia (NWASCO) has set a benchmark of 25 % for the well performing utility in Zambia (NWASCO, 2015). Makaya and Hensel (2014) indicated that high NRW may lead to low levels of service efficiency resulting in the increase of cost of water abstraction, treatment and distribution. The high NRW in Livingstone Town is contributing to the high operating cost for the company. Livingstone Town in the year 2014 accounted for about 62 % of total cost of electricity for the entire company as more water was treated compared to the actual demand due to the water losses (SWSC, 2014).

Due to high NRW which has resulted in high operation cost in Livingstone Town, service coverage is at 81 % as there is no new investment in newly opened up areas thereby affecting the financial variability of SWSC (SWSC, 2015). This can therefore affect the tourism potential for Livingstone Town. According to Kingdom *et al*. (2006), no proper NRW management can be planned without the quantification of real and apparent losses. Breaking down non-revenue water into various components may assist the water utility to improve knowledge and documentation of the distribution system including problem and risk areas. This helps in setting up realistic targets for reduction of NRW (Liemberger, 2002). The use of a hydraulic model in estimating leakage and the partitioning of NRW into various components will help to better understand what happens to the water after leaving the plant. Hydraulic models are also economical and accurate in estimating the water losses in the water networks as they are less costly and reliable when compared to other methods of determining losses in the distribution network.

1.4 Main Objective

The main objective of the study was to investigate suitability of using EPANET in estimating leakages, and opportunities for optimizing non-revenue water management for Livingstone Town, Zambia.

1.4.1 Specific Objectives

In order to achieve the main objective of the study, the following specific objectives were considered;

1. To establish the historical trends of NRW for Livingstone Town from 2008 to 2015.
2. To determine the physical losses through the use of hydraulic simulation model (EPANET) particularly for Lizuma ward.
3. To partition NRW into various components in order to identify specific areas that need optimization in Lizuma Ward.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Global perspective of Non-Revenue Water

Water loss is considered as a global problem and major issue in water resource management that requires a solid and effective management strategy (Alkasseh *et al.*, 2013). This can only be achieved through a better understanding of the causes of water loss and the factors that influence it (Alkasseh *et al.*, 2013). According to Adachi *et al*. (2014), leakage from water distribution networks has been drawing the attention of water supply industries worldwide. This is mainly because leakage causes economical loss, contamination risk, and excessive environmental load in terms of water resources and operational energy consumption (Adachi *et al*., 2014). Xu *et al*. (2014) stated that about 1.2 billion people, or almost one-fifth of the world's population, live in areas of physical water scarcity and at the same time, water use has been increasing at more than twice the rate of population growth in the last century.

Due to structural deterioration of the pipe network, water losses exist in any water distribution system. The problem is more severe in developing than in developed countries (Kingdom *et al.*, 2006). This is due to lack of financial resources to maintain the water distribution systems, less availability of needed technologies for detecting and locating leaks, and lack of qualified and trained personnel. In addition, it is also due to low level of public awareness and corruption (Kingdom *et al.*, 2006). The leakages from the water distribution systems in developing countries are estimated at 45 Million Cubic Meter (MCM) per day, and about 30 MCM of water which is delivered to the consumers daily is not billed due to various reasons (Al-omari, 2013).

Based on the global water and sanitation assessment carried out by WHO and UNICEF in 2000, on average in the large cities in North America, the NRW was estimated at 15 % while in Africa, Asia, Latin America and the Caribbean it was at 39 %, 42 %, 42 % and 42 % respectively as shown in Figure 2.1 (WHO, 2000). NRW in most of urban distribution systems in developing world ranges from 40 % to 60 % (Baietti *et al.*, 2006; Schwartz, 2008). Van der Zaag (2003) stated that the normal percentages for non-revenue water in the system are from 15 % to 25 %, including 5 % 'losses' in the treatment plants. SIDA (2000) reported that non-revenue water in the range of 15 % to 20 % of the produced quantity is often a realistic and sustainable level for developing countries. The NRW water for Southern Africa Development Community (SADC) ranges from 11 % to 61 % as reported by Mugabi and Castro (2009).

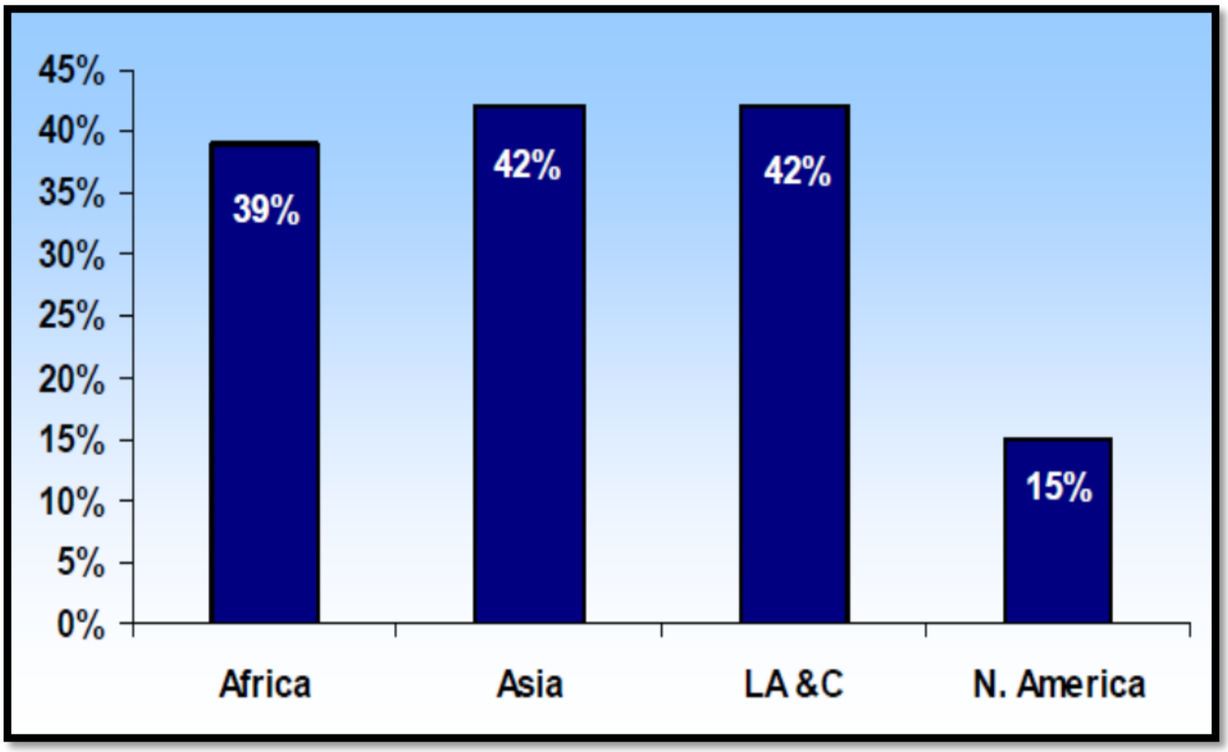


Figure 2.1 Status of NRW on a Global Scale (Source: Sharma, 2008)

Most utilities in Africa normally report a crude figure of NRW hence there is no proper reduction strategies planned for NRW (Kingdom *et al.*, 2006). High levels of water losses has remained one of the major problem facing commercial utilities in Zambia (Simbeye, 2010). According to Simbeye (2010), most water Utilities in Zambia do not have proper data on water losses in their water distribution network upon which planning and corrective measures can be based. Reduction of NRW can only be achieved once quantification and partition of NRW into various components is carried out (Motiee *et al.*, 2007a). In conclusion, globally NRW water is still a challenge but the problem is more severe in developing countries. This is because of lack of quantification and partitioning of non-revenue water into various components due to unavailability of data.

2.2 Non-Revenue Water

Water losses occur in all water systems; generally it is the amount of water which varies and this reflects the kind of asset maintenance levels for the water utility (Dighade *et al.*, 2015). NRW can be defined as the water supplied by the water utility to the consumers but not billed which can be estimated by subtracting the volume of the billed authorized consumption from the system input volume (Farley *et al.*, 2008). According to Xin *et al*. (2014), NRW includes physical and commercial losses.

2.2.1 Physical Losses

Physical losses (Real losses) are losses which occur as a result of storage overflow, pipe bursts and leaks (Farley *et al.*, 2008). According to Kingdom *et al*. (2006), around 90 % of water that is physically lost from leaks cannot be seen on the surface but in the long run the leaks might eventually become visible after many years, but until then, large volumes of water could have been lost each and every day. Sometimes, undetected leaks can be quite large, such as those that run directly into a sewer or a drain channel (Farley *et al.*, 2008). Kanakoudis and Muhammetoglu (2014) stated that a water utility that does not practice a policy of efficient and intensive active leakage control will always have a high level of leakages, except if the infrastructure is new or is in excellent condition.

According to Kingdom *et al*. (2006), the three main components of physical losses include leakage from transmission and distribution mains, leakage and overflows from the utility's reservoirs and storage tanks as well as leakage on service connections up to the customer's meter. Kingdom *et al*. (2006) stated that leakages from transmission and distribution mains are the major physical losses which normally occurs in most of distribution networks. Leakages and overflows from reservoirs and storage tanks are easily quantified but most of the overflow normally occur at night hence the monitoring system should be put in place to avoid such occurrences (Kingdom *et al.*, 2006).

Leakages from tanks are calculated using a drop test where the utility closes all inflow and outflow valves, measures the rate of water level drop, and then compute the volume of water lost (Kingdom *et al.*, 2006). Farley *et al*. (2008) stated that the volume of water lost from an individual pipe burst does not only depend on the flow rate of the event, but is also a function of run time which is often overlooked. In addition to the above, age and pipe material are parameters that influence leakage magnitudes in most of the cases (Motiee *et al.*, 2007b). This comes as a result of a combination of corrosion of pipes and high water pressures which increase breakages, and result in more leakage (Motiee *et al.*, 2007b).

Leakages from a water distribution network can be determined by adopting several approaches. Tabesh *et al*. (2009) stated that the simulation of physical loses using EPANET model has many advantages as compared to other models like SANFLOW, PRESMAC and ECONOLEAK. The following are the short comings of these models;

1. SANFLOW model

   There are two major short comings using SANFLOW model, it uses estimated values for reported and unreported bursts and uses the arithmetic average in calculating the total daily leakage which are not realistic due to the diurnal pressure variations.

2. PRESMAC model

   The PRESMAC model has been used to evaluate the maximum possible leakage reduction and for pressure management purposes through minimizing the pressure in the critical node. The problem with this model is that it does not use a hydraulic model to calculate leakage and pressure values. As a result pressure is estimated by considering only simplifications that assign total demand to the critical node and then calculating the pressure of this node using the head and loss relationship. Therefore, there is uncertainties in carrying out the analysis in complex networks (McKenzie, 2001).

3. ECONOLEAK model

   ECONOLEAK model uses annual water balance method in calculating real losses in which apparent losses are considered as a percentage of total NRW. The BABE concept is then used in the estimating of the leakage components. This model only uses the estimate values in calculation of NRW components (Tabesh *et al.,* 2009).

Therefore in order to evaluate the hydraulic performance of the distribution system to come up with realistic figures, EPANET can be used to simulate leakage in the water networks (Tabesh *et al.*, 2009). EPANET is one of the computer based hydraulic models developed by USEPA to perform hydraulic simulations within a pressurized pipe network (Rossman, 2000). It applies the simplest relationship between flow and pressure in determining the leakage, as follows:

$Q_i = C_i P_i^N$ ……………………………………………………………..Equation (2.1)

Where Qi = leakage discharge, Pi= pressure, Ci = coefficient related to the characteristics of nodes and N is the pressure exponent which varies in a range of 0.5 – 2.5 for real water networks and can be set to 0.5 for burst flows through fixed area orifices.

Calibration of hydraulic simulation model (EPANET): Hydraulic calibration is a process of comparison between the models results to the results obtained from the field. The purpose of calibration is to increase the confidence in the results obtained from the hydraulic simulation (Paton, 2005). When calibrating EPANET hydraulic simulation model, parameters that may be adjusted may include water demand patterns, water demand, pressure, friction factors and pump discharges (Walskai *et al.*, 2003). Nicolini (2011) stated that the predictive ability of the model depends on the calibration. The availability of calibrated model is of fundamental importance for water utility company as it can be used as a decision support tool (Nicolini, 2011).

2.2.2 Apparent losses

Apparent losses, also known as commercial losses are losses which occur due to metering errors, water theft and billing anomalies (Kingdom *et al.*, 2006). Souza and Costa (2014) indicated that apparent losses include losses which are as a result of measurement errors (flow-meters), illegal connections and unaccounted for uses like irrigation, street washing, and firefighting. According to Dighade *et al*. (2015), apparent losses are caused by under-registration of customer meters, inaccurate meters, meter not working, vandalized meters, bypassed meters, bribery and corruption of meter readers. Farley and Liemberger (2004) started that apparent losses are due to lack of proper customer metering policy and education, and regulatory and legislative policies, while Toprak *et al*. (2008), stated that apparent losses are some nominal percentage of the system input volume which are assumed based on the figures from other utilities.

Metering Errors: Metering errors are apparent losses which can easily be introduced through negligence, aging meters, or even corruption during the process of reading the meters and billing customers (Farley *et al.*, 2008). According to Farley *et al*. (2008), incompetent or inexperienced meter readers may read the meter incorrectly or make simple errors, such as placing a decimal in the wrong place if the meter reading is done manually without the use of a data logger. According to Liemberger (2010), other factors which contribute to metering errors are dirty dials, faulty meters, and jammed meters. Arregui *et al*. (2005) stated that depositions may cause over registration at medium to high flows and under registration at low flows in the early years after the installation of the meter but on the long term, depositions may grow so large such that they can prevent the impeller from rotating, temporarily or permanently, causing a severe under registration of the meter. Lack of asset management assessment is directly linked to non-revenue water (Matichich *et al.*, 2014).

Meter testing can be done in the field to check if the meter is under/over registering by connecting a control meter which has been certified to be in good condition in series with the meter to be tested normally 3-5 days. Mainly to check on the consumption on both meters if they are the same or the use of a meter testing bench if available to test the accuracy of meters (Liemberger, 2010; Mutikanga *et al.*, 2011a). Figure 2.2 shows the procedure in determining metering error adopted from Mutikanga *et al*. (2011a). The water use pattern need to be determined for more than five years in order to determine the actual pattern for a particular community (Mutikanga et al., 2011a). The accuracy of a water meter is a function of the circulating flowrate, in particular, a water meter registers no consumption at all when the flowrate is below its start-up flow rate, and registers with more than 5 % error when the flow rate is between its start-up flow rate and its minimum flow rate (Fantozzi and Lambert, 2007). Therefore, the ability of meters to accurately measure water consumption strongly depends on the flowrates at which consumers use water (Fantozzi and Lambert, 2007). Figure 2.3 shows the meter error curve for a well performing meter when subjected to different flows suggested by International Organization for Standardization (ISO) (Arregui *et al.*, 2005).

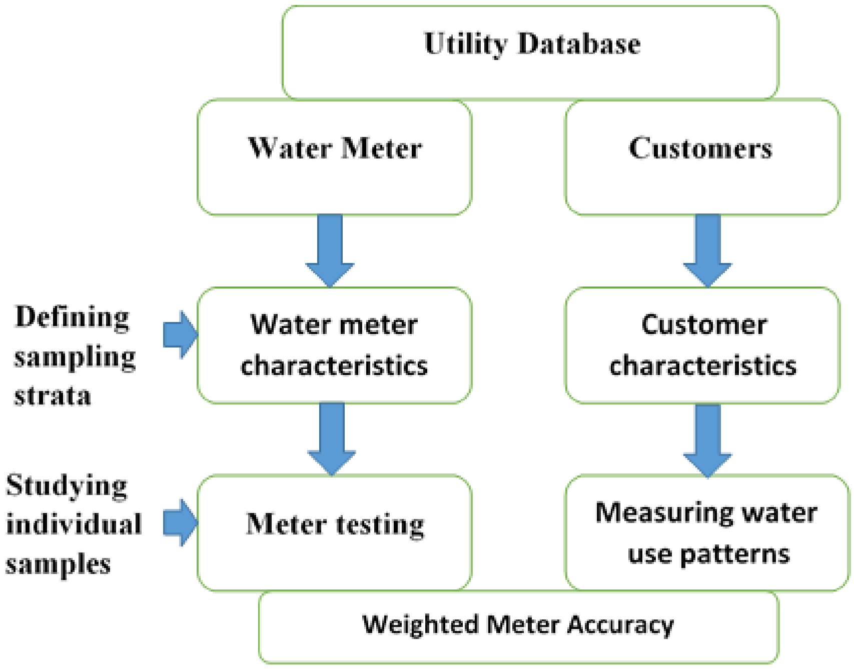


Figure: 2.2: Methodology for determining metering error (Adopted from Mutikanga *et al*. 2011a)

A normal operating meter should under or over register to acceptable levels of ± 5 % and ± 2 % at different flows respectively. Between minimum flow rate, Q_{min}, and transitional flow rate, Q_t, the allowed meter error is ±5 % while from transitional flow rate, Q_t, up to maximum flow rate, Q_{max}, the allowed meter error is ± 2 % (Pack, 1997). It can therefore be concluded that when computing apparent water losses, metering errors should be taken into consideration as one of the factors which contributes to the water losses.

Stuck or broken meters: Stopped or broken meters record zero flows when the customer is actually using the water (Mutikanga *et al.*, 2011b). The number of stuck or broken meters can be estimated from meter records or a sample survey (Farley, 2001). During meter readings, meter readers take record of all meters which are stuck and are not recording at all. Volume lost due to stuck meters can be calculated from meter records or from estimates of per capita consumption but average consumption on the other hand does not represent the true consumption of the customer and usually under-estimates the consumption (Farley, 2001).

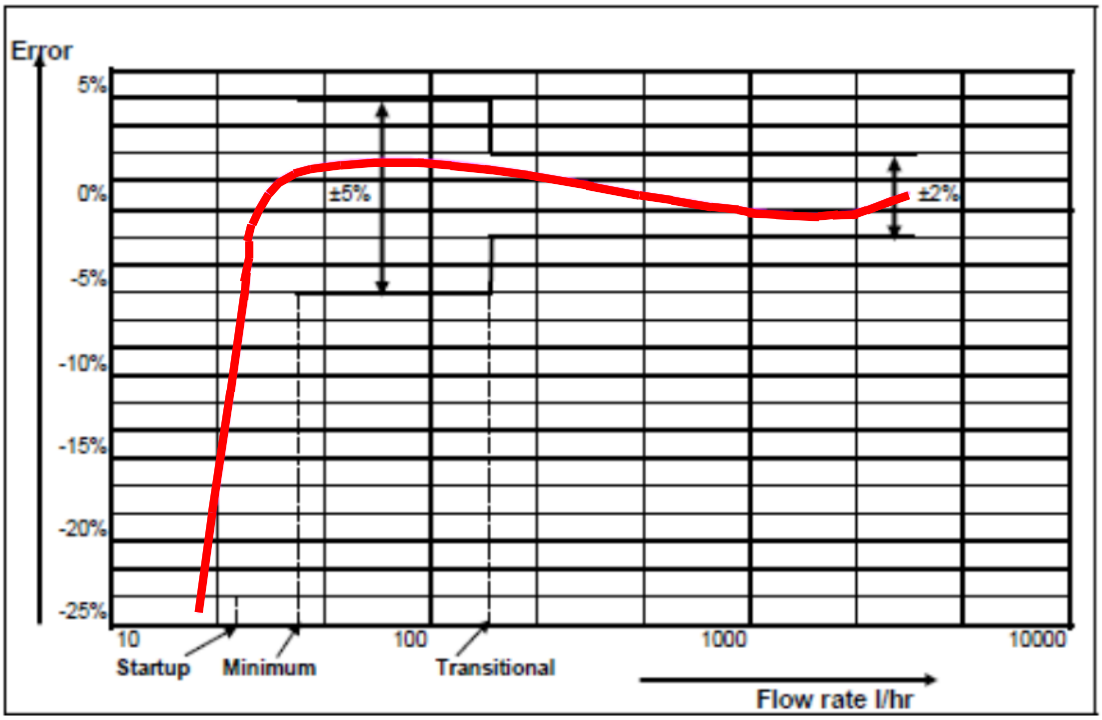


Figure 2.3: Customer meter error curve (Adopted from Harawa *et al*, (2015))

Meter records help in computing an average consumption of the customer based on the past consumption patterns (Farley, 2001). The estimated consumption from struck or broken meters are also the source of NRW because the consumption pattern at households are not usually the same therefore computations of customer usage based on the past consumption might not be the best way (Mutikanga *et al.*, 2011b). Broken or stuck meters should therefore be replaced as soon as they are noticed and taken into consideration when estimating the apparent water losses.

Unauthorized Consumption: According to Liemberger (2010), illegal connections, meter tampering, meter bypasses, meter reader corruption and illegal hydrant use are some of the major unauthorized consumption which contributes to high NRW. According to Thornton *et al*. (2008), unauthorized consumption is a label for water that is taken against the policies of the water utility. Liemberger (2010) indicated that for proper assessment of NRW, causes of NRW have to be established.

Studies carried out in India according to Mathur and Vijay (2013) indicated that components of NRW comprised of 1.5 % to 3.5 % public use, 3.5 % to 6.5 % illegal water connections, 10 % to 15 % meter under registration, and 75 % to 85 % leakages. The determination of various components which make up the total NRW is a critical aspect in the management of the NRW.

2.3 Non-Revenue Water Management

The main key in developing a non-revenue water management is to gain a better understanding of components of NRW, and the factors which influence its components (Kanakoudis and Muhammetoglu, 2014). According to Klingel and Knobloch (2015), establishing a detailed top-down leakage assessment or water balance is a starting point of efficient planning and implementation of non-revenue water management strategy in water supply systems. Puust *et al*. (2010) stated that in order to determine how much water is being lost in a distribution system, there is need to know the system water supply and the different components of water consumption during the period under consideration. Lambert and Hirner (2000) pointed out that any discussion of water losses must be based on a standard terminology. Klingel and Knobloch (2015) stated that the water loss task force of the International Water Association (IWA) came up with the standardized form of water balance which has been adopted uniformly worldwide. Figure 2.4 shows how NRW can be calculated as a universally agreed format (Liemberger, 2010).

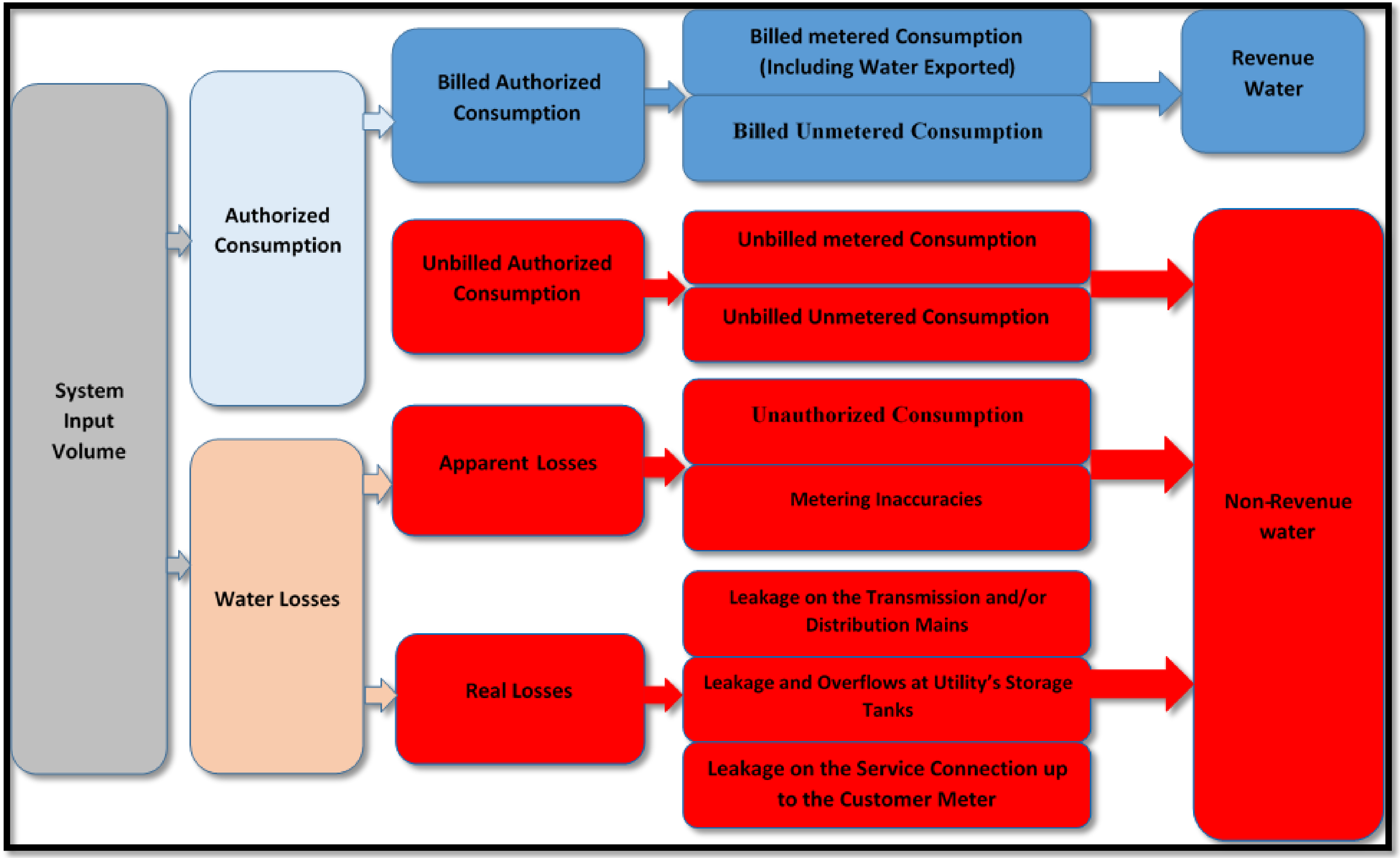


Figure 2.4: Computation of non-revenue water (Adopted from Liemberger, 2010)

The computation involves comparing the water supplied into the system as input volume with the authorized consumption and the water losses (Liemberger, 2010). In order to calculate the NRW, a distinction is made between billed, unbilled authorized consumption and apparent and real losses. Billed and unbilled authorized consumption can be metered or unmetered (Liemberger, 2010). The components of unbilled consumption and water losses add up to non-revenue water. The computation can either be done yearly or monthly. Farley and Liemberger (2004) indicated that apparent losses can be addressed through long term measures which involves changes to customer metering policy and education as well as regulatory and legislative policies coupled with the division of network system into district meter areas (DMAs). According to Dighade *et al*. (2015), apparent losses can be reduced through proper record keeping and improvement in the technical skills of the personnel in charge of meter installation and testing while Arregui *et al*. (2005) stated that there is need to choose the right type of meters based on the amount of pressure in the system and the soil condition of the area because they affect the performance of water meters.

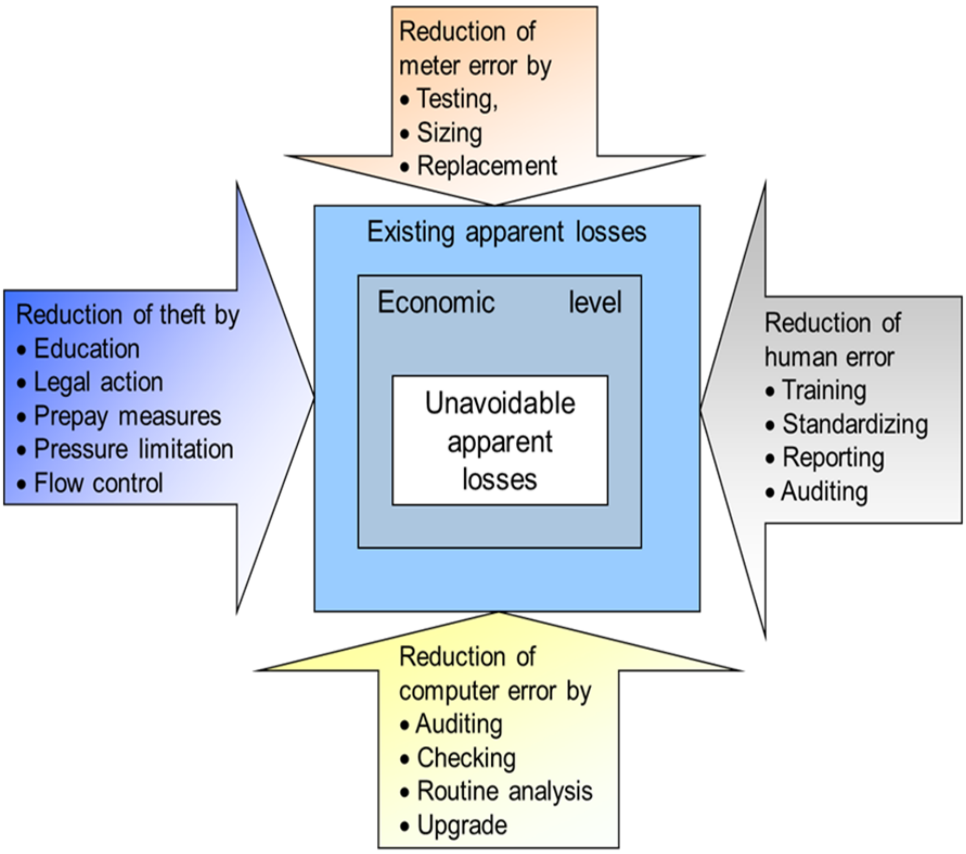


Figure 2.5: Components of apparent loss management program (Adopted from Sharma, 2008)

Souza and Costa (2014) suggested that apparent losses can be minimized by using more accurate measurement equipment, installation of meters and regular surveying of the system for the purpose of detection of illegal connection and leakages. Figure 2.5 gives a summary of how the apparent losses can be reduced. Apparent losses cannot be eliminated completely as it can become very uneconomical but there is need that measures should be put in place which should be either short or long term (Kanakoudis and Muhammetoglu, 2014).

According to Fanner (2004), the most significant factors affecting the level of real losses in a water distribution network is the general condition of the mains and service pipes which can be avoided by ensuring that control measures are followed strictly. This involves the improved response time for leak repair, improved maintenance, replacement and rehabilitation as well as pressure management. Farley *et al*. (2008) stated that the sustainability of physical loss control strategy must comprise of regular active leakage control, pipeline and asset management, repairing of leaks in a timely and efficient manner as well as pressure management. Figure 2.6 shows the strategies which should be implemented in order to reduce the real losses (Sharma, 2008). In conclusion real losses cannot be eliminated completely as they become uneconomical. They can only be reduced to acceptable levels.

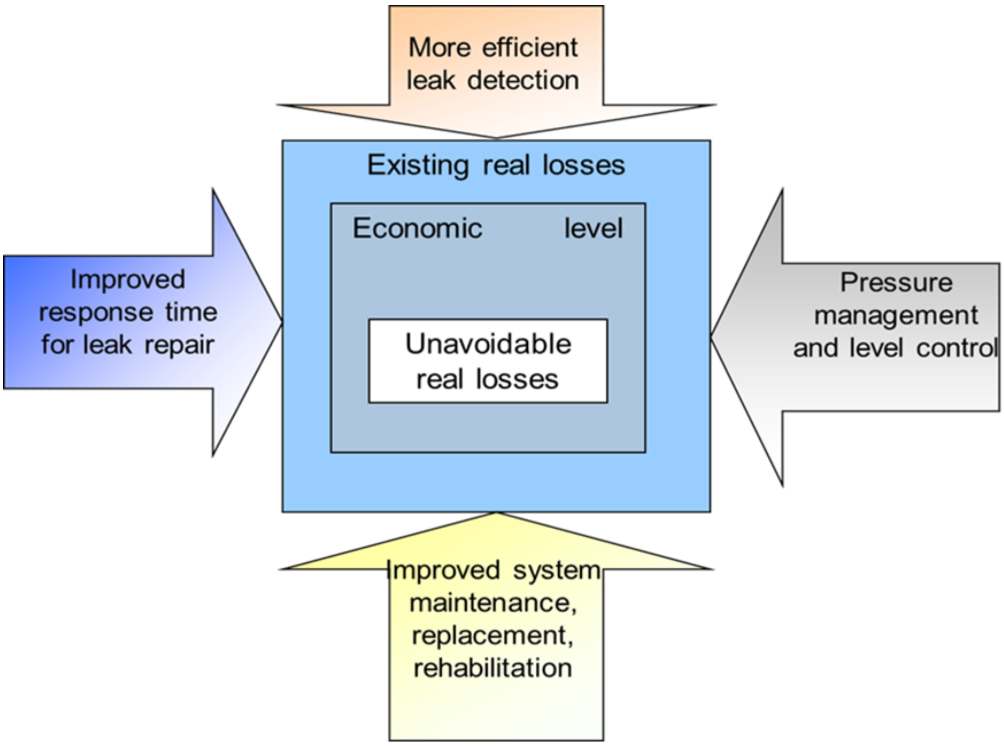


Figure 2.6: Components of a proactive real loss management program (Adopted from Sharma, 2008)

2.3.1 Infrastructure Leakage Index

A better interpretation of the actual real losses in any distribution network is obtained by comparing technical indicator for real losses (TIRL) also known as current annual real losses (CARL) with a best assessment of unavoidable annual real losses (UARL) for local conditions (Farley, 2001). The Current Annual Real Losses (CARL) comprises of the physical water losses from the pressurised system, up to the point of measurement of customer use and is normally calculated as the total water lost less the apparent losses (Seago *et al.*, 2004). In other words, it is the annual volume lost through all types of leaks, bursts and overflows and depends on frequencies, flow rates, and average duration of individual leaks.

The lowest technically achievable annual volume of real losses for well maintained and well managed systems is known as Unavoidable Annual Real Losses (UARL) (Radivojević *et al.*, 2007). UARL is defined by Çakmakcı *et al*. (2007) as that portion of underground leakage lost but considered not economical to locate and repair or too small to detect using current technology as shown in Figure 2.7. System specific values of UARL can be assessed using a formula developed by the Water Losses Task Force (IWA) (Liemberger and McKenzie, 2005).

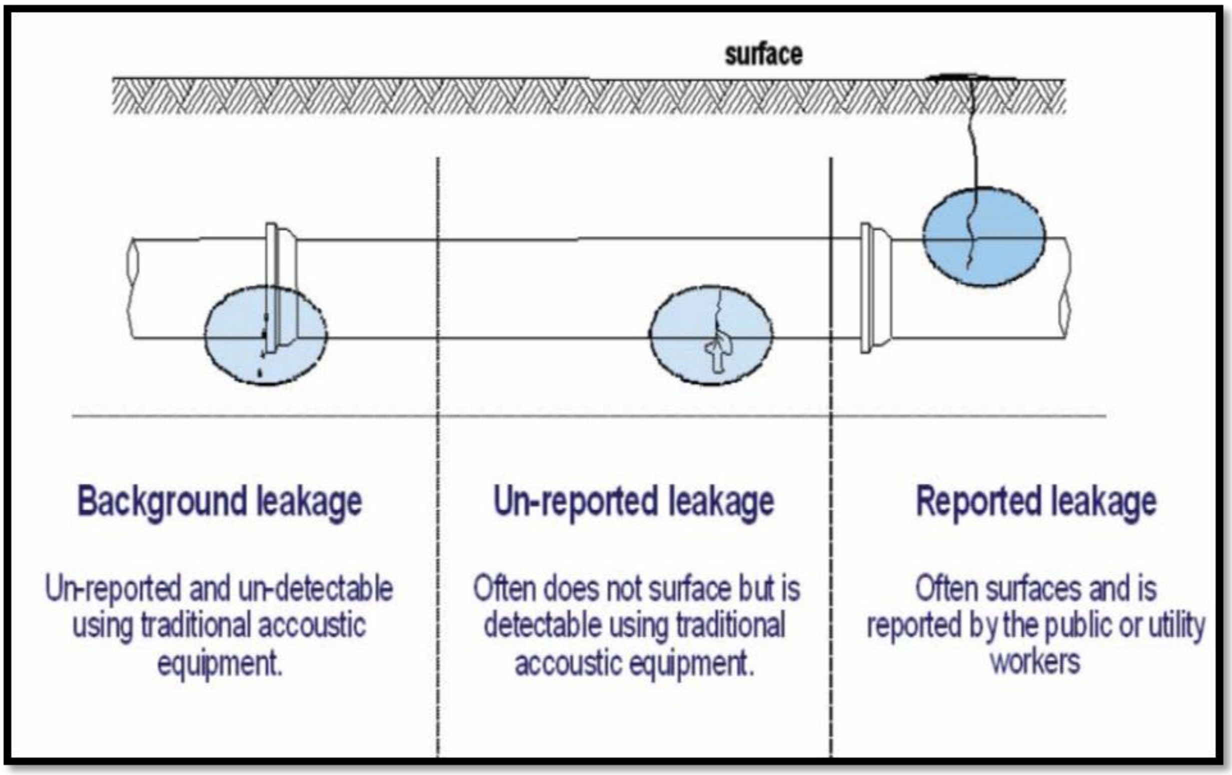


Figure 2.7: Unavoidable Annual Real Losses (Adopted from Sharma, 2008)

According to Lambert and Lalonde (2005), the general equation for calculation of UARL is as illustrated in Equation 2.2

UARL = (18 × Lm + 0.8 × Nc + 25×Lp) × P ………………………Equation (2.2)

Where, Lm is the length of water lines in the distribution networks, Nc, is number of service water connections, Lp is the total length of unmetered connection (Distance of the connection line from the connection to the customer meter) and P is the average operating pressure in meters.

The ratio of the actual CARL to UARL related to the local system is a useful non-dimensional index of the system performance (Thornton and Lambert, 2005). This is known as infrastructure leakage index (ILI) and it is worked out as:

$ILI = \frac{CARL}{UARL}$ …………………………………………………………Equation (2.3)

The infrastructure leakage index saves as an indication on the performance of the water utility company and the kind of action which the company have to do in order to reduce the real losses when in use with the World Bank Institute (WBI) Banding System (Liemberger and McKenzie, 2005). The WBI banding system as shown in Table 2.1 uses a matrix approach to identify a technical performance category (Bands A to D) for a utility's management of real losses, and guidance on the type of actions the utility should undertake.

Table 2.1: NRW Physical Loss Assessment Matrix (Liemberger and McKenzie, 2005)

Technical performance category		ILI	Real Losses in Litres/connection/day when the system is pressurized at an average pressure of:				
			10 m	20 m	30 m	40 m	50 m
High Income countries	A1	< 1.5		< 25	< 40	< 50	< 60
	A2	1.5 - 2		25-50	40-75	50-100	60-125
	B	2 - 4		50–100	75–150	100–200	125–250
	C	4 - 8		100–200	150–300	200–400	250–500
	D	> 8		> 200	> 300	> 400	> 500
Low and Middle Income Countries	A1	< 2	< 25	< 50	< 75	< 100	< 125
	A2	2 - 4	25-50	50-100	75-150	100-200	125-250
	B	4 - 8	50–100	100–200	150–300	200–400	250–500
	C	8 -16	100–200	200–400	300–600	400–800	500–1,000
	D	> 16	> 200	> 400	> 600	> 800	> 1,000

Most African water supply systems would hardly achieve an ILI value of less than 2.0 and values in the range of 5.0 to 10.0 are relatively common and represent systems in a reasonable condition (McKenzie *et al.*, 2002a)

The interpretation of Bands A to D is as follows:

i. A1: World class NRW management performance, there is less potential for further NRW reductions unless there is still potential for pressure reductions or the accuracy improvement of large customer meters
ii. A2: Further NRW reduction may be uneconomic unless there are water shortages or very high water tariffs. Therefore a detailed water audit is required to identify cost-effective improvements
iii. B: Possibilities for further improvement in all aspect of NRW management reduction strategies
iv. C: Poor leakage management, tolerable only if water resources are plentiful and cheap
v. D: Very inefficient use of resources, indicative of poor maintenance and system condition in general

Pickard *et al*. (2008) indicated that there is need to prioritize NRW management by categorizing them in short, medium or long term measures. It can therefore be deduced that NRW management involves coming up with long term and short term measures because of lack of financial capabilities for most of the utilities in developing countries for immediate implementation of all NRW reduction strategies. The management strategies should be based on the analysis carried out from the water balance taking into consideration of cost implication of the suggested strategies.

2.4 Benefit and Cost Analysis of NRW Management Implementation

In the implementation of the NRW management, a business approach should be applied that allows the comparison of implementation costs, resultant NRW reduction saving and service level improvements compared with current situation prevailing which should act as a base line (Pickard *et al.*, 2008). Kanakoudis and Muhammetoglu (2014) indicated that the reduction in the raw water volumes results in direct benefits of reduced energy costs while the reduced bursts frequencies causes direct maintenance cost reduction and indirect potential benefits includes reduction in personnel, insurance and vehicle operation costs.

Farley *et al*. (2008) stated that there is need to identify the economic level when setting out the initial NRW reduction strategies which requires the comparison of the cost of water being lost against the cost of undertaking the NRW reduction activities as illustrated in Figure 2.8. Kingdom *et al*. (2006) stated that the total cost to water service providers caused by NRW worldwide is conservatively estimated at US$141 billion per year, with a third of it occurring in the developing world. In developing countries, about 45 million cubic meters of water is lost daily through water leakage in the distribution network which can serve nearly 200 million people (Kingdom *et al*., 2006). Based on these findings, it can therefore be concluded that implementation of NRW management has a lot of benefits to the operations of water utilities but analysis should be done before any implementation of the NRW strategies.

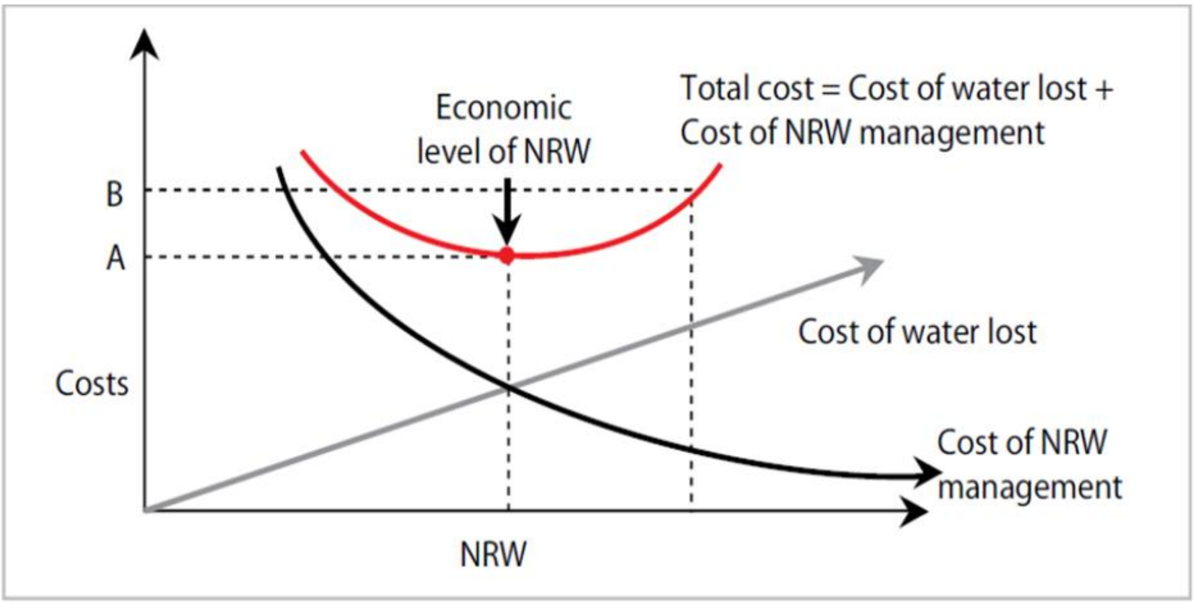


Figure 2.8: Economical level of non-revenue water reduction (Adopted from Farley *et al.* 2008)

CHAPTER THREE

3.0 STUDY AREA

3.1 Geographical location, catchment morphology and climate

The study was conducted in Livingstone Town which is located in the Southern Province of Zambia, specifically Lizuma Ward. The Republic of Zambia is located in the Southern part of Africa. It is a land locked country neighbouring with Angola to the west, the Democratic Republic of Congo to the north, Malawi to the east, Tanzania to the north east, Mozambique, Zimbabwe, Botswana and Namibia to the south (Mulenga, 2003). Zambia approximately lies mostly between latitude 8° and 18°S and longitudes 22° and 34°E with a total area of 752,614 km^2 in size (Acioly *et al.*, 2012). The capital city of Zambia is Lusaka located in the south central part of Zambia (Mulenga, 2003). Zambia's terrain is mostly high plateau with some hills and mountains (Acioly et al., 2012).

The Republic of Zambia has four major Rivers and four major lakes (Chansa and Milanzi, 2010). One of the major river is the Zambezi River which is Africa's fourth largest river and the country's longest, spanning a total distance of 3,540 km. It is on this river that the mighty Victoria Falls which is located in Livingstone Town and the world's largest man-made Lake, the Lake Kariba lies (Chansa and Milanzi, 2010). In the Southern part of the country is the Kafue River which spills into the Zambezi River and in the Eastern Zambia is the Luangwa River. The Northern part of the country is endowed with two Rivers namely the Chambeshi and Luangwa Rivers, and three lakes namely Lake Tanganyika, Mweru and Bangweulu all known for their beauty and diversity of species in and around them.

Livingstone Town is the tourist capital of Zambia located in the Southern Province of Zambia as shown in Figure 3.1. It was established in 1905 and named after the famous British Explorer Dr. David Livingstone (McLachlan and Binns, 2014). Before the capital of Northern Rhodesia was moved from Livingstone to Lusaka in 1935, the town was a major European settlement (McLachlan and Binns, 2014). It is located at latitude 17°51'00 and longitude 25°51'00 and at an elevation of 986 m above the sea level. It lies 10 km to the north of the Zambezi River and a border town with road and rail connections to Zimbabwe on the other side of the Victoria Falls (Liu and Floyd, 2014). Figure 3.1 shows the location of Livingstone Town and Luzuma Ward.

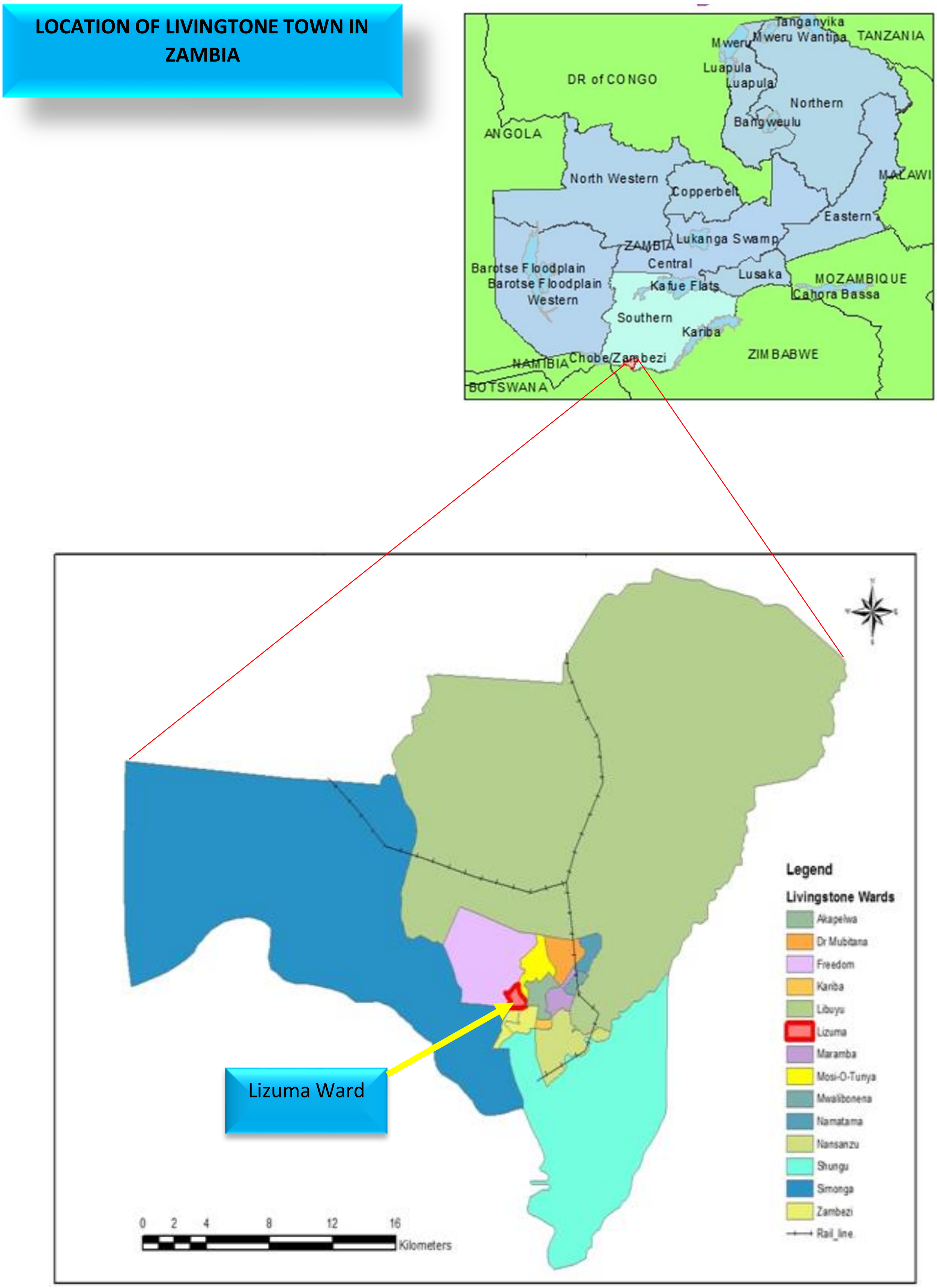


Figure 3.1: Location map for the Town of Livingstone in Zambia

Livingstone Town has a tropical climate which comprises of wet and mild dry seasons with large temperature differences between day and night. The annual mean temperature in Livingstone is 21.8 °C. The warmest month is October with an average temperature of 26.2 °C while June is the coolest months with an average temperature of 16 °C. The town receives an average annual rainfall of about 692 mm. The average elevation ranges from 690 m to about 1200 m.

3.2 Population Size, Growth and Economic activities

During the 2010 census, the population of Livingstone Town was estimated at 136,897 people with an annual growth rate of 3.2 % (CSO, 2013). The current population as at the year 2016 can be estimated at 165,376 people. It is comprised of high and low cost houses mostly former council houses. The tourism sector is the only sector which is currently flourishing hence the town has quite a number of hotels and lodges (McLachlan and Binns, 2014). The number of tourists visiting Livingstone Town was estimated at an average of 400,000 to 500, 000 per year (ZNTB, 2009). The main attraction in Livingstone is wildlife, Victoria Falls, museum visits and township as well as village tours.

3.3 Water Supply

Southern Water and Sewerage Company is mandated to supply water to 21 towns of Southern province of Zambia (NWASCO, 2015). It has its headquarters situated in Choma District which is the Provincial Headquarters for Southern Province. Choma Town became the headquarters of Southern Province in 2012 because it is centrally located but before 2012, Livingstone Town was the Provincial Headquarters of Southern Province. Livingstone Town is the tourism capital city of Zambia. The water utility companies in Zambia came about due to the water sector reforms in the early 1990s with the view to improve the water and sanitation services in the country (Mbilima, 2011). Initially the local councils were in charge for service provision of water but after commercialisation, water utility companies are now in charge of water supply and sewerage services (Mbilima, 2011). For easy operation and service delivery by SWSC, three regions were created in Southern Province namely Central, Northern and Southern Regions. Southern region comprises of Kazungula and Livingstone Towns only.

Most of the people in Livingstone depend on SWSC for their water supply as it is very expensive to drill a borehole due to the low water table (Roland *et al.*, 2007). About one out of five boreholes drilled during larger exploration campaigns in the past years was unsuccessful as the ground water resources are limited (Roland *et al.*, 2007). Raw water is abstracted from the Zambezi River which is at a distance of about 7 km from the treatment plant with an elevation difference of about 106 m, the plant being at a higher elevation (Illiso, 2013). The plant was located at a higher elevation as compared to most parts of Livingstone for the purpose of gravitation of the water to avoid the pumping cost. However due to the expansion of Livingstone Town, certain areas are now fed through direct pumping (SWSC, 2015). The oldest treatment unit at the treatment plant was built in 1953. The design treatment capacity of the plant is 33,102 m^3/day (SWSC, 2012). The treatment plant has three treatment units and eight storage reservoirs as illustrated in the systematic diagram in Figure 3.2. Figure 3.2 also shows main distribution lines from the treatment plant to the various zones. The total number of customers connections in Livingstone Town is 21, 210 connections which is made up of 3,921 domestic high cost, 2,736 medium low cost, 13,663 domestic low cost, 581 commercial and industrial, 132 churches and 77 institutions. Currently the plant is operating at its full capacity but before 2015, only 22,000 m^3/day of water was produced.

The increase in the treatment capacity came about as a result of the rehabilitation works which were carried out from 2013 to 2015. The project was funded by the government of Zambia at a total cost of US 9.2 million (65 million ZMK) (SWSC, 2015). This was mainly to improve the water supply in Livingstone Town prior to the co-hosting of the United National World Tourism Organisation (UNWTO) general assembly in 2013. Some of the works which were carried out included laying of 600 mm transmission main from the Zambezi River to the treatment plant, building two ground reservoirs of capacity 1500 m^3 each in Highlands residential area and a 6 km rising main 250 mm in size from the treatment plant to the two ground reservoirs in highlands. In addition minor rehabilitation works in the treatment plant and replacing of old water network in Libuyu compound were also carried out. The weighted water supply hours in Livingstone is at 18 hours (SWSC, 2015). Highlands's residential area was created in the year 2008 but up to now, there is no water network. Reservoir levels recorded in the month of January and February 2016 daily at 06:00 hours in the treatment plant showed that all the reservoirs were above 61 % full. Reduction of NRW in Livingstone can improve the supply hours and reduction in operation cost. Thus resulting in improved revenue collection and cost savings which can be channelled to servicing of new areas.

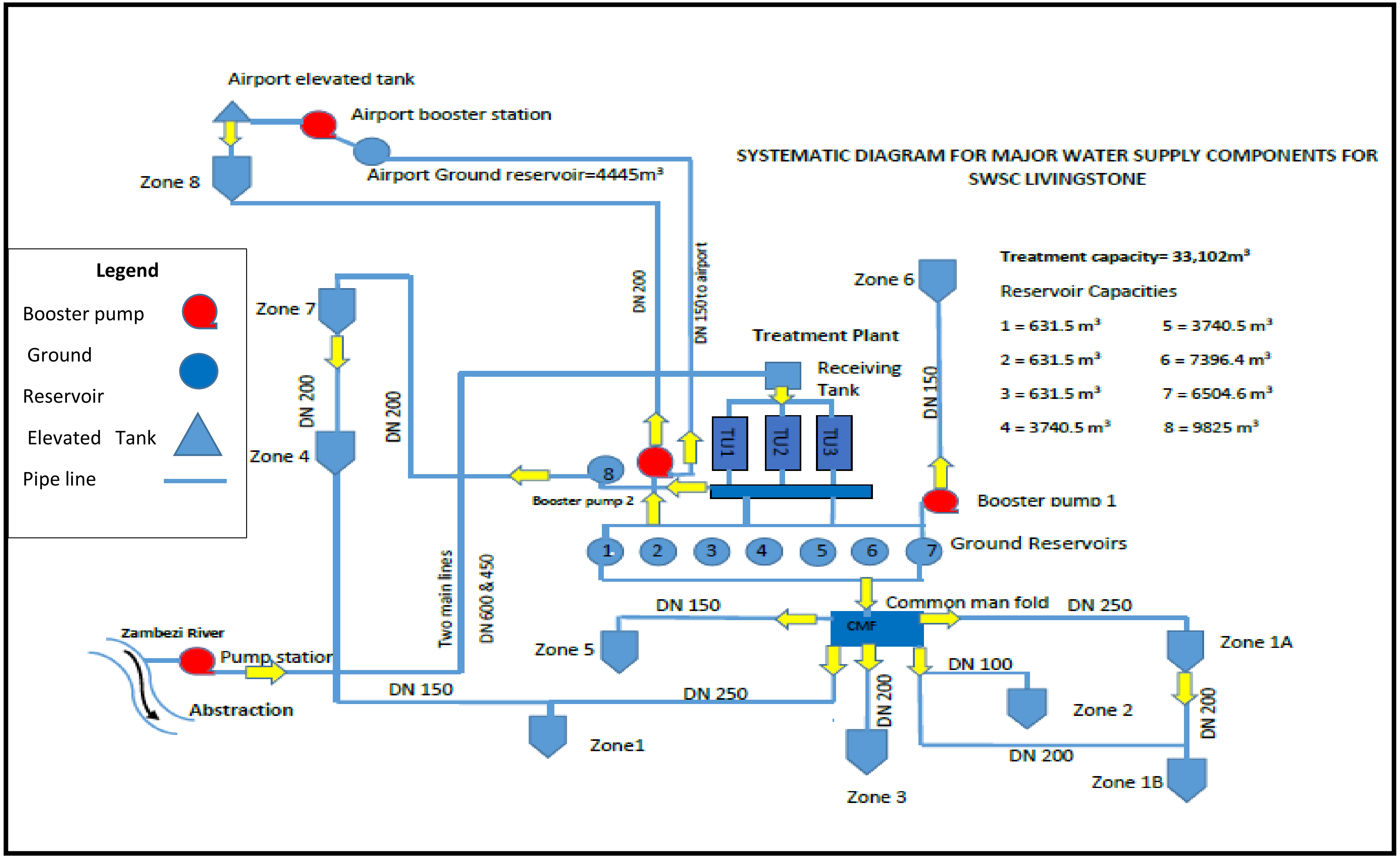


Figure 3.2: Systematic diagram for major supply components

NWASCO, (2015) sector report highlighted that there is lack of meter management and replacement which may increase NRW. According to NWASCO (2015), SWSC cited a number of challenges which they face in their operations. The main ones were low tariff rates which are less than capital and operating cost recovery rates as well as high cost of maintenance material. The other challenge is difficulty in sourcing maintenance materials for asbestos pipes (AC) as there is no local producer in Zambia for this type of pipes and fittings.

3.5 Specific study area

The study was carried out in Livingstone Town specifically in Lizuma Ward located between Kanzungula Road and the Mulobezi Railway Line which are between latitude 17° 51' 27.17" and 17° 51' 43.34" and Longitude 25° 50'12.14" and 25° 51' 04.78". The area mainly consists of low costs houses and it houses one of the busiest markets where farmers from nearby farms come and sell their farm produce. The area will have a modern intercity bus station which is yet to be opened soon to the public where all long route buses will be operating from.

The water supply coverage in Lizuma Ward is at 100 % (SWSC, 2015). Part of the area is under automatic meter reader (AMR) pilot project which was funded by the Devolution Trust Fund of Zambia in 2012 (SWSC, 2015). The project is aimed at reducing the meter reading errors by taking the meter reading remotely. The total population in the Lizuma Ward in 2010 was estimated at 3,361 people (CSO, 2013). Therefore projecting at growth rate of 3.2 %, the population in 2016 can be estimated at 4,061 people as calculated in section 5.3.1. Appendix I contains photos showing the type of leakages occurring in Lizuma Ward. The total distribution network length of Lizuma Ward is 6.5 km with 1442 number of water connections. The water network in Lizuma Ward consists of AC, galvanized iron and PVC pipes. Most of the pipes are old (more than 15 years) as the performance enhancement project in 2012 concentrated only on metering (SWSC, 2014).

CHAPTER FOUR

4.0 MATERIALS AND METHODS

4.1 Study design

The raw water used in Livingstone Town is abstracted from the Zambezi River which is the shared water course with other Southern Africa Countries. Livingstone Town depends only on surface water due to low water table (Roland *et al.*, 2007). The Zambian Government has placed emphasis on the diversification of the economy to avoid dependence on the mining industry and one of the key industry which has attracted a lot of attention is the tourism industry (ZDA, 2014). Livingstone Town being the tourism capital of Zambia, good water supply is cardinal to the development of the tourism industry. Lizuma Ward is one of the oldest wards in Livingstone and was selected for the study as it has functional bulk meters. This was possible to measure the amount of water going into the area. Figure 4.1 shows the Lizuma Ward network map for the main supply lines (50 - 150 mm) with spatial distribution of data logging points.

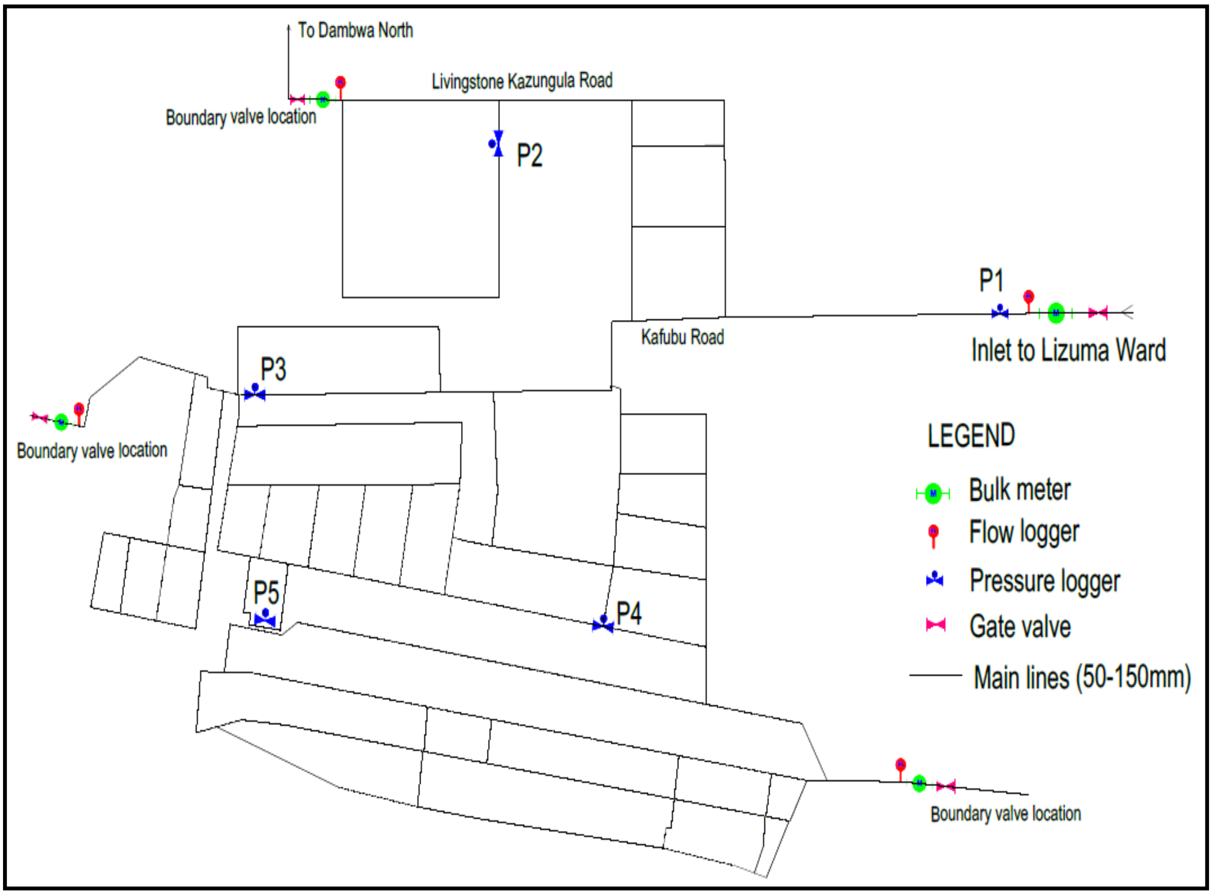


Figure 4.1: Lizuma Ward water network map

The metering ratio for the area is at 97 % while 3 % are unmetered. However NWASCO, (2015) sector report highlighted that there is lack of meter management in Livingstone Town.

4.2 Data collection, Monitoring and Frequency

This section highlights the data collected based on the specific objectives of the study. The study focused on amount of water supplied, billed water, pressure in the distribution system, billing anomalies and assessment of status of water meters. Historical data on water produced and billed was collected for a period of eight years to establish trends of NRW for Livingstone Town. Table 4.1 gives a summary of the data collected and period monitored according to the specific objectives.

Table 4.1: Data collection process and period of collection

Item	Objectives	Data	Source	Period	Purpose
1	To establish the historical trends of NRW for Livingstone town from 2008 to 2015	●water supply per month ●Billing per month ●Customer connections	●Water supply data from the operation department ●Billing data and number of connection from the commercial department	2008-2015	Calculation of NRW for the past eight years
2	To determine the cause of physical losses through the use of hydraulic simulation model(EPANET) particularly for Lizuma ward	●Pressure measurement ●Flow measurements ●Length of the pipe and size ●Age of the pipe and pipe material ●GPS coordinates for pipe nodes	● Field pressure measurement ●GPS coordinates from the fields ●Minimum night flow measurement	Study period	Calculation of physical losses
3	To partition NRW into various components in order to identify specific areas that needs optimization	●Meter errors ●Billing anomalies ●Leakages ●Household questionnaire covering service quality indicators	●Meter testing ●Meter readings ●Physical losses from specific objective 2	Study period	Apparent and physical determination

4.2.1. To establish the historical trends of NRW for Livingstone Town

Data collection involved carrying out a desk study on the production and consumption figures for the past eight years to check the performance of the water utility company. To establish trends of non-revenue water for Livingstone Town, two important data sets were required.

These were water supplied in the distribution system and the water billed in Livingstone Town as recommended by Lambert (2003). The historical data on the water production from 2008 to 2015 was collected from the operations department who are in charge of water production and distribution. Data on monthly billed water was collected from the commercial department who are in charge of water billing and revenue collection. In addition to the above data, corresponding number of customers served in terms of number of connections which were billed during this same period was also collected from the commercial department.

4.2.2 Trends of NRW for Lizuma Ward January to March, 2016

In order to determine NRW trend for Lizuma Ward, data on supplied and billed volume was collected through bulk meter readings and from the commercial department respectively. The bulk meter readings were taken during the period from 25th December 2015 to 25th March 2016. Monthly inflows to Lizuma Ward were therefore calculated as the difference between two consecutive monthly bulk meter readings. The meter readings for domestic water meters are normally taken from 20th to 25th of each month by meter readers. This made the calculation of NRW more accurate as the supplied and the billed volumes were taken during the same time period. Supplementary data obtained from the commercial department was the corresponding number of active customer served in terms of number of connections. Klingel and Knobloch (2015) highlighted that it is misleading to use percentage in expressing NRW as a measure of operational efficiency. Expressing NRW in terms of volume lost per connection is a useful performance indicator for target setting in the reduction of the NRW (Klingel and Knobloch, 2015). The number of connections was used in the computation of volume of water per connection.

4.3 Calculation of Real losses and Partitioning of NRW

4.3.1 Flow logging

Data logging exercise for Lizuma Ward distribution network was carried out in order to obtain the volume of water into Lizuma Ward. Flow loggers were installed at the entrance to the zone and at the boundary valves to Lizuma Ward. The results from the flow logging were used in modelling of the real losses.

4.3.2 Pressure logging

Pressure loggers were installed at the inlet to Lizuma Ward and different selected points within the ward distribution network during the same period of flow logging. There were five points where pressure was measured within the network. The results from pressure logging was used in coming up with the Average Zonal Pressure (AZP) in the area for computation of the hourly leakage rate.

4.3.3 Description of data logging devices

Flow logging was carried out using TDS 100H Ultrasonic Flow Meters. TDS 100H ultrasonic flow meters are designed to measure the fluid velocity of liquid within a closed pipe. They are measuring systems which are easy to use and install. The TDS - 100H series ultrasonic flow meter uses the well-known transit time measurement principle plus propriety signal processing and ultrasonic transceiver technology. When an ultrasonic signal is transmitted through the flowing liquid, there is a time difference (transit time) between the upstream and downstream transducers which is proportional to the flow velocity. The device measure flows between 0.01 to 32 m/s with an accuracy of ± 0.5 % to ± 2 %. They are used to measure liquid flows in pipe diameter of 50-700 m and operate at a liquid temperature less than 160 °C (PCE-Instruments, 2015).

Pressure logging was carried out using a Vermor type of data loggers. The devices are manufactured by Vernon Morris Utility Solutions in the United Kingdom. They are portable data loggers which can be installed at strategic locations within the distribution network and they have an accuracy of ± 1 %. Operating temperature is from 20 ° C to 50 ° C. The pressure recorder can be fitted with weekly or daily charts in either imperial or metric scales (Vernon Morris, 2010).

4.3.4 Meter inaccuracies

In order to determine the meter inaccuracies, a TEC-100 model water meter testing bench was used to determine the accuracy of domestic water meters as suggested by Sánchez (2007) and IWA (IWA, 2008) at different flow rates. One domestic meter was tested at a time.

4.3.5 Other data collected

For proper analysis of Lizuma Ward, other supplementary data was gathered through administering questionnaires, reviews of operations reports to determine the age of the pipes and meters and exposing of pipes for the purpose of verification of pipe size and material.

4.4 Data Analysis and Interpretation

4.4.1 Trends of Non-Revenue water

The NRW for the entire Livingstone Town and Lizuma Ward were analysed based on a water balance method in which the difference between water supplied and water billed was calculated as recommended by Lambert (2003) and Motiee *et al*. (2007). The NRW for Livingstone Town was calculated yearly while that of Lizuma Ward was done monthly. According to Motiee *et al*. (2007), the water balance in a water network system can be defined as:

$Q_S = Q_A + Q_L$ ……………………………………………………..Equation (4.1)

Where:

Q_S = Water supplied (m^3/year, m^3/month)

Q_A = Authorized consumption (m^3/year, m^3/month)

Q_L = Total water losses (m^3/year, m^3/month)

In order to establish if there was any variation and whether a distinctive trend was observed for NRW during the period under investigation, statistical analysis was carried out by computation of the coefficient of variation (CV) for the NRW as well as performing a Mann-Kendall trend test respectively. Mann-Kendall trend test is a nonparametric test used to identify a trend in a series.

4.5 Modelling of Real Losses and computation of Apparent Losses

4.5.1 Real Losses

Data collected in the field included nodal coordinates, pipe material, pipe size, flow measurement and average zonal pressure which were used in the modelling of real losses in EPANET hydraulic simulation model as suggested by Karadirek *et al*. (2012). The purpose of flow and pressure logging was to obtain the volume of water into the ward and Average Zonal Pressure which were used in simulating daily/monthly leakages (Tabesh *et al*., 2009). The process of hydraulic modelling started with coming up with network map which was used in an EPANET environment. Figure 4.2 shows a flow diagram which highlights steps which were taken in creating a network map for Lizuma Ward.

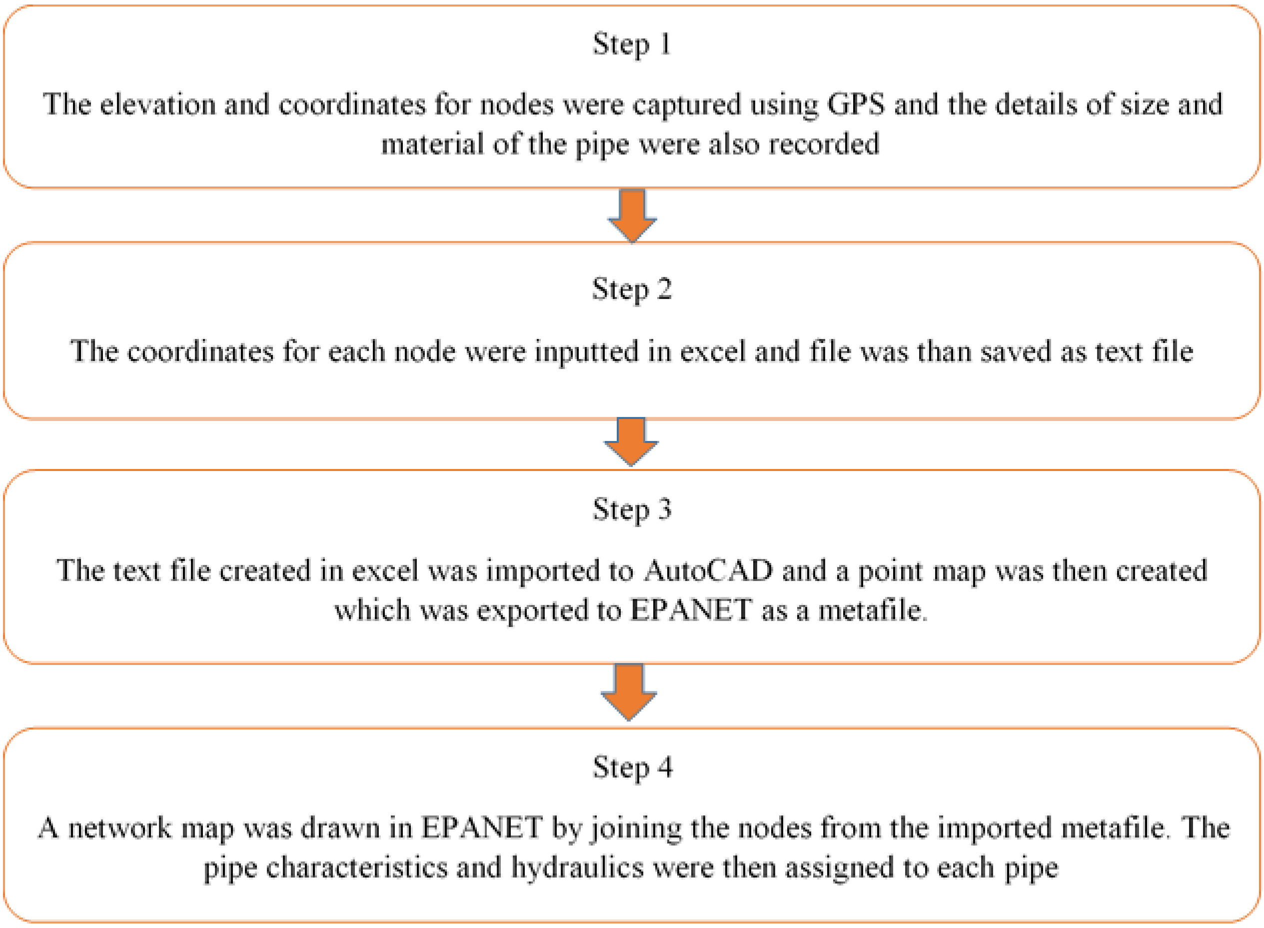


Figure 4.2: Flow chart for creating network map

Burrows *et al*. (2003) stated that EPANET model can be used to simulate leakage in the water distribution networks which applies the relationship between leakage and pressure. Based on this relationship the following steps were carried out as recommended by Tabesh *et al*. (2009) in calculating the real losses:

Step 1: The first step was to get the Minimum Night Flow (MNF) and the average pressure for Lizuma Ward through data logging. According to Xin *et al*. (2014), MNF in urban cities normally occurs during the early morning period, from 01:00 to 04:00 hours. During this period, few customers use water and by using the consumption during this period, it reflects the actual leakage which occurs in the water distribution network. The MNF and the average zonal pressure were used for calculation of the network leakage.

Step 2: The network leakage at MNF was calculated using Equation 4.2. The night uses was taken as 6 % of total population with consumption of 10 l/head/h (McKenzie, 1999).

$Q_{L,MNF} = MNF - \text{Night Uses}$……………………………………Equation (4.2)

Step 3: The third step involved calculating the volumetric consumption which was obtained by deducting the total network hourly leakage from the total inflow per day. The total inflow which was used was the average inflow into Lizuma Ward measured during the three months period (January to March 2016). The network hourly leakage was obtained using Equation 4.3 which is a function of network leakage and pressure as suggested by Tabesh *et al*. (2009). The hourly pressure was used in the computation of the network hourly leakage.

$Q_{L,t} = Q_{L,MNF} \times (P_t / P_{MNF})^N$……………………………………...Equation (4.3)

Where; Pt = Pressure at any time t

P_{MNF} = Pressure at MNF

N = Pressure exponent

T = Time in hours

The pressure exponent varies in a range of 0.5 – 2.5. Tabesh *et al*. (2009) stated that 0.5 is used for burst flows through fixed area orifices. A high figure of pressure exponents is for background leakages such as weeping joints where the area of the joint leakage opening may vary with pressure for flexible pipe material Nazif *et al*. (2010) recommended a value of 1.18 which is close to unit to the be used for a normal distribution network in the analysis of leakages. This in agreement with the earlier works by Germanopoulos (1985). The value of 1.18 pressure exponent was used in the computation. The summation of the $Q_{L,t}$ values for 24 hour period added up to the total daily leakage.

Step 4: The EPANET model was run based on the elevation differences without inputting volumetric consumption so as to obtain the nodal pressure which were used for calculation of the first estimate of the emitter coefficient C using Equation 4.4.

$$C = \frac{Q_{L,MNF}}{\sum_{I=1}^{NJ}\left(\sum_{J=1}^{NK}\frac{L_{ij}}{2} \times P_i^N\right)}$$ ……………………………………...Equation (4.4)

Where; NK is sum of the pipes connected to node i, $Q_{L,MNF}$ is the network leakage at MNF, NJ is the total number of nodes and P_i is the pressure at node i and N is the pressure exponent.

Step 5: The volumetric consumption calculated in step 3 was distributed to the nodes and EPANET was run to produce new nodal pressure at MNF and the second emitter coefficient (C) was calculated based on the pressure at the nodes.

Step 6: The nodal consumption was then calculated using Equation 4.5 from the results obtained from step 5

$Q_{L.i} = \sum_{j=1}^{NK} \frac{L_{ij}}{2} C.P_i^N$ ……………………………………………… Equation (4.5)

Where; NK is the number of pipes connected to node i, and C and P as determined from step 5

Step 7: The nodal consumption calculated from step 6 was then updated by adding volumetric consumption as determined from step 3 as new inputs to the model for each node.

Step 8: EPANET was then run based on the new consumption calculated from step 7 to produce new nodal pressure. Tabesh *et al*. (2009) stated that at this stage a check has to be carried out if the nodal pressure in step 8 is equal to the nodal pressure in step 5. If the pressure values are different, then the nodal consumption have to be updated as stated in step 7 then a check has to be carried out to verify if updated consumption are equal to the total volumetric consumption and network hourly leakage (volumetric consumption + network hourly leakage). If they are not equal, the emitter coefficient C should be changed through an iteration process until they are equal.

Step 9: Involved changing the emitter coefficient C such that the nodal consumption were equal to the total volumetric and network hourly leakage. The new pressure values were then calculated by running the EPANET model based on the calculated nodal consumption obtained from the iteration process.

Step 10: The leakage in each pipe length was calculated using Equation 4.6. The real losses were computed by the summation of all the pipe leakages calculated from Equation 4.6 from all the pipes in the network.

$Q_{L.ij} = Q_{L.i} \times \frac{L_{ij}}{\sum L_I} + Q_{L.j} \frac{L_{ij}}{\sum L_j}$………………………………….…... Equation (4.6)

In order to check on the accuracy of EPANET hydraulic model in estimating real losses, a two sample t-test was performed to check if there was a significant difference in the means of measured and simulated inflow to Lizuma Ward as while as measured and simulated pressure on selected points where pressure logging was carried out.

Modelling of real losses using SANFLOW model: The SANFLOW model was used to estimate the real losses in the distribution network so as to compare with the results obtained from the EPANET hydraulic simulation model. Minimum Night Flows from flow logging results were inputted into the SANFLOW Model to compute Excess Night Flows (ENF) from which real losses were calculated according to Mckenzie (1999). Real losses (RL) were therefore computed as follows;

Expected Night Use = background losses + normal night use……...Equation (4.7)

Excess Night Flow (ENF) =Measured MNF-Expected night use….. Equation (4.8)

RL (m^3/month) = ENF (m^3/h) × Hour Day Factor (HDF) × 30 days/month…..Equation (4.9)

Infrastructure Leakage Index (ILI): To better understand the level of performance of the water utility company, Infrastructure Leakage Index (ILI) as suggested by Seago *et al.* (2004) needs to be computed, which is the ratio of the Current Annual Real Losses (CARL) to the Unavoidable Annual Real Losses (UARL). Equation 4.10 was used in calculating the UARL.

UARL = (18 × Lm + 0.8 × Nc + 25×Lp) × P …………………….. Equation (4.10)

Where, Lm is the length of mains, Nc, is number of service water connections, Lp is the total length of unmetered connection (Distance of the connection line from the connection to the customer meter) and P is the average operating pressure in meters.

As a Performance Indicator (PI), the ILI represents a measure of the combined performance of three infrastructure management activities for real losses namely; the speed and quality of repairs, active leakage control and assets management under a certain average operating pressure (Dighade *et al.*, 2015). World Bank Institute Banding System can be used to assign the technical category where the utility falls based on the calculated ILI and the operating pressure (Liemberger and McKenzie, 2005). The ILI provides an indication of how serious the leakage occurring in a particular area is as compared to the theoretical minimum acceptable level of leakage that can be achieved (Seago *et al.*, 2004). The ILI was calculated using Equation 4.11:

$\mathrm{ILI} = \frac{\mathrm{CARL}}{\mathrm{UARL}}$……………………………………………………..Equation (4.11)

4.5.2 Apparent Losses

The total apparent losses (TAPL) was determined from the difference between the average NRW determined for Lizuma Ward and the real losses calculated from the EPANET model as illustrated in Equation 4.12.

TAPL =Average NRW – RL……………………………………….…Equation (4.12)

***Partitioning of Apparent Losses**:* Since Total Apparent Losses (TAPL) comprises of meter errors, billing anomalies and unauthorized consumptions, apparent losses were then further partitioned into losses due to meter errors, billing anomalies and unauthorized consumptions.

Apparent losses due to meter errors: To establish losses due to metering errors, a total of 25 customer meters were uninstalled in Lizuma Ward and tested for accuracy using a meter testing bench at SWSC water audit laboratory in Livingstone Town. Lizuma Ward is made up of five sections namely DAs, DBs, DC, Villa Estate and Zambezi Saw Mills. The water meters in all five section are less than five years old. A total of five meters were tested from each section which was based on stratified random sampling as recommended by (Mutikanga *et al.*, 2011a). The sampling was carried out after every fifth house. Each meter was mounted on the testing beach and a known volume of water was passed through it (Arregui *et al.*, 2005). The meter testing bench is fixed with calibrated cylinders which measure the volume required to pass through the meters to be tested.

The error was then obtained as the difference between the meter reading and the known volume which passed through the meter (Arregui *et al.*, 2005). As proposed by Sanchez (2007) and Arregui *et al*. (2005), the meters were tested at three different flow rates namely; low flow rate test where a 10 litre volume was passed through the meters at 25 l/h and corresponding meter readings taken. A second test, a 100 litre volume of water was passed through the meters at a flow rate of 500 l/h and the final test which was at a high flow rate, a 100 litre volume of water was passed through the meters at a flow rate of 1000 l/h and the corresponding meter reading was taken. The meter error was computed using Equation 4.13 for each of the particular flow rates and then the weighted metering error was calculated using Equation 4.14 as recommended by Mutikanga *et al*. (2011b).

$E = \frac{V_m - V_a}{V_a}$………………………………………………………...Equation (4.13)

Where: E is metering error

V_m is the measured (registered) volume

V_a is the actual volume

Weighted metering Error was computed as follows;

$$E_W = \frac{E_L V_L}{V_T} + \frac{E_M V_M}{V_T} + \frac{E_H V_H}{V_T} \text{....Equation (4.14)}$$

Where: E_L is the meter error at low flow

E_M is the meter error at medium flow

E_H is the meter error at high flow

V_L is the actual volume at low flow

V_M is the actual volume at medium flow

V_H is the actual volume at high flow

V_T is the total volume which is the summation of V_L, V_M and V_H

The volume of water lost (V_{LM}) due to meter inaccuracies was than determined using equation 4.15 (Mutikanga *et al.*, 2011b)

$$V_{LM} = \text{TAPL} \times E_M \text{....Equation (4.15)}$$

Where: TAPL is the Total Apparent Water Loss

E_W = weighted meter error

Apparent losses due to billing anomalies: The apparent water losses due to billing anomalies where determined by carrying out an independent meter reading exercise which was used in the computation of the billing error factor (Mutikanga *et al.*, 2011a; Harawa *et al.*, 2015). A number of customers to be sampled was first determined using Equation 4.16 as recommended by Stattrek (2007).

$$n = \frac{(z^2 \times P \times q) + ME^2}{ME^2 + Z^2 \times P \times \frac{q}{N}} \text{....Equation (4.16)}$$

Where: n = sample size, z = critical standard score, P=population proportion, q=population

Proportion, ME = Marginal Error and N=total population.

The following assumptions were made for the equation to be valid.

1. The Margin of Error, ME, is plus or minus 5% or 0.05 (Stattrek, 2007).
2. The confidence level is 95% or 0.95, Thus, alpha = 1 - 0.95 = 0.05.
3. The critical standard score (z) is the value for which the cumulative probability is 1-alpha/2 = 1 - 0.05/2 = 0.975. For cumulative probability of 0.975, critical standard score (z) = 1.96 (Stattrek, 2007).
4. 95% of the connections were in good condition, (thus p=95% and q= 5%)

Therefore replacing in Equation 4.16, the sample size was determined as follows;

$$\frac{(1.96^2 \times 0.95 \times 0.05) + 0.05^2}{0.05^2 + 1.96^2 \times 0.95 \times \frac{0.05}{1442}} = 70.43 \quad \text{approx. } 71 \text{ connections}$$

A total of 71 meter readings were taken independently as SWSC meter readers were also carrying out the meter reading exercise for preparing the bills. The first independent meter reading exercise was done in January, the second in February and the third in March so as to have two sets of consumption. Equation 4.17 was used in the computing of billing error factor.

For a sample size of n customers, the billing error factor, BEF, was estimated by Equation 4.17 as suggested by Harawa *et al.* (2015).

$$\text{BEF} = \frac{\sum_{i=1}^{n} V_{SWSCi} - \sum_{i=1}^{n} V_{IMRi}}{\sum_{i=1}^{n} V_{IMRi}} \text{...Equation (4.17)}$$

Where;

- V_{IMRi} = Monthly measured consumption for customer i from independent meter reading
- $\sum_{i=1}^{n} V_{IMRi}$= Total monthly measured consumption for n customers from independent meter reading
- V_{SWSCi} = Monthly billed consumption for customer i from SWSC commercial department
- $\sum_{i=1}^{n} V_{SWSCi}$ = Total monthly billed consumption for n customers from SWSC commercial department

The billing error factor was then computed as an average of the two billing error factor computed for February and March. The purpose of having two sets of consumption data in the computation of the billing error factor was to reduce the error which would have occurred if one data set of consumption was used.

Therefore total water lost due to billing anomalies was estimated as follows;

L_{TWBA}= Total Apparent Losses (TAPL) × Average Billing Error Factor

Thus; L_{TWBA}= TAPL × BEF_{AV} ……………………………………Equation (4.18)

Apparent losses due to Unauthorized Consumption: The Volume lost through unauthorized consumption was estimated based on the assumption that Total Apparent Loss consists of losses due to meter inaccuracies, billing anomalies and unauthorized consumption. In determining unbilled authorized and unbilled unmetered consumption, the unbilled authorized consumption were approximated as 5 % of authorized consumption while the unbilled unmetered consumption contribution to unbilled authorized consumption was taken to be 1.25 % as suggested by McKenzie (1999).

The volume lost through unauthorized consumption was estimated using Equation 4.19.

L_{UAC} = TAPL – L_{LM} – L_{TWBA}……………………………….…Equation (4.19)

4.5.3 Supplementary Data Collected

In order to get the views of customers on the service provision of SWSC, questionnaires were administered in the Lizuma Ward. The minimum sample size to administer the questionnaires was based on the formula recommended by Stattrek, (2007) as shown in section 4.5.2. A total of 71 questionnaires were administered randomly in Lizuma Ward. Questionnaires were administered to get views from customers on the occurrences of pipe bursts, response to pipe bursts and leakages, supply hours and pressure of water. Other data collected included the population for the study area. The last census was carried out in 2010.In order to come up with the 2016 population, the population for 2010 had to be projected using Equation 4.20.

$P_P = P_O\,(1 + r)^n$………………………………………………...Equation (4.20)

Where; P_p is the projected population, Po is the initial population, r is the growth rate and n is the number of years of population projection.

CHAPTER FIVE

5.0. RESULTS AND DISCUSSIONS

5.1 Non Revenue Water (NRW) trend

5.1.1 Historical trends of water supplied, billed water and NRW for Livingstone Town from 2008 to 2015

The results of historical trends of water supplied, billed water and of non-revenue water from 2008 to 2015 are shown in Figure 5.1. The analysis of historical data showed that the minimum and maximum supplied volume was 8.5 Mm^3/year and 10.43 Mm^3/year in the year 2008 and 2015 respectively with an average of 9.02 Mm^3/year. This showed an increase of about 1.93 Mm^3/year of supplied volume from 2008 to 2015.

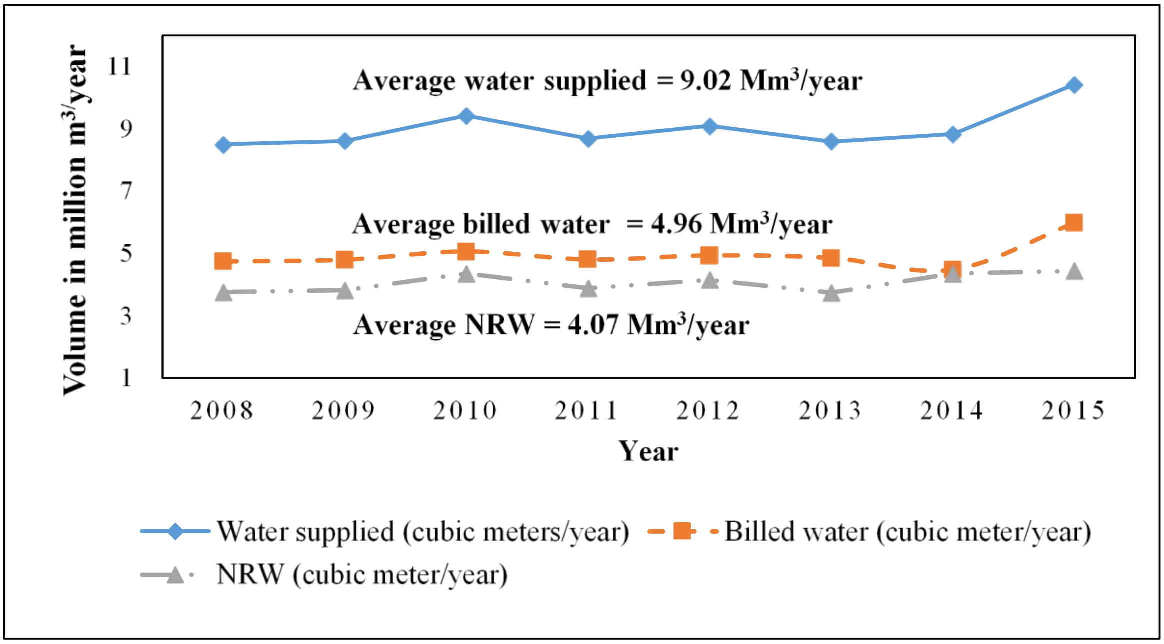


Figure 5.1: Trends of water supplied, billed water and NRW from 2008-2015

The minimum water billed was 4.36 Mm^3/year in the year 2014 while the maximum water billed was 5.98 Mm^3/year in the year 2015 with an average water billing of 4.96 Mm^3/year. The average volume of water lost for the eight year period was 4.07 Mm^3/year. The minimum water loss occurred in the year 2013 while the maximum was in the year 2015 which were 3.74 Mm^3/year and 4.45 Mm^3/year respectively as shown in Figure 5.1. Appendix II shows the NRW calculation for each year. The increase in the supplied water resulted in the increase in the billed volume from 2014 to 2015. The increase in the water supplied was as a result of rehabilitation works at the raw water intake where three new pump set of pumping capacity 720 m^3/h were installed, therefore the total number of pump set became four in the year 2014 inclusive of the old pump set which has a pumping capacity of 1,100 m^3/h. In addition a new transmission line of 600 mm was constructed from the intake to the treatment plant. The rehabilitation works resulted in having two transmission lines (600 mm and 450 mm) and four pump sets (SWSC, 2015). Therefore, there was an increase in the amount of water treated hence more water supplied into the distribution network.

The coefficient of variation (CV) for water supplied and non-revenue water was found to be 0.07 and that of billed volume was found to be 0.08 from 2008 to 2015. This means that there was less variability of water supplied, billed water and NRW. This was also confirmed with Mann-Kendall trend tests which proved that there was no distinctive pattern of trend observed for water supplied, billed water and NRW from 2008 to 2015 as the computed p-value was greater than significance level 0.05. The computed p-value for water supplied, billed water and NRW was 0.179, 0.454 and 0.135 respectively. Appendix III, IV and V shows the summary of the statistical test results.

5.1.2 Trend of NRW as a percentage of water supplied

The NRW as a percentage of the water supplied presented in Figure 5.2 shows an average NRW of 45 % with NRW in 2014 at 49 % while in 2015 was found to be 43 % as maximum and minimum respectively. Statistical analysis performed on this data indicated that the CV for NRW was 0.04 therefore it showed low variability of NRW from year to year. The Mann-Kendall trend tests indicated that there was no increasing or decreasing trend in NRW during the period under investigation as the computed p-value (0.898) was greater than significant level (0.05) as shown in Appendix VI.

The decrease in NRW from 2014 to 2015 was due to the rehabilitation works in Libuyu compound, police and prisons camps where the old asbestos iron and galvanized steel pipes were replaced (Illiso, 2013). The value of NRW obtained confirms the finding of Gumbo (2004) that NRW for Southern Africa cities range from 18 % to 65 %. However, the average NRW value of 45 % for Livingstone is not acceptable and is above the figure of 20 % as set by Gumbo (2004) for Southern African countries and also a target of 25 % for a well performing utility in Zambia as recommended by NWASCO.

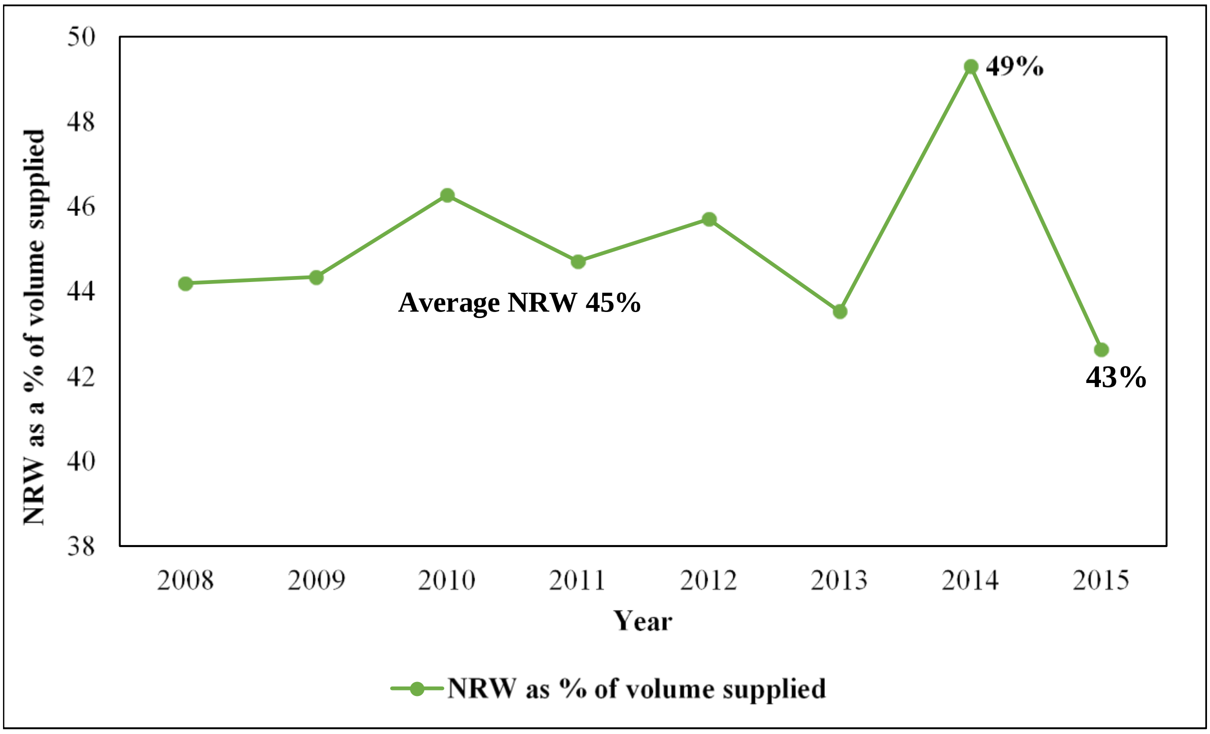


Figure 5.2: NRW as a percentage of supplied volume from 2008-2015

Worldwide a target of 23 % as set by the World Bank for a well performing utilities as reported by Tynan and Kingdom (2002) is way below the average NRW for Livingstone Town. NRW cannot be eliminated completely as it becomes uneconomical as highlighted by Sharma (2008). Since the calculated CV was 0.04 for NRW as a percentage of water supplied which is close to zero, one can therefore conclude that NRW was almost constant. Measures should be put in place to reduce NRW to acceptable levels.

5.1.3 Historical trend of water lost per connection per year

NRW was computed in terms of the volume of water lost per connection per year to gain better understanding of performance of SWSC in Livingstone Town where management of NRW is concern as shown in Figure 5.3. Expressing NRW as a percentage indicates only the financial performance of the utility company but it is unsuitable for assessing the efficiency of management of distribution system (Liemberger and McKenzie, 2005; Liemberger *et al.*, 2007).

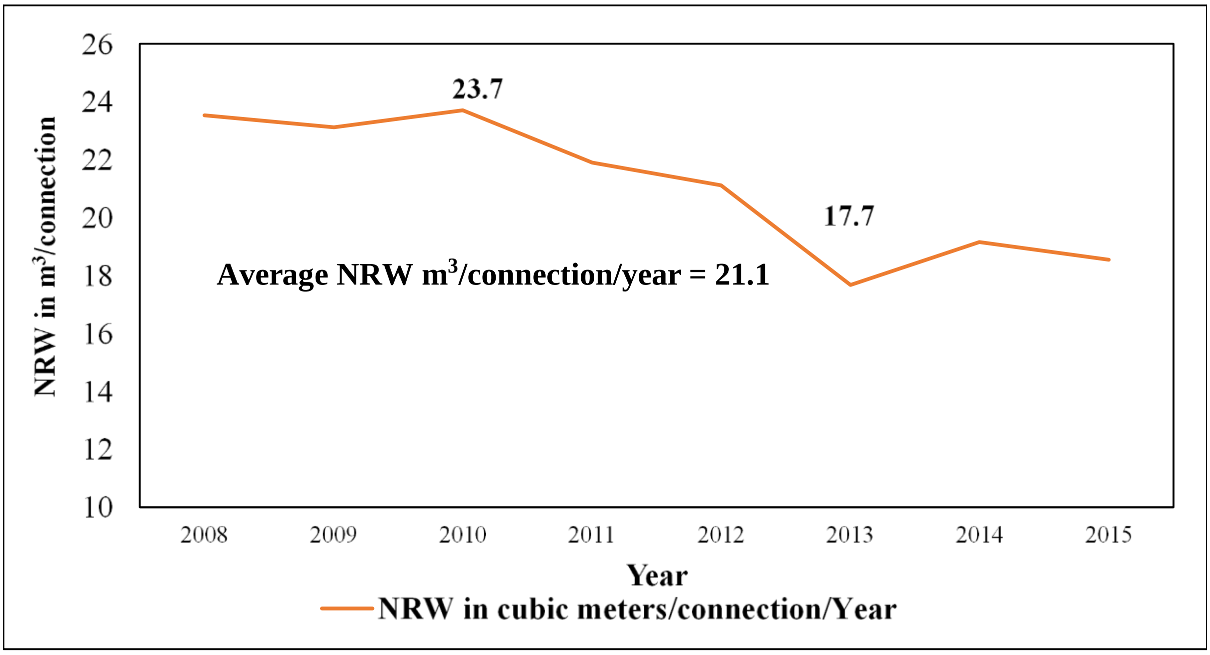


Figure 5.3: NRW in cubic meter per connection per year

From the calculated NRW in cubic meters per connection as shown in Figure 5.3, the CV was found to be 0.11 and results using the Mann-Kendall trend tests indicated that there was a negative trend observed during the period under consideration as the computed Sen's slope value was - 0.79. The computed p-value of 0.014 was also lower than the significant level 0.05 as shown in Appendix VII. The results showed that the increase in the number of water connection had a bearing on the NRW. Using average consumption of 20 m^3 which is in block two of SWSC tariff structure as shown in Appendix VIII, the amount of revenue lost in monetary terms yearly from the calculated NRW of 4.07 Mm^3/year was estimated at 1.7 million USD as shown in the calculation in Appendix VIII.

5.2 Trends of NRW for Lizuma Ward

During the period of study, bulk meter readings were taken for the specific study area every 25th of each month starting on 25th December 2015 to 25 March 2016 in order to determine the volume of water supplied to Lizuma Ward for the month January, February and April. The billed volume for the area was obtained from the commercial department Livingstone office. The water supplied and billed water in Lizuma Ward was used in the computation of the NRW. Table 5.1 summaries the bulk meter reading, water supplied, billed water and the calculated NRW in cubic meter per month for Lizuma Ward.

Table 5.1: Summary of NRW for Lizuma Ward from January to March, 2016

Months	Bulk meter reading (m^3/month)	Supplied water in (m^3/month)	Billed water (m^3/month)	NRW (m^3/month)	NRW as a percentage
Dec	480,913				
Jan	525,015	44,102	14,041	30,061	68%
Feb	569,504	42,289	15,070	27,219	64%
Mar	602,315	35,011	13,220	21,791	62%
	Average	40,467	14,110	26,357	65%

Figure 5.6 shows graphically representation of supplied, billed non-revenue water for Lizuma Ward. The average NRW for Lizuma Ward was found to be 65 % with a maximum of 68 % and minimum of 62 %.

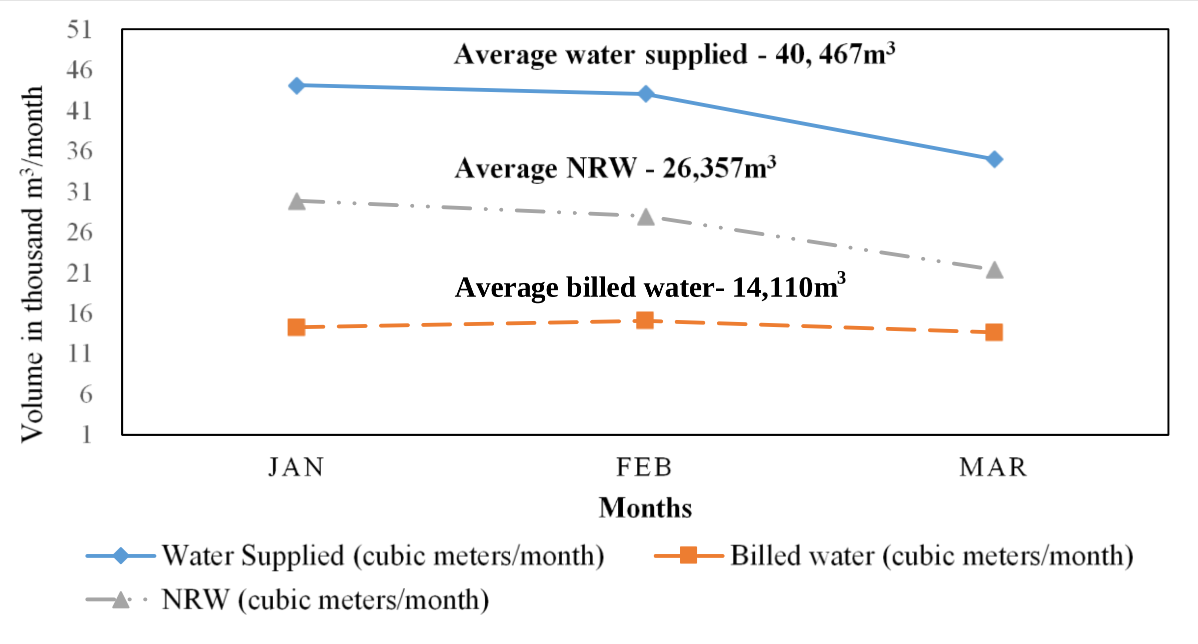


Figure 5.6: Trends of water supplied, billed water and NRW for Lizuma Ward

Statistical analysis performed on the NRW for Lizuma Ward, the CV was found to be 0.17 as shown in Appendix IX. The water lost in cubic meter per connection per month was 18.3 m^3/connection/month. The average water lost in cubic meter per kilometre per month was found to be 4,056.9 m^3/km/month. The CV for the supplied and billed water was found to be 0.12 and 0.05 respectively. This means that there was less variation in the supplied and billed volumes for the three months period as the coefficient of variations for supplied and billed volume were close to zero respectively. The average consumption of water in the low cost houses is normally in block two of SWSC tariff structure. Based on the NRW of 26,410.5 m^3/month and using average consumption 13 m^3 which is in block two as shown in tariff structure in Appendix X, the total amount of revenue lost on a monthly basis in monetary terms was estimated at 11,332.3 USD. The NRW for Lizuma Ward was way above the recommended value of 23 % by Tynan and Kingdom (2002) for a well performing utility.

5.3 Partitioning of NRW into real and apparent losses

5.3.1 Real Losses

Real losses were established using EPANET Model version 2.0 as explained in Section 4.5.1. The average Minimum Night Flow (MNF) was used in the computation of the leakage at minimum night flow (Q_{LMNF}). The consumption is at its lowest during this period as illustrated in Figure 5.7, as proposed by Tabesh *et al*. (2009).

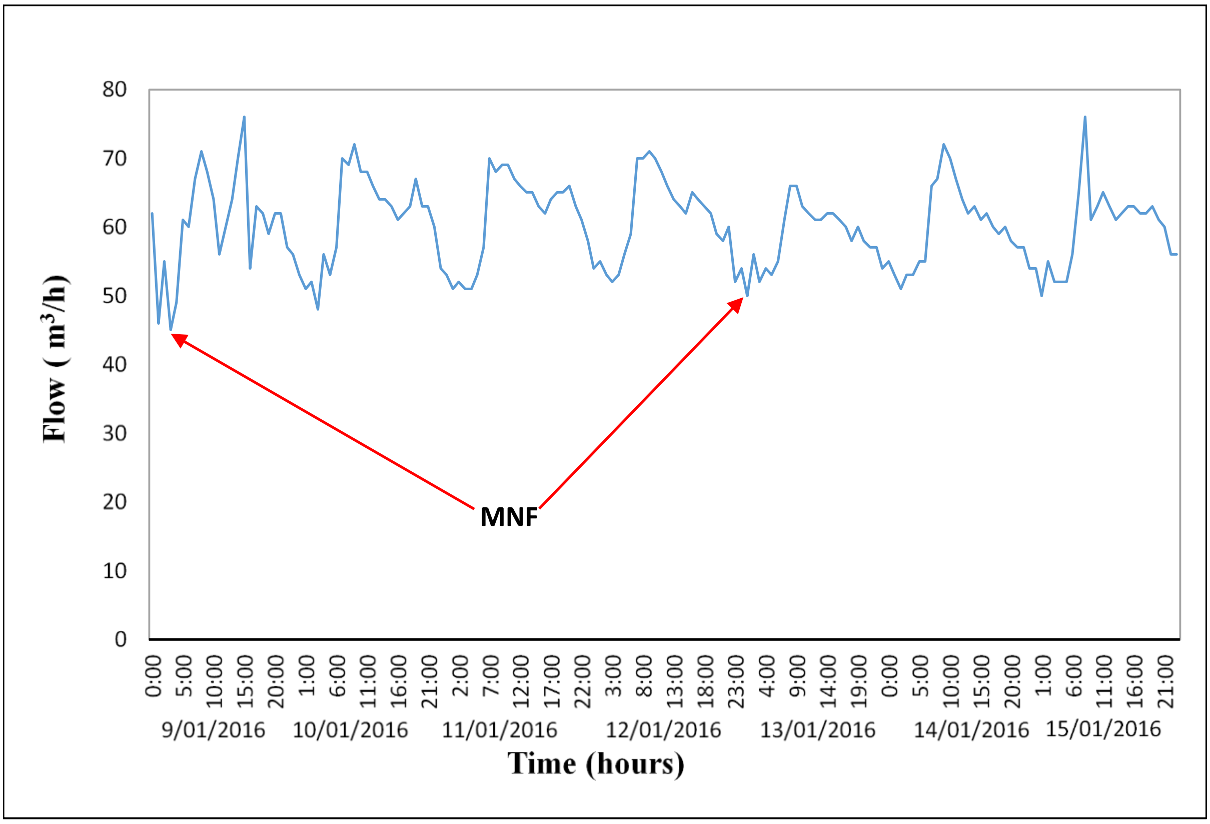


Figure 5.7: Flow variation for the period from 9/01/2016-15/01/2016

The average MNF of 50.43 l/h determined from the seven day flow logging was used in the computation of the leakage at minimum night flow. Figure 5.7 shows the flow variation at the inlet to Lizuma Ward. Boundary valves during the data collection were not opened hence they recorded zero flows. The statistical analysis performed on the measured MNF to Lizuma Ward, coefficient of variation for the 7 days period was found to be 0.07 which is close to zero. Therefore the less difference in the measured minimum night flows (MNF) was not significant during the flow logging

The Average Zonal Pressure (AZP) for the area was obtained by measuring the pressure at five different locations within the ward as shown in Figure 4.1 and Appendix XI. Figure 5.8 shows variation of pressure during the seven day logging period for the five pressure logging points. The zonal average pressure was used in the calculation of hourly leakages rate for Lizuma Ward. The ratio of average zonal pressure at any time (t) and at minimum night flow was used in the computation of the hourly leakage rate. Only the hourly average zonal pressure were used in the computations.

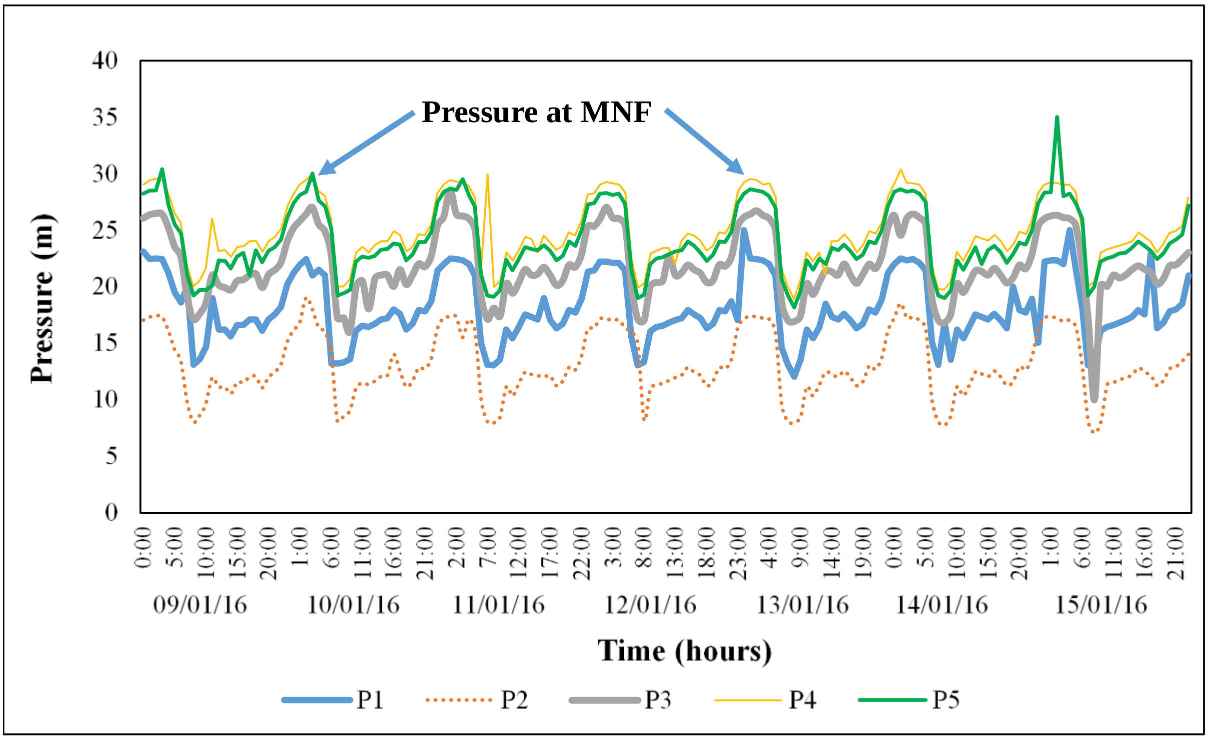


Figure 5.8: Average pressure variation for the period from 9/01/2016-15/01/2016

(P1- Inlet to Lizuma (Bus station), P2 - Dambwa Basic School, P3- Sambono Road (House No. D1, P4- Undi Street (Market) and P5- Mongu Road (House No. ZSM 2))

Hydraulic parameters: Based on the process as explained in section 4.5.1, a network map for the ward was created in EPANET and before carrying out any simulation in EPANET, certain hydraulic parameters were adjusted to that of the condition of the network under simulation. Appendix XII shows the nodal coordinates used in producing the network map of the area.

Hydraulic parameters which were used in EPANET are tabulated in Table 5.2 as suggested by Rossman, (2000).

Table 5.2: Hydraulic parameters

Items	Units/Hydraulic parameters
Flow units	Litres/second
Head loss Formulae	Hazen Williams
Specific gravity	1
Roughness	PVC pipe-145
	Asbastors-120
	Poly pipes-145
	Galvanized Iron 120

In order to calculate the night use for Lizuma Ward, computation of the population was carried out first by projecting the 2010 population (3,361 people) to 2016 at a projected growth rate of 3.2 % based on CSO (2013) census. This was done using Equation 4.20. The population projection for 2016 for Lizuma Ward was calculated as 4,061 people. Active population at night was taken as 6 % of the total population with consumption of 10 l/head/h as recommended by McKenzie (1999) based on studies carried in various parts of the world.

Thus consumption at night;

$$\text{Night use (l/hour)} = 6/100 \times 4061\text{(people)} \times 10 \text{ (l/people/h)}$$

$$= 2440 \text{ l/h}$$

After computing the night use, network leakage at MNF was calculated and used to calculate the hourly leakage rate. The leakage at MNF was calculated using Equation 4.2.

$$Q_{LMNF}\text{ (l/h)} = (50.43(\text{m}^3/\text{h})\ 10^3\ (\text{l/m}^3)) - 2440 \text{ (l/h)}$$

$$= 47990 \text{ l/h}$$

The leakage at MNF was then used to compute the hourly leakage rate taking into consideration the pressure at different time of the day using Equation 4.3 as shown in Table 5.3. The network leakage for the day was obtained by the summation of the hourly leakage rate. Table 5.3 shows the computed hourly leakage rate. The hourly leakage rate is at its highest from 01:00 hours to 04:00 hours.

Table 5.3: Calculation of the total leakage rate

Time	Average Pressure (m)	Pt/P_{MNF}	$(Pt/P_{MNF})^N$	Q_{LMNF}	Hourly leakage rate (l/d)
0:00	23.47	0.949	0.9402	47,990	45,120
1:00	24.31	0.983	0.9800	47,990	47,028
2:00	24.71	0.999	0.9988	47,990	47,934
3:00	24.73	1.000	0.9998	47,990	47,981
4:00	24.72	1.000	0.9995	47,990	47,965
5:00	24.25	0.980	0.9770	47,990	46,886
6:00	23.34	0.944	0.9339	47,990	44,818
7:00	18.96	0.767	0.7309	47,990	35,074
8:00	16.00	0.647	0.5984	47,990	28,717
9:00	15.34	0.620	0.5693	47,990	27,322
10:00	16.65	0.673	0.6268	47,990	30,081
11:00	18.38	0.743	0.7048	47,990	33,822
12:00	18.76	0.759	0.7220	47,990	34,647
13:00	18.82	0.761	0.7247	47,990	34,779
14:00	19.42	0.785	0.7518	47,990	36,078
15:00	19.37	0.783	0.7498	47,990	35,982
16:00	19.61	0.793	0.7605	47,990	36,496
17:00	19.87	0.803	0.7724	47,990	37,068
18:00	19.53	0.790	0.7569	47,990	36,322
19:00	18.76	0.759	0.7219	47,990	34,642
20:00	19.01	0.769	0.7333	47,990	35,190
21:00	20.16	0.815	0.7856	47,990	37,699
22:00	20.10	0.813	0.7829	47,990	37,570
23:00	21.03	0.851	0.8261	47,990	39,645
	Total network leakage (l/day)				**918,867**

The summation of the hourly leakage ($Q_{L,t}$) values for 24 hour periods added up to the total daily leakage (918,867 l/d). The daily leakage was then used in calculating the volumetric part of the nodal consumption by deducting it from the daily inflow to the network. The daily inflow to the area was the average inflow during the month of January, February and March which were taken from the bulk meter reading. The average inflow to Lizuma Ward was equal to 1,348,911.11 l/day. Therefore the volumetric consumption litres per day was calculated as 430,044.01 litres/day. EPANET was first run based on the pressure difference without consumptions at the nodes in order to obtain the first estimate of emitter coefficient C. The results are shown in Table 5.4.

Table 5.4: First estimation of emitter coefficient C

Nodes	Pressure	C1	Q_{ij}	Nodes	Pressure	C1	Q_{ij}
5	52.92	0.00000937807	0.135276	**42**	62.92	0.00000937807	0.105862
6	51.92	0.00000937807	0.274429	**43**	62.92	0.00000937807	0.151291
7	51.92	0.00000937807	0.189429	**44**	62.92	0.00000937807	0.271449
8	50.92	0.00000937807	0.189094	**46**	62.92	0.00000937807	0.185957
9	48.92	0.00000937807	0.134758	**47**	61.92	0.00000937807	0.17461
10	52.92	0.00000937807	0.191876	**48**	64.92	0.00000937807	0.200997
11	52.92	0.00000937807	0.198983	**49**	64.92	0.00000937807	0.185332
12	48.92	0.00000937807	0.213813	**50**	65.92	0.00000937807	0.153973
13	48.92	0.00000937807	0.156843	**51**	65.92	0.00000937807	0.125863
14	48.92	0.00000937807	0.156446	**52**	66.92	0.00000937807	0.129951
15	48.92	0.00000937807	0.150772	**53**	68.92	0.00000937807	0.546278
16	48.92	0.00000937807	0.15591	**54**	68.92	0.00000937807	0.076298
17	50.92	0.00000937807	0.085648	**55**	68.92	0.00000937807	0.12432
18	59.92	0.00000937807	0.209755	**56**	69.92	0.00000937807	0.080521
19	60.92	0.00000937807	0.148608	**57**	70.92	0.00000937807	0.163614
20	59.92	0.00000937807	0.03587	**58**	56.92	0.00000937807	0.121684
21	60.92	0.00000937807	0.148877	**59**	66.92	0.00000937807	0.076976
22	61.92	0.00000937807	0.164249	**60**	66.92	0.00000937807	0.109776
23	62.92	0.00000937807	0.170505	**61**	57.92	0.00000937807	0.17229
24	62.92	0.00000937807	0.140951	**62**	57.92	0.00000937807	0.128299
25	62.92	0.00000937807	0.181803	**63**	57.92	0.00000937807	0.148154
26	63.92	0.00000937807	0.187144	**64**	57.92	0.00000937807	0.141477
27	64.92	0.00000937807	0.191881	**65**	57.92	0.00000937807	0.118954
28	64.92	0.00000937807	0.204262	**66**	61.92	0.00000937807	0.186917
29	62.92	0.00000937807	0.292043	**67**	62.92	0.00000937807	0.163808
30	64.92	0.00000937807	0.305106	**68**	60.92	0.00000937807	0.154923
31	74.92	0.00000937807	0.648277	**69**	54.92	0.00000937807	0.13258
32	59.92	0.00000937807	0.12327	**70**	56.92	0.00000937807	0.122816
33	74.92	0.00000937807	0.12582	**71**	57.92	0.00000937807	0.092828
34	73.92	0.00000937807	0.12266	**72**	57.92	0.00000937807	0.071883
35	49.92	0.00000937807	0.142018	**73**	55.92	0.00000937807	0.271029
36	49.92	0.00000937807	0.145983	**74**	55.92	0.00000937807	0.08468
37	54.92	0.00000937807	0.224448	**77**	55.92	0.00000937807	0.252234
38	61.92	0.00000937807	0.262796	**78**	57.92	0.00000937807	0.140801
39	97.92	0.00000937807	0.492315	**79**	56.92	0.00000937807	0.126208
40	61.92	0.00000937807	0.256243	**80**	71.92	0.00000937807	0.156831
41	64.92	0.00000937807	0.258265	**82**	57.92	0.00000937807	0.26311
				Total (l/s)			**13.331**

The computed volumetric consumption was then distributed to the nodes as the consumption at each node as suggested by Tabesh et al. (2009). The distributed nodal consumption was used in the calculation of the emitter coefficient C as the second trial after running the simulation. The total volumetric consumption and the network leakage were summed up which saved as a control in the calculation of the emitter coefficient C in the iteration process (Tabesh *et al.*, 2009).

The sum of volumetric consumption and network leakage rate was 15.612 l/s. Table 5.5 gives a summary of the computed values. Step 5 to 10 as explained in section 4.5.1 gives details how the simulation were carried out in computing of physical losses. Table 5.6 shows the first trial for the simulated nodal consumption and the calculated emitter coefficient C.

Table 5.5: Summary of the calculation

Volumetric Consumption (l/s)	Network Leakage (l/s)	Distribution at each node (l/s)	Total Volumetric and Network Leakage Rate (l/s)
4.977	10.635	0.066	15.612

Table 5.6: First trial for the simulation of the leakage in the network

Nodes	C3	Qij	0.066+Qij	Nodes	C3	Qij	0.066+Qij
5	0.000024889	0.129492	0.195492	**42**	0.000024889	0.107525	0.17352467
6	0.000024889	0.232807	0.298807	**43**	0.000024889	0.153017	0.21901695
7	0.000024889	0.159739	0.225739	**44**	0.000024889	0.279099	0.34509883
8	0.000024889	0.15263	0.21863	**46**	0.000024889	0.187758	0.25375845
9	0.000024889	0.099335	0.165335	**47**	0.000024889	0.171896	0.23789635
10	0.000024889	0.165159	0.231159	**48**	0.000024889	0.212417	0.27841738
11	0.000024889	0.170285	0.236285	**49**	0.000024889	0.195629	0.26162897
12	0.000024889	0.156822	0.222822	**50**	0.000024889	0.165915	0.23191524
13	0.000024889	0.114708	0.180708	**51**	0.000024889	0.135573	0.20157252
14	0.000024889	0.114417	0.180417	**52**	0.000024889	0.142865	0.20886537
15	0.000024889	0.110188	0.176188	**53**	0.000024889	0.622376	0.68837581
16	0.000024889	0.113943	0.179943	**54**	0.000024889	0.086926	0.15292642
17	0.000024889	0.068254	0.134254	**55**	0.000024889	0.141638	0.207638
18	0.000024889	0.217594	0.283594	**56**	0.000024889	0.093299	0.15929871
19	0.000024889	0.156541	0.222541	**57**	0.000024889	0.192665	0.25866532
20	0.000024889	0.036464	0.102464	**58**	0.000024889	0.102655	0.16865473
21	0.000024889	0.151587	0.217587	**59**	0.000024889	0.084625	0.15062529
22	0.000024889	0.167856	0.233856	**60**	0.000024889	0.12082	0.18682006
23	0.000024889	0.176853	0.242853	**61**	0.000024889	0.150456	0.21645597
24	0.000024889	0.147902	0.213902	**62**	0.000024889	0.111864	0.17786364
25	0.000024889	0.189592	0.255592	**63**	0.000024889	0.129108	0.19510834
26	0.000024889	0.198241	0.264241	**64**	0.000024889	0.12329	0.18928982
27	0.000024889	0.206165	0.272165	**65**	0.000024889	0.103662	0.16966212
28	0.000024889	0.218181	0.284181	**66**	0.000024889	0.183931	0.24993079
29	0.000024889	0.300399	0.366399	**67**	0.000024889	0.165254	0.23125449
30	0.000024889	0.326281	0.392281	**68**	0.000024889	0.148836	0.21483576
31	0.000024889	0.81659	0.88259	**69**	0.000024889	0.104693	0.17069284
32	0.000024889	0.115688	0.181688	**70**	0.000024889	0.104746	0.17074576
33	0.000024889	0.15844	0.22444	**71**	0.000024889	0.081742	0.14774186
34	0.000024889	0.152291	0.218291	**72**	0.000024889	0.063266	0.12926607
35	0.000024889	0.108672	0.174672	**73**	0.000024889	0.223793	0.2897932
36	0.000024889	0.111707	0.177707	**74**	0.000024889	0.070041	0.13604105
37	0.000024889	0.183851	0.249851	**77**	0.000024889	0.209338	0.27533817
38	0.000024889	0.269486	0.335486	**78**	0.000024889	0.124372	0.19037194
39	0.000024889	0.782735	0.848735	**79**	0.000024889	0.107931	0.17393079
40	0.000024889	0.25293	0.31893	**80**	0.000024889	0.187564	0.25356383
41	0.000024889	0.273697	0.339697	**82**	0.000024889	0.232892	0.29889156
						Total	**18.215**

The iteration processes are shown in Appendix XIII while Table 5.7 shows the final results of the pressure, emitter coefficient C and demand at each node.

Table 5.7: Final simulated pressure, volumetric and network leakage rate at each node

Nodes	Pressure	C16=(C15+C12)/2	Qij	0.066+Qij	Nodes	Pressure	C16=(C15+C12)/2	Qij	0.066+Qij
5	22.3	0.000020029	0.104	0.170	42	27.88	0.000020029	0.087	0.153
6	19.75	0.000020029	0.187	0.253	43	27.78	0.000020029	0.123	0.189
7	19.65	0.000020029	0.129	0.195	44	28.17	0.000020029	0.225	0.291
8	18.57	0.000020029	0.123	0.189	46	27.74	0.000020029	0.151	0.217
9	16.52	0.000020029	0.080	0.146	47	26.72	0.000020029	0.138	0.204
10	20.38	0.000020029	0.133	0.199	48	29.75	0.000020029	0.171	0.237
11	20.28	0.000020029	0.137	0.203	49	29.72	0.000020029	0.157	0.223
12	16.45	0.000020029	0.126	0.192	50	30.71	0.000020029	0.134	0.200
13	16.41	0.000020029	0.092	0.158	51	30.7	0.000020029	0.109	0.175
14	16.41	0.000020029	0.092	0.158	52	31.71	0.000020029	0.115	0.181
15	16.4	0.000020029	0.089	0.155	53	33.66	0.000020029	0.501	0.567
16	16.4	0.000020029	0.092	0.158	54	33.66	0.000020029	0.070	0.136
17	18.37	0.000020029	0.055	0.121	55	33.66	0.000020029	0.114	0.180
18	27.03	0.000020029	0.175	0.241	56	34.64	0.000020029	0.075	0.141
19	27.84	0.000020029	0.126	0.192	57	35.62	0.000020029	0.155	0.221
20	26.57	0.000020029	0.029	0.095	58	21.55	0.000020029	0.083	0.149
21	27.05	0.000020029	0.122	0.188	59	31.71	0.000020029	0.068	0.134
22	27.58	0.000020029	0.135	0.201	60	31.74	0.000020029	0.097	0.163
23	28.38	0.000020029	0.142	0.208	61	22.58	0.000020029	0.121	0.187
24	28.66	0.000020029	0.119	0.185	62	22.55	0.000020029	0.090	0.156
25	28.51	0.000020029	0.153	0.219	63	22.54	0.000020029	0.104	0.170
26	29.35	0.000020029	0.160	0.226	64	22.54	0.000020029	0.099	0.165
27	30.17	0.000020029	0.166	0.232	65	22.54	0.000020029	0.083	0.149
28	30.02	0.000020029	0.176	0.242	66	26.71	0.000020029	0.148	0.214
29	28.18	0.000020029	0.242	0.308	67	27.72	0.000020029	0.133	0.199
30	30.05	0.000020029	0.263	0.329	68	25.75	0.000020029	0.120	0.186
31	39.84	0.000020029	0.657	0.723	69	19.66	0.000020029	0.084	0.150
32	24.83	0.000020029	0.093	0.159	70	21.75	0.000020029	0.084	0.150
33	39.83	0.000020029	0.128	0.194	71	22.74	0.000020029	0.066	0.132
34	38.83	0.000020029	0.123	0.189	72	22.73	0.000020029	0.051	0.117
35	17.4	0.000020029	0.087	0.153	73	20.79	0.000020029	0.180	0.246
36	17.4	0.000020029	0.090	0.156	74	20.82	0.000020029	0.056	0.122
37	20.28	0.000020029	0.148	0.214	77	20.88	0.000020029	0.168	0.234
38	27.66	0.000020029	0.217	0.283	78	22.8	0.000020029	0.100	0.166
39	63.43	0.000020029	0.630	0.696	79	21.8	0.000020029	0.087	0.153
40	26.78	0.000020029	0.204	0.270	80	36.6	0.000020029	0.151	0.217
41	29.82	0.000020029	0.220	0.286	82	22.84	0.000020029	0.187	0.253
Total (l/s)									**15.612**

In order to compute the losses in each pipe length Equation 4.6 was used. For example pipe 1 with total length 75.53 m joining node 61 and 69 with summation of total length of pipes that joins these nodes as 250.33 m and 305.52 m respectively, The leakage in pipe 1 was computed as follows;

$$Q_{L.ij} = Q_{L.i} \times \frac{L_{ij}}{\sum L_I} + Q_{L.j} \frac{L_{ij}}{\sum L_j} = 0.084 \times \frac{75.53_{ij}}{\sum 250.33_I} + 0.121 \frac{75.53}{\sum 305.52} = 0.0554 l/s$$

Table 5.8 gives a summary of the calculation. The summation of the leakage in each pipe length gave the total physical losses for Lizuma Ward as shown in Appendix XIV. The total real losses as shown Appendix XIV were calculated as 8.699 l/s. Therefore converting it into cubic meters per month was 22,548 m^3/month which translate to about 85 % of the real losses from the average NRW of 26,357.2 m^3/month.

Table 5.8: Determination of physical losses in for each pipe

Pipe ID	**Length**	**Start node Q_{ij}**	**End node Q_{ji}**	**ΣL_{ij}**	**ΣL_{ji}**	**Leakage (l/s)**
1	75.53	0.084251489	0.121079336	250.33	305.52	0.0554

Estimation of the real using SANFLOW model: Real losses were also estimated using the SANFLOW model so as to compare the result from the EPANET simulation model. Minimum flows from flow logging results occurring between 0:00 hours and 4 hours were taken as MNF in the analysis, as proposed by Thornton and Lambert (2005). Table 5.9 shows the default parameters which were used in the model as proposed by McKenzie (1999).

Table 5.9: Default parameters for SANFLOW model (McKenzie, 1999)

Description	**Default Value**
Background Losses from Mains	40 l/km. h
Background losses from connections	3 l/connection. h
Background losses from properties	1 l/connection. h
% of population active during night flow exercise	6%
Quantity of Water Used in toilet cistern	10l
Number of Small non-domestic users	30
Average use for small non-domestic users	50 l/h
a Use by large non-domestic users	1.2m^3/h
Background Losses Pressure Exponent	1.5
Burst/leaks pressure exponent	0.5

The minimum night flow for each day was used in the computation of the real losses. An average was then calculated as the estimated real losses for Lizuma Ward distribution network. Data logging results collected on 09-01-2016 was used as a sample calculation for estimating the real losses using Equation 4.7, 4.8 and 4.9. Measured MNF from flow logging data (Appendix XV) was 45 m^3/h and from SANFLOW Model analysis, based on Equations 4.7 and 4.8, the Excess Night Flow (ENF) was calculated as 37.76 m^3/h. The Hour Day Factor (HDF) of 18 was applied as recommended by Wegelin (2015). The hour day factor ranges from 18 to 22 hours/day, the higher value of HDF is used when there is pressure control systems in the distribution network (Wegelin, 2015).

The real losses were then calculated using Equation 4.9:

$$\text{Real Losses } (m^3/\text{month}) = \text{ENF } (m^3/h) \times (\text{h/day factor}) \times 30 \text{ days/month}$$

$$= 37.76 \ m^3/h \text{ x } 18 \text{ h/day x } 30 \text{ days/month}$$

$$= 20{,}390.40 \ m^3/\text{month}$$

Table 5.10 shows the summary of the calculation and Appendix XV gives a detailed computation of the real losses for each day.

Table 5.10: Summary of the calculation of real losses

Date of Measurement	Measured Minimum Night Flow (MNF) (m^3/h)	Excess Night Flow (ENF) (m^3/h)	Real Loss (m^3/month)
9/1/2016	45	37.76	20,390
10/1/2016	47	39.68	21,429
11/1/2016	47	39.76	21,470
12/1/2016	50	42.78	23,103
13/01/2016	49	41.80	22,574
14/01/2016	48	40.72	21,990
15/01/2016	49	41.72	22,531
Average			**21,927**

The real losses were estimated as 21,927 m^3/month, therefore contributing about 83 % to NRW. The difference between the estimated real losses from EPANET hydraulic simulation model (85 %) and SANFLOW model (83 %) was 2 %. This therefore shows that there is no big difference from the real losses calculated from EPANET hydraulic simulation model.

This analysis concluded that real losses (85 %) were the main contributing factor to NRW. This might be attributed to the leakages in the network. There is no active leak detection activity in the Lizuma Ward as the utility mostly depends on the complaints from customers in detection of leakages. The customers mostly report the leakage once they are affected as very few would report leakages/bursts based on the findings from the questionnaires administered. Only 31 % indicated that they have reported leakage/burst while 69 % have never as shown in Table 5.11. Appendix XVI shows an example of the questionnaire used.

Table 5.11: Summary of the household survey

No	Major issues	Values and Frequencies			
1	Colour of water	Clear	Brownish after rains	Brownish after intermittent water supply	Generally clear
		54.9 %	28.2 %	9.9 %	7.0 %
2	Number of days of continuous water supply	Less than 3 days	3 - 5 days	5 - 7 days	
		0	29.6 %	70.4 %	
3	Water supply hours in a day	Less than 5 hours	6 -11 hours	11 - 24 hours	
		0	22.50 %	77.50 %	
4	Number of people reporting on pipe bursts/Leakages	Reported	Have never reported		
		31.0 %	69.0 %		
5	Causes of pipe bursts and leakages	High pressure	Vandalism	Ageing infrastructure	Poor workmanship
		43.3 %	9.9 %	25.4 %	22.5 %
6	Views on service level of SWSC	Poor	Good	Very Good	Excellent
		23.9 %	43.7 %	29.6 %	2.8 %

Tabesh and Saber (2012) stated that phenomena in water supply systems such as leakages are a function of pressure. The continuous water supply coupled with old pipes (over 15 years) in some parts of the network might results in a high leakage rate and bursts as 77.5 % households receive 12 to 24 hours of water supply in Lizuma Ward while 22.5 % receives about 6 -11 hours of supply based on the questionnaire administered as summarized in Table 5.11 . Most of the time the network is pressurized.

Comparison between measured and simulated flows into Lizuma Ward: In order to check the performance of the model, a validation process was carried out by comparing the measured and simulated inflow to Lizuma Ward. The measured inflow was plotted together with the simulated inflow to Lizuma Ward against a 24 hour time period as illustrated in Figure 5.9.

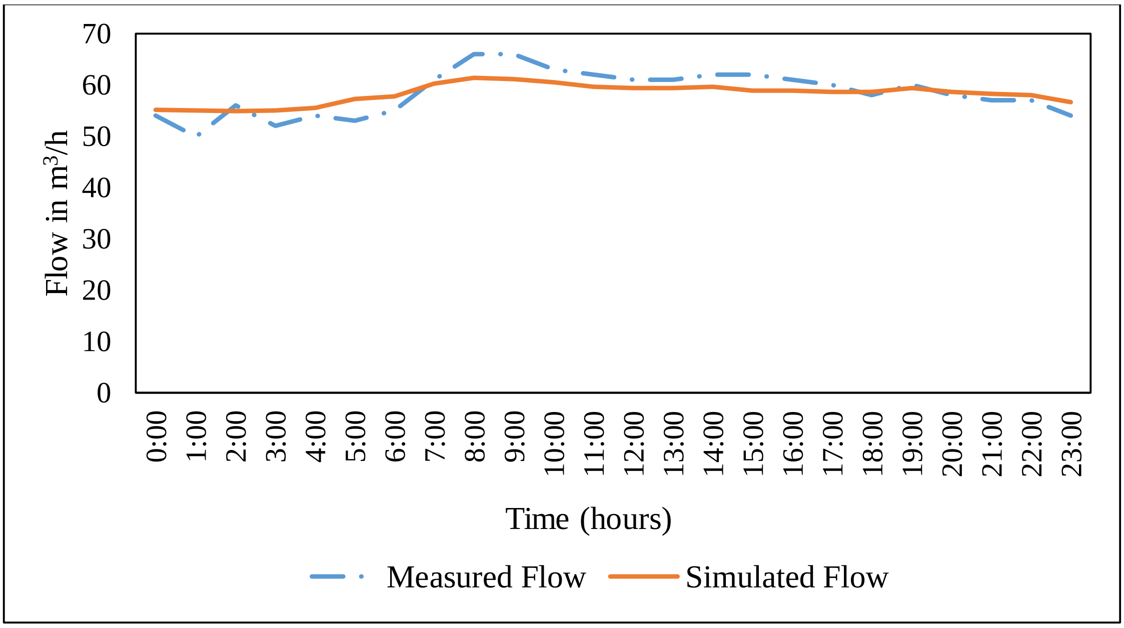


Figure 5.9: Comparison between measured and simulated flows into Lizuma Ward

Statistical analysis was performed using a t-test on the simulated and the measured inflow to Lizuma Ward. Results showed that the p-value (0.852) was greater than the significant level (0.05) as calculated in Appendix XVII. It can therefore be deduced that there was no different between the mean of the measured inflow and the simulated inflow to Lizuma Ward. The results from the t-test show the reliability of using EPANET in estimating the real losses. EAPENT is a free software which is available online. Most of the models like SANFLOW have parameters that need to be assessed for one to come up with the actual consumption to avoid a lot of errors when estimating real losses in a particular country. In order to use such models in a different part of the world, there is need that experiments are carried out on different consumption like domestic household, industrial and non-domestic properties since the life styles are different. Studies carried by Mutikanga *et al*. (2011a) in Uganda used 10 l/property/h for quantifying the property losses when estimating background losses while McKenzie 1999 proposed 1 l/property/hour. EPANET hydraulic simulation model is therefore cheaper and time serving in estimating of real losses in a water distribution network compared to other methods.

Comparison between measured and simulated Pressure in Lizuma Ward: Comparison of measured and simulated pressure was carried out in order to check if there was a significance difference between the simulated and measure pressure using a t-test on five different locations were pressure logging was carried out. One of the locations was at the inlet to Lizuma Ward and the other ones were within the Ward. Figure 5.11 and 5.12 shows the plots of simulated and measured pressure at P1, P2, P3, P4 and P5 as shown in the network map Figure 5.10. The t-tests performed on the simulated and measured pressure gave p-values of 0.842, 0.18, 0.131, 0.247 and 0.66 which was greater than the significance level of 0.05.

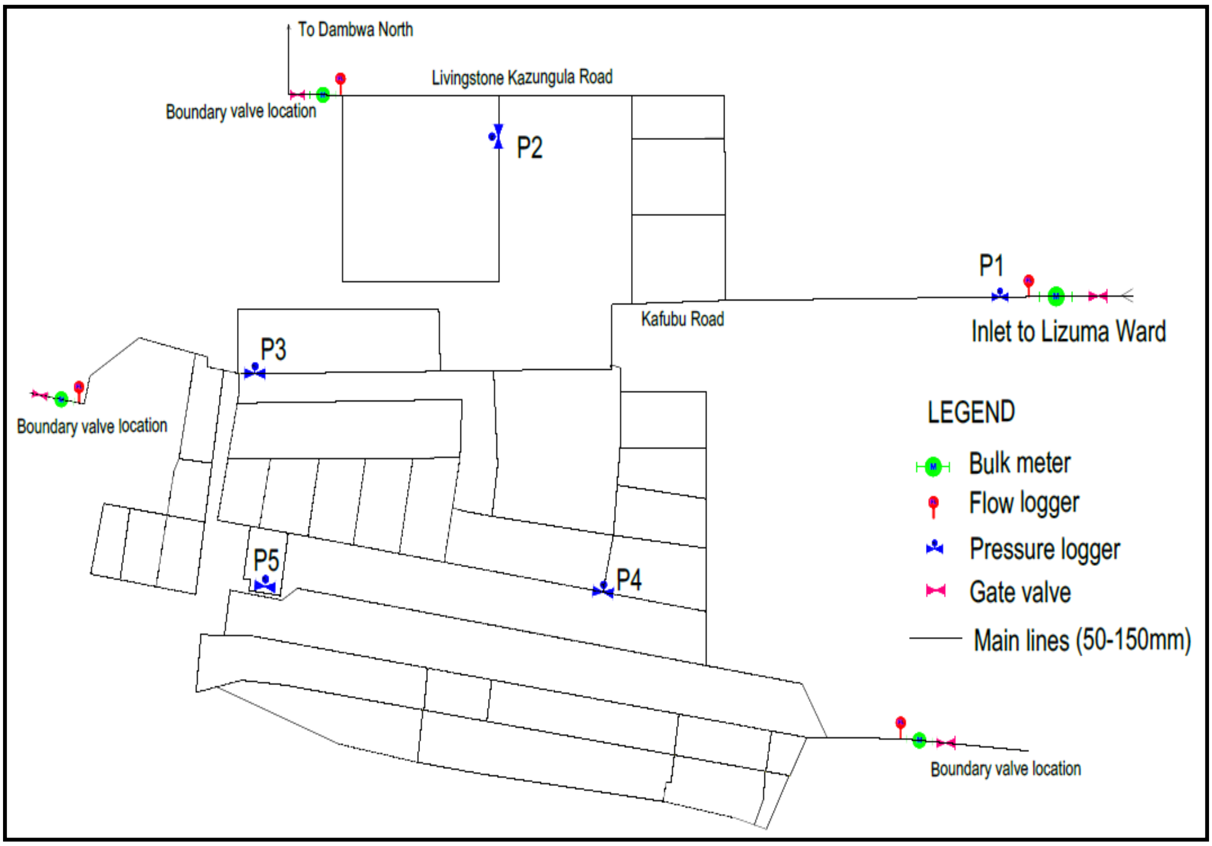
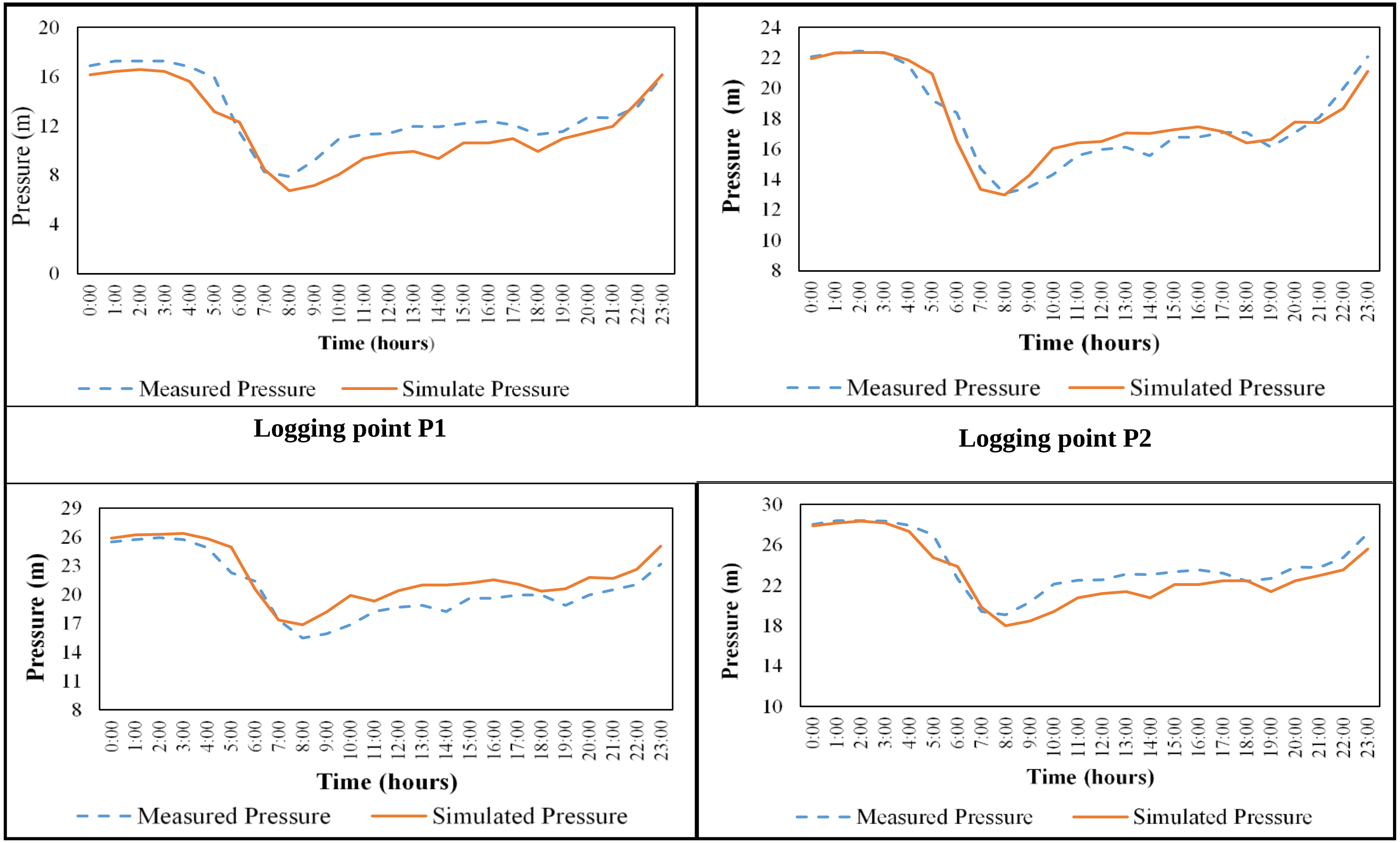


Figure 5.10: Lizuma Ward water network map



Logging point P3 **Logging point P4**

Figure 5.11: Comparison between measured and simulated pressure at P1, P2, P3 and P4

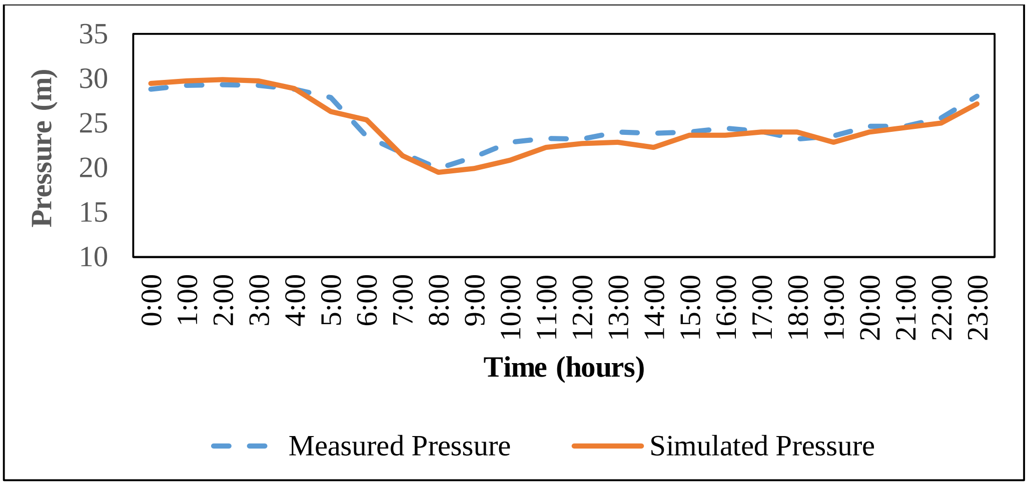


Figure 5.12: Comparison between measured and simulated pressure at logging point P5

The summary of results of the t-tests performed is shown in Appendix XVIII. The t-test results on all the logging points showed a p-value greater than the significant level (0.05). This shows that there was no difference between the mean of measured and simulated pressure. It can therefore be deduced that there was no difference between the measured and simulated pressure hence EPANET gave accurate results of real losses estimation thus showing the reliability of using EPANET in determining the real losses.

Infrastructure Leakage Index (ILI) computation: In order to check on the performance of the utility, Infrastructure Leakage Index (ILI) which is the ratio of the Current Annual Real Losses (CARL) to the UARL had to be computed for Lizuma Ward as recommended by Lambert and McKenzie, (2005). Equation 4.10 was used to compute UARL. The total length and list of accounts of the unmetered connection is shown in Appendix XIX. The average pressure (26.3 m) from the results of EPANET was used in the calculation of UARL.

Thus; UARL (l/day) = ((18 × 6.496) + (0.8 × 1442) + (25×0.454)) × 26.3

= 39,653.18 l/day

Changing the UARL into cubic meters per month and computing the ILI using Equation 4.11, the ILI was found to be 22.3 according to the calculation below;

$$\text{ILI} = \frac{22{,}548}{1011.79} = 22.3$$

From the calculated ILI of 22.3 compared to least technical performance category (D) for low and middle income countries in Table 5.12 World Bank Institute Banding System. It shows that there was very inefficient use of resources which is an indicative of poor maintenance, lack of active leak detection, and system condition in general as the calculated ILI (22.3) was higher than ILI of 16 as shown in Table 5.12 (Lambert and McKenzie, 2005).

Table 5.12: Word Bank Institute Banding System (Liemberger and McKenzie, 2005)

Technical Performance category	ILI		Real losses in litres/connection/day When the system is pressurized at an average pressure of:				
			10m	20m	30m	40m	50m
High income countries	A1	<1.5		< 25	< 40	< 50	< 60
	A2	1.5 - 2		25 - 50	40 - 75	50 - 100	60 - 125
	B	2 - 4		50 - 100	75 - 150	100 - 200	125 - 250
	C	4 - 8		100 - 200	150 - 300	100 - 400	250 - 500
	D	> 8		> 200	> 300	> 400	> 500
Low and middle income countries	A1	< 2	< 25	< 50	< 75	< 100	< 125
	A2	2 - 4	25 - 50	50 - 100	75 - 150	100 - 200	125 - 250
	B	4 -8	50 - 100	100 - 200	150 - 300	200 - 400	250 - 500
	C	8 - 16	100 - 200	200 - 400	300 - 600	400 - 800	500 - 1,000
	D	> 16	> 200	> 400	> 600	> 800	> 1,000

Liemberger and Mckenzie (2005) highlighted that ILI is the most appropriate performance indicator for real losses as recommended by IWA and AWWA. It can therefore be concluded that the main contributing factor to high NRW were the real loses as there was less asset maintenance, lack of active leak detection and lack of speedy and quality leakage repair. This is therefore causing the high leakage rate of 85% as estimated in section 5.3.1.

5.3.2 Apparent Losses

The NRW is made up of apparent and real losses; the Total Apparent Losses was therefore computed by subtracting the real losses from the average NRW as illustrated in Equation 4.12

Thus; TAPL (m^3/month) = Average NRW – RL

=26,537 (m^3/month) - 22,548(m^3/month)

= 3,989 m^3/month

The TAPL contribution was found to be 15 % of NRW which was made up of billing anomalies, unauthorized consumption and meter inaccuracy. Studies done in Kampala City in Uganda by Mutikanga *et al*. (2011a) found out that the total apparent water losses were found to be 37 % of which metering inaccuracies, meter reading errors, billing error and authorized consumption contribution to apparent water losses were 22%, 1.4%, 3.5% and 10% respectively. It was therefore prudent to partition the apparent water into its various components so as to determine the different contribution factors to TAPL. This helps in setting target for the reduction of NRW since the main factors contributing to apparent water losses will be known.

Apparent losses due to meter inaccuracy: A total of 25 customer meters were uninstalled using stratified sampling. Five (5) meters were sampled from each of the five section in Lizuma Ward. Tests were carried out at three different flowrates namely; low, medium and high as recommended by Arregui *et al*. (2005) at the SWSC Livingstone laboratory using a Tec meter testing beach. From the 25 meters sampled, 2 meters were found to be stuck as they could not record any flow. The meters which were tested were the dry dial electromed multi jet type of meters. The volume lost due to metering error was found by first determining the weighted metering error using Equation 4.14. The results showed that the average meter errors at low flow rate, medium flow rate and high flow rate tests were 2.2 %, 2.9 % and 3.3% respectively. The volume used at low, medium and high flows was 10,100,100 litres respectively. The results showed that the metering error at low flows was within the tolerable accuracy of ± 5, therefore it was not considered in calculating the weighted metering error. The metering errors at medium and high flow were not within the tolerable accuracy of ± 2 hence they were used in the computation of weighted metering error. The results of the meter testing are tabulated in Appendix XX. The results showed that the meters were over registering by 3.1 % to TAPL.

$E_w = ((2.9 \times 100)/ 200) + (3.3 \times 100)/ 200 = 3.1\ \%$

Therefore the volume increase in billing due to meter error was computed using Equation 4.15.

$V_{LM} = 3.989\ (m^3/month) \times 3.1/100 = 123.7\ m^3/month$

Apparent losses due to billing anomalies: The apparent losses due to billing anomalies were determined by carrying out an independent reading exercise as recommended by Mutikanga *et al*. (2011a) at the same time when SWSC meter readers were getting the meter reading which is carried out from 20^{th} to 25^{th} of each month. The consumption which was used in calculating the billing error factor was for January and February. This helped in eliminating errors since the average consumption of two months was used in the calculation of billing error factor. The minimum sample size was determined based on Strattek (2007) Equation as explained in section 4.5.2. A total of 71 customer meter reading were read for each particular month and the billing error factor was determined by Equation 4.17 as explained in section 4.5.2. The consumption for each particular month was used in the calculating of the billing error factor. The average billing error factor was then calculated from the two calculated billing error factor to come up with the actual billing error factor. Appendix XXI gives a summary of the meter readings taken by independent and SWSC meter readers for each month respectively.

The January billing error factor was computed as follows;

Total monthly measured consumption for all sampled customers from independent meter reading,

V = 1468.12 m^3/month

Total monthly billed consumption for all sampled customers by SWSC commercial department

V = 1253 m^3/month

For a sample size of n customers, the billing error factor is given by:

$$\mathrm{BEF} = \frac{\sum_{i=1}^{n} V_{SWSCi} - \sum_{i=1}^{n} V_{IMRi}}{\sum_{i=1}^{n} V_{IMRi}} = \frac{1253 - 1468.12}{1468.12} = -\,0.15$$

The February billing error factor was computed as follows;

Total monthly measured consumption for all sampled customers from independent meter reading,

V = 1456.58 m^3/month

Total monthly billed consumption for all sampled customers from SWSC commercial department SWSC,

V = 1141.58m^3/month

For a sample size of n customers, the billing error factor was calculated as:

$$\mathrm{BEF} = \frac{\sum_{i=1}^{n} V_{SWSCi} - \sum_{i=1}^{n} V_{IMRi}}{\sum_{i=1}^{n} V_{IMRi}} = \frac{1141.58 - 1456.58}{1456.58} = -0.22$$

The actual billing error factor was then computed by averaging the two calculated billing error factor for the two months. This assisted in having a true reflection since a proper representation occurring was able to be captured as there was reduction in the error which would have occurred if only one independent reading sample was taken. The apparent water loss due to billing anomalies was computed using Equation 4.18.

$$\mathrm{BEF_{Av}} = \frac{\mathrm{BEF_{Jan}} + \mathrm{BEF_{Feb}}}{2} = \frac{0.15 + 0.22}{2} \times 100 = -18\ \%$$

The volume of water lost due to billing anomalies was than computed as follows;

Thus;

L_{TWBA} (m^3/month) $=$ TAPL $\times$ BEF_{AV}

$= 3{,}989$ (m^3/month) $\times$ 18/100

$= 718.02$ m^3/month

Unauthorized consumption: Apparent water losses comprises of billing errors, billing anomalies and unauthorized consumption. In order to determine the unauthorized consumption, the billing anomalies were subtracted from the total apparent water losses as the calculated billing anomalies were in negative meaning there was loss in revenue. There was gain in revenue due to metering error as the meters were over registering. Therefore to compute unauthorized consumption Equation 4.19 was used with losses due to metering error being positive.

L_{UAC} (m^3/month) $=$ TAPL (m^3/month) + L_{LM} (m^3/month) – L_{TWBA} (m^3/month)

$= 3{,}989$ (m^3/month) +123.7 (m^3/month) – 718.02 (m^3/month)

$=3{,}394.68$ m^3/month

Therefore unauthorized consumption contribution to total apparent water losses was 85.1 %. In conclusion the main contributing factor to the apparent losses in Lizuma Ward was the unauthorized consumption while the billing anomalies (under billing) contribution was 18 %. The meters were over registering by 3.1 %. This therefore reflects lack of proper tracking of unauthorized consumption in the area by the water audit team.

Knobloch (2015) stated that the water loss task force of the International Water Association (IWA) came up with the standardized form of water balance which has been adopted uniformly worldwide. Figure 5.13 shows a summary of agreed format of NRW calculation of NRW.

The total real losses comprised of leakage on transmission and/or distribution mains and leakage on Service Connections in Lizuma Ward.

Table 5.13: Summary of the calculated breakdown of the NRW

Water supplied ***40,467.3 m^3/month***	Authorized Consumption ***14,815.5 m^3/month***	Billed Authorized Consumption ***14,110 m^3/month***	Billed Metered Consumption ***12,410 m^3/month***	Revenue Water ***14110.0 m^3/month***
			Billed Unmetered Consumption ***1700.0 m^3/month***	
		Unbilled Authorized Consumption ***705.5 m^3/month***	Unbilled Metered Consumption ***529.1 m^3/month***	Non-Revenue Water(NRW) ***26,357.3 m^3/month***
			Unbilled Unmetered Consumption ***176.4 m^3/month***	
	Water Losses ***25,651.8 m^3/month***	Apparent Losses ***3,989.0 m^3/month***	Unauthorized Metering Consumption ***3394.7m^3/month***	
			Customer Metering Inaccuracies ***-123.7 m^3/month***	
			Data Handling Errors ***718 m^3/month***	
		Real Losses ***21,662.8 m^3/month***	Leakage on Transmission and/or Distribution Mains	
			Leakage on Service Connections	

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

From this study, the following conclusions were made:

1. The study established that there was no distinctive trend observed for NRW for the eight year (2008-2015) period. The average NRW of 45 % for Livingstone Town as well as 65% for Lizuma Ward were found to be higher than the recommended NRW of 23 % for developing countries in Africa.
2. EPANET was successfully used in the estimation of real losses for Lizuma Ward. The contribution of real losses to non-revenue water was found to be 85 % in Lizuma Ward.
3. The main contributing factor to NRW was the real losses while apparent water losses contributed 15%. The study established that the main contributing factor to apparent losses were unauthorized consumption (85.1 %). The meters were found to be over registering by 3.1% and there was under billing of 18 %.

6.2. Recommendations

The following recommendations were made;

Short term

1. SWSC water audit team should consider investigating unauthorized consumption in Lizuma Ward.
2. SWSC should consider using EPANET in determining leakages in the distribution system. This will assist in prioritizing the areas where the pipe replacements needs to be carried since the results from EPANET will give the exact location where the leakages are occurring. This will help to in reducing NRW real losses being the main contribution factor to NRW.

Long term

1. There is need for replacement of old pipes to avoid the loss of water as real losses are the main contributors to the water losses.

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APPENDICES

Appendix I: Water leakages in Lizuma Ward

Using improper fitting for sealing a leakage on a 50 mm AC pipe in Villa Estate

Background leakage along Kafubu Road

Leakage on the connection line connecting the water meter in Zambezi Sawmills

Pipe burst near the Dambwa community hall

Appendix II: NRW calculation for 8 years (2008-2015)

Table IIa

Months	Metered	Unmetered	Total consumption m^3	Supplied volume m^3	NRW m^3	NRW
Jan-08	191925	145673	337598	721152	383554	53%
Feb-08	220880	144273	365153	714439	349286	49%
Mar-08	230267	145903	376170	710562	334392	47%
Apr-08	260358	148173	408531	713523	304992	43%
May-08	256861	150754	407615	725421	317806	44%
Jun-08	262096	152551	414647	718335	303688	42%
Jul-08	241762	151465	393227	700132	306905	44%
Aug-08	229685	152551	382236	615706	233470	38%
Sep-08	256700	156199	412899	721132	308233	43%
Oct-08	273063	157552	430615	715439	284824	40%
Nov-08	284413	158275	442688	723033	280345	39%
Dec-08	210457	161686	372143	720754	348611	48%
			4,743,522	***8,499,628***		
Jan-09	250421	146672	397093	772669	375576	49%
Feb-09	238853	145273	384126	710572	326446	46%
Mar-09	228741	145904	374645	712522	337877	47%
Apr-09	255899	149173	405072	701589	296517	42%
May-09	263740	150766	414506	715215	300709	42%
Jun-09	240692	152442	393134	725421	332287	46%
Jul-09	240095	154475	394570	719334	324764	45%
Aug-09	274598	152552	427150	728410	301260	41%
Sep-09	259545	156199	415744	739322	323578	44%
Oct-09	238952	157543	396495	677540	281045	41%
Nov-09	254124	158376	412500	705799	293299	42%
Dec-09	220915	161677	382592	710632	328040	46%
			4797627	***8619025***		

Appendix II continued

Table IIb

Months	Metered	Unmetered	Total consumption m^3	Supplied volume m^3	NRW m^3	NRW
Jan-10	256,583	145572	402,155.00	736122	333967	45%
Feb-10	236,340	144273	380,613.00	756971	376358	50%
Mar-10	210,573	145813	356,386.00	718182	361796	50%
Apr-10	245,359	146273	391,632.00	725644	334012	46%
May-10	232,523	151744	384,267.00	710672	326405	46%
Jun-10	238,272	151543	389,815.00	712522	322707	46%
Jul-10	241,431	151455	392,886.00	702589	309703	46%
Aug-10	245,545	152552	398,097.00	715215	317118	46%
Sep-10	238,943	156199	395,142.00	725321	330179	46%
Oct-10	246,340	157552	403,892.00	718333	314441	46%
Nov-10	250,221	139611	389,832.00	728410	338578	46%
Dec-10	237,745	143596	381,341.00	759322	377981	50%
			4,666,058	***8,709,303***		
Jan-11	229532	145673	375,205.00	733413	358208	49%
Feb-11	203429	144273	347,702.00	657100	309398	47%
Mar-11	238271	145903	384,174.00	710632	326458	46%
Apr-11	245546	148173	393,719.00	717123	323404	45%
May-11	254477	150754	405,231.00	710632	305401	43%
Jun-11	250432	152551	402,983.00	778956	375973	48%
Jul-11	252017	151465	403,482.00	721263	317781	44%
Aug-11	274751	152551	427,302.00	725648	298346	41%
Sep-11	265588	156199	421,787.00	733569	311782	43%
Oct-11	276654	157552	434,206.00	742612	308406	42%
Nov-11	241740	158275	400,015.00	715023	315008	44%
Dec-11	246944	161686	408,630.00	742789	334159	45%
			4,804,436.00	***8688760***		

Appendix II continued

Table IIc

Months	Metered	Unmetered	Total consumption m^3	Supplied volume m^3	NRW m^3	NRW
Jan-12	248462	142663	391,125.00	753618	362493	48%
Feb-12	225466	143093	368,559.00	799885	431326	54%
Mar-12	231223	151126	382,349.00	725634	343285	47%
Apr-12	276674	151463	428,137.00	742354	314217	42%
May-12	247981	152629	400,610.00	728273	327663	45%
Jun-12	275126	157995	433,121.00	783109	349988	45%
Jul-12	258993	161578	420,571.00	783899	363328	46%
Aug-12	266191	163255	429,446.00	755215	325769	43%
Sep-12	275578	166588	442,166.00	744244	302078	41%
Oct-12	244617	168400	413,017.00	788854	375837	48%
Nov-12	247246	169916	417,162.00	744244	327082	44%
Dec-12	238143	172419	410,562.00	742891	332329	45%
			4,936,825.00	***9,092,220.00***		
Jan-13	218120	167394	385,514.00	731378	345864	47%
Feb-13	217354	169596	386,950.21	681234	294283.8	43%
Mar-13	242146	174111	416,257.31	674278	258020.7	38%
Apr-13	241233	176693	417,925.94	720201	302275.1	42%
May-13	230028	179225	409,252.64	730895	321642.4	44%
Jun-13	241333	181826	423,158.68	732895	309736.3	42%
Jul-13	230885	184364	415,248.96	714823	299574	42%
Aug-13	231631	184915	416,546.40	727825	311278.6	43%
Sep-13	231631	184914	416,545.00	737125	320580	43%
Oct-13	212459	184844	397,302.58	729525	332222.4	46%
Nov-13	203385	189666	393,051.49	681043	287991.2	42%
Dec-13	186125	192226	378,350.76	737935	359584.2	49%
			4,856,103.97	***8,599,156.73***		

Appendix II continued

Table IId

Months	Metered	Unmetered	Total consumption m^3	Supplied volume m^3	NRW m^3	NRW
Jan-14	189566	200976	390,542.19	745789	355246.8	48%
Feb-14	191661	198104	389,765.11	743438	353672.9	48%
Mar-14	210226	188753	398,978.54	734569	335590.5	46%
Apr-14	223226	173039	396,265.48	702230	305964.5	44%
May-14	163411	113938	277,348.76	705707	428358.2	61%
Jun-14	235440	108914	344,354.32	756892	412537.7	55%
Jul-14	228239	114322	342,560.97	715028	372467	52%
Aug-14	234861	129764	364,624.70	738456	373831.3	51%
Sep-14	249198	110378	359,576.16	744244	384667.8	52%
Oct-14	231901	107844	339,745.11	726939	387193.9	53%
Nov-14	242764	119116	361,880.18	749768	387887.8	52%
Dec-14	253882	258056	511,937.83	769532	257594.2	33%
			4,477,579.35	***8,832,592.00***		***593%***
Jan-15	235220	251059	486,278.67	837629	351350.3	42%
Feb-15	239877	232785	472,661.56	865221	392559.4	45%
Mar-15	239607	240019	479,626.25	799571	319944.8	40%
Apr-15	236244	223162	459,406.26	806499	347092.7	43%
May-15	259409	221192	480,600.50	820036	339435.5	41%
Jun-15	262074	222793	484,867.16	885853	400985.8	45%
Jul-15	255706	231597	487,303.43	845231	357927.6	42%
Aug-15	278787	239106	517,893.28	887393	369499.7	42%
Sep-15	290099	243064	533,162.94	898920	365757.1	41%
Oct-15	296240	249407	545,646.79	890333	344686.2	39%
Nov-15	301845	227170	529,015.31	891556	362540.7	41%
Dec-15	284117	221947	506,063.56	1000540	494476.4	49%
			5,982,525.71	***10428782***		

Appendix III: Water supplied from 2008-2015 statistical analysis

Supplied Volume: XLSTAT 2016.02.27444 - Mann-Kendall trend tests - Start time: 4/7/2016 at 9:02:50 PM / End time:4/7/2016 at 9:02:50 PM

Confidence interval (%): 5
Confidence interval (%)(Sen's slope): 5

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation	CV
Supplied Volume million cubic meter	8	0	8	8.500	10.430	9.024	0.645	0.071

Mann-Kendall trend test / Two-tailed test (Supplied Volume million cubic meter):

Kendall's tau	0.429
S	12.000
Var(S)	0.000
p-value (Two-tailed)	0.179
alpha	0.05

The p-value is computed using an exact method.
Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The risk to reject the null hypothesis H0 while it is true is 17.89%.

Appendix IV: Billed water from 2008-2015 statistical analysis

XLSTAT 2016.02.27444 - Mann-Kendall trend tests - Start time: 4/7/2016 at 9:06:26 PM / End time:4/7/2016 at 9:06:27 PM

Confidence interval (%): 5
Confidence interval (%)(Sen's slope): 5

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation	CV
Billed Volume million cubic meter	8	0	8	4.480	5.980	4.959	0.446	0.09

Mann-Kendall trend test / Two-tailed test (Billed Volume million cubic meter):

Kendall's tau	0.255
S	7.000
Var(S)	64.333
p-value (Two-tailed)	0.454
alpha	0.05

The exact p-value could not be computed. An approximation has been used to compute the p-value.
Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The risk to reject the null hypothesis H0 while it is true is 45.44%.

Appendix V: NRW in cubic meter per year (2008-2015) statistical analysis

XLSTAT 2016.02.27444 - Mann-Kendall trend tests - Start time: 4/7/2016 at 9:09:27 PM / End time:4/7/2016 at 9:09:27 PM

Confidence interval (%): 5
Confidence interval (%)(Sen's slope): 5

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation	CV
NRW in million cubic meter	8	0	8	3.740	4.450	4.066	0.299	0.073437

Mann-Kendall trend test / Two-tailed test (NRW in million cubic meter):

Kendall's tau	0.473
S	13.000
Var(S)	64.333
p-value (Two-tailed)	0.135
alpha	0.05

The exact p-value could not be computed. An approximation has been used to compute the p-value.
Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The risk to reject the null hypothesis H0 while it is true is 13.46%.

Appendix VI: NRW as a percentage of supplied volume statistical analysis

XLSTAT 2016.02.27444 - Mann-Kendall trend tests - Start time: 4/7/2016 at 8:47:44 PM / End time:4/7/2016 at 8:47:44 PM

Confidence interval (%): 5
Confidence interval (%)(Sen's slope): 5

Summary statistics

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation	CV
NRW	8	0	8	0.430	0.490	0.451	0.019	0.0418

Mann-Kendall trend test / Two-tailed test (NRW):

Kendall's tau	0.077
S	2.000
Var(S)	60.667
p-value (Two-tailed)	0.898
alpha	0.05

The exact p-value could not be computed. An approximation has been used to compute the p-value.
Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0. The risk to reject the null hypothesis H0 while it is true is 89.78%.

Appendix VII: Statistical analysis of NRW in cubic meters/connection/year

XLSTAT 2016.02.27444 - Mann-Kendall trend tests - Start time: 5/27/2016 at 11:59:18 AM

Confidence interval (%): 5

Confidence interval (%)(Sen's slope): 5

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation	CV
NRW cubic meter /Connection/year	8	0	8	17.660	23.696	21.090	2.377	0.112722

Mann-Kendall trend test / Two-tailed test (NRW cubic meter /Connection/year):

Kendall's tau	-0.714
S	-20.000
Var(S)	0.000
p-value (Two-tailed)	0.014
alpha	0.05

The p-value is computed using an exact method.

Test interpretation:

H0: There is no trend in the series

Ha: There is a trend in the series

As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.

The risk to reject the null hypothesis H0 while it is true is lower than 1.41%.

Sen's slope: -0.79

Appendix VIII: Calculation of revenue loss in monetary terms

Table VIIIa: Southern Water and Sewerage Company Limited block tariff structure

	Blocks (m^3)	Amount in ZMK	Amount in USD
1	0-6	3.2	0.291
2	6-20	4.72	0.429
3	20-50	5.62	0.511
4	50 and above	6.48	0.589

Exchange rate 1 USD to 11 ZMK

Average losses for the eight year period in monetary terms

Using block two the average consumption being at $20m^3$ which is at a rate of 4.72 ZMK. Since the average NRW in Cubic meter was 4.07 Mm^3, therefore the revenue loss can be computed as follows;

$4.07\times10^6 \times 4.72 = 19.21$ million ZMK

Therefore in USD was at 1.7million USD

Appendix IX: NRW for Lizuma Ward statistical analysis

XLSTAT 2016.02.27444 - Mann-Kendall trend tests - Start time: 4/8/2016 at 5:47:13 PM / End time:4/8/2016 at 5:47:17 PM

Confidence interval (%): 5
Confidence interval (%)(Sen's slope): 5

Summary statistics

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation	CV
NRW for the study area	3	0	3	21.390	29.860	26.410	4.448	0.1684

Mann-Kendall trend test / Two-tailed test (NRW for the study area):

Kendall's tau	-1.000
S	-3.000
Var(S)	0.000
p-value (Two-tailed)	0.333
alpha	0.05

The p-value is computed using an exact method.
Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The risk to reject the null hypothesis H0 while it is true is 33.33%.

Appendix X: Calculation of water losses in monetary terms for Lizuma Ward

	Blocks (m^3)	Amount in ZMK	Amount in USD
1	0-6	3.2	0.291
2	6-20	4.72	0.429
3	20-50	5.62	0.511
4	50 and above	6.48	0.589

Exchange rate 1 USD to 11 ZMK

Average losses for Lizuma Ward on a monthly basis

Average consumption being at $13m^3$ for domestic low cost which is in block two of SWSC water tariffs at a rate of 4.72 ZMK per cubic meter of water. Since the average NRW in Cubic meter was $26{,}410.5m^3$/month, therefore the revenue loss can be computed as follows;

$$26{,}410.5\ m^3/\text{month} \times 4.72Z\ MK/m^3 = 124{,}657.56\ ZMK$$

Therefore in USD was 11,332.5 USD.

Appendix XI: Pressure and flow logging point locations

Pressure Logging Points			
ID	Location	Coordinates	Elevation
1	Inlet to Lizuma (Bus station) Ward 150mm pipe line	17 51' 26.58"S 25 50' 55.26"E	910
2	Dambwa Basic School on a 75mm pipe line	17 51' 18.60"S 25 50' 33.61"E	914
3	Sambono Road (House No. D1) 75mm pipe line	17 51' 31.20"S 25 50'20.69"E	902
4	Undi Street (Market) 63mm	17 51' 32.92"S 25 50'39.30"E	900
5	Mongu Road (House No. ZSM 2) 63mm Pipe line	17 51' 35.57"S 25 50' 28.75"E	898
Flow logging			
ID	**Location**	**Coordinates**	**Elevation**
1	Inlet to Lizuma Ward 150mm pipe line	17 51' 26.58"S 25 50' 55.26"E	910
2	Boundary Valve, Along Kazugula road(Mount Meru service station) 50mm pipe line	17 51' 16.62"S 25 50' 25.41"E	912
3	Boundary Valve Near Chalo Bantu Bar 75mm pipe line	17 51' 40.67"S 25 50' 48.11"E	903

Appendix XII: Pipe nodal coordinates

Nodes	Longitudes	Latitudes	Height
1	25.84855556	-17.85736111	910
2	25.84605556	-17.85736111	911
3	25.84602778	-17.8565	911
4	25.846	-17.85555556	912
5	25.846	-17.85461111	914
6	25.84261111	-17.85463889	914
7	25.84261111	-17.85513889	914
8	25.84261111	-17.85675	913
9	25.84169444	-17.8567222	913
10	25.84169444	-17.85516667	914
11	25.84172222	-17.85461111	914
12	25.84022222	-17.85458333	912
13	25.84177778	-17.85797222	865
14	25.84233333	-17.85708333	908
15	25.83941667	-17.85705556	905
16	25.83941667	-17.85772222	907
17	25.83748611	-17.85868611	905
19	25.83800833	-17.85871667	906
21	25.83968611	-17.85744722	905
22	25.83871111	-17.857725	905
23	25.83903611	-17.85777222	906
24	25.83932778	-17.85779444	907
25	25.83919167	-17.85817222	907
26	25.83887222	-17.85874444	908
27	25.83836111	-17.85875	906
28	25.83881667	-17.85945278	907
29	25.83826389	-17.85934167	906
30	25.83729167	-17.85918889	905
31	25.83723611	-17.86008333	905
32	25.83805833	-17.86031667	905
33	25.83854444	-17.86043056	906
34	25.84661111	-17.86136111	903
35	25.84552778	-17.86111111	888
36	25.84622222	-17.86176	888
37	25.84555556	-17.86163889	889
38	25.83893611	-17.86065278	892
39	25.83902222	-17.86031944	893
40	25.83918611	-17.86020833	874
41	25.83943056	-17.86032222	894

Appendix XII continued

Nodes	Longitudes	Latitudes	Height
42	25.839675	-17.86037222	894
43	25.83904167	-17.85949444	896
44	25.83933056	-17.85952222	896
45	25.83957222	-17.85952222	896
46	25.8399	-17.85964167	897
47	25.8401	-17.85963056	897
48	25.84076944	-17.85969444	898
49	25.84136111	-17.85988889	898
50	25.84208056	-17.85993889	898
51	25.84411389	-17.86027222	898
52	25.84556944	-17.86050556	898
53	25.845575	-17.85988611	898
54	25.84564722	-17.85930833	899
55	25.84565	-17.85874722	900
56	25.84566389	-17.85813333	900
57	25.84436944	-17.85813056	902
58	25.844425	-17.85787222	903
59	25.84430833	-17.85785	902
60	25.84430556	-17.85738889	903
61	25.84431111	-17.85871389	901
62	25.84427222	-17.8591	900
63	25.84425	-17.85968333	900
64	25.842675	-17.8594222	900
65	25.84218056	-17.85935	900
67	25.84156667	-17.85877778	900
68	25.841	-17.85877222	901
69	25.84026667	-17.85878611	901
70	25.839625	-17.8588	900
71	25.83915556	-17.85881389	902
72	25.84218333	-17.85816389	901
73	25.84274167	-17.85783611	901
74	25.84219444	-17.85780556	901
66	25.84222222	-17.85877778	900
75	25.84431667	-17.85643056	898
76	25.844325	-17.85550833	898
76	25.844325	-17.85550833	898
76	25.844325	-17.85550833	898
water works	25.83972222	-17.83803056	973.24
mosey road	25.86119722	-17.84274722	943.063
council	25.85508611	-17.849	934.53
National milling	25.85522225	-17.85756944	915.33

Appendix XIII: Iteration for calculation of the coefficient of C

Table 1: 1st trial

Node	Pressure (m)	C1	Q_{ij} (l/s)	Node	Pressure (m)	C1	Q_{ij} (l/s)
5	52.92	0.00000937807	0.135276	**42**	62.92	0.00000937807	0.105862
6	51.92	0.00000937807	0.274429	**43**	62.92	0.00000937807	0.151291
7	51.92	0.00000937807	0.189429	**44**	62.92	0.00000937807	0.271449
8	50.92	0.00000937807	0.189094	**46**	62.92	0.00000937807	0.185957
9	48.92	0.00000937807	0.134758	**47**	61.92	0.00000937807	0.17461
10	52.92	0.00000937807	0.191876	**48**	64.92	0.00000937807	0.200997
11	52.92	0.00000937807	0.198983	**49**	64.92	0.00000937807	0.185332
12	48.92	0.00000937807	0.213813	**50**	65.92	0.00000937807	0.153973
13	48.92	0.00000937807	0.156843	**51**	65.92	0.00000937807	0.125863
14	48.92	0.00000937807	0.156446	**52**	66.92	0.00000937807	0.129951
15	48.92	0.00000937807	0.150772	**53**	68.92	0.00000937807	0.546278
16	48.92	0.00000937807	0.15591	**54**	68.92	0.00000937807	0.076298
17	50.92	0.00000937807	0.085648	**55**	68.92	0.00000937807	0.12432
18	59.92	0.00000937807	0.209755	**56**	69.92	0.00000937807	0.080521
19	60.92	0.00000937807	0.148608	**57**	70.92	0.00000937807	0.163614
20	59.92	0.00000937807	0.03587	**58**	56.92	0.00000937807	0.121684
21	60.92	0.00000937807	0.148877	**59**	66.92	0.00000937807	0.076976
22	61.92	0.00000937807	0.164249	**60**	66.92	0.00000937807	0.109776
23	62.92	0.00000937807	0.170505	**61**	57.92	0.00000937807	0.17229
24	62.92	0.00000937807	0.140951	**62**	57.92	0.00000937807	0.128299
25	62.92	0.00000937807	0.181803	**63**	57.92	0.00000937807	0.148154
26	63.92	0.00000937807	0.187144	**64**	57.92	0.00000937807	0.141477
27	64.92	0.00000937807	0.191881	**65**	57.92	0.00000937807	0.118954
28	64.92	0.00000937807	0.204262	**66**	61.92	0.00000937807	0.186917
29	62.92	0.00000937807	0.292043	**67**	62.92	0.00000937807	0.163808
30	64.92	0.00000937807	0.305106	**68**	60.92	0.00000937807	0.154923
31	74.92	0.00000937807	0.648277	**69**	54.92	0.00000937807	0.13258
32	59.92	0.00000937807	0.12327	**70**	56.92	0.00000937807	0.122816
33	74.92	0.00000937807	0.12582	**71**	57.92	0.00000937807	0.092828
34	73.92	0.00000937807	0.12266	**72**	57.92	0.00000937807	0.071883
35	49.92	0.00000937807	0.142018	**73**	55.92	0.00000937807	0.271029
36	49.92	0.00000937807	0.145983	**74**	55.92	0.00000937807	0.08468
37	54.92	0.00000937807	0.224448	**77**	55.92	0.00000937807	0.252234
38	61.92	0.00000937807	0.262796	**78**	57.92	0.00000937807	0.140801
39	97.92	0.00000937807	0.492315	**79**	56.92	0.00000937807	0.126208
40	61.92	0.00000937807	0.256243	**80**	71.92	0.00000937807	0.156831
41	64.92	0.00000937807	0.258265	**82**	57.92	0.00000937807	0.26311
				Total (l/s)			**13.331**

Table 2: 2nd Trial

Nodes	C2	Qij (l/s)	0.066+Qij (l/s)	Nodes	C2	Qij (l/s)	0.066+Qij(l/s)
5	0.00002040079	0.136916	0.202916	**42**	0.00002040079	0.106498	0.172498
6	0.00002040079	0.250951	0.316951	**43**	0.00002040079	0.151541	0.217541
7	0.00002040079	0.172157	0.238157	**44**	0.00002040079	0.27633	0.34233
8	0.00002040079	0.166751	0.232751	**46**	0.00002040079	0.185995	0.251995
9	0.00002040079	0.111847	0.177847	**47**	0.00002040079	0.171355	0.237355
10	0.00002040079	0.176034	0.242034	**48**	0.00002040079	0.207865	0.273865
11	0.00002040079	0.181708	0.247708	**49**	0.00002040079	0.191469	0.257469
12	0.00002040079	0.176589	0.242589	**50**	0.00002040079	0.161525	0.227525
13	0.00002040079	0.129183	0.195183	**51**	0.00002040079	0.132036	0.198036
14	0.00002040079	0.128785	0.194785	**52**	0.00002040079	0.138383	0.204383
15	0.00002040079	0.124046	0.190046	**53**	0.00002040079	0.597599	0.663599
16	0.00002040079	0.128273	0.194273	**54**	0.00002040079	0.083466	0.149466
17	0.00002040079	0.074551	0.140551	**55**	0.00002040079	0.135999	0.201999
18	0.00002040079	0.218628	0.284628	**56**	0.00002040079	0.089209	0.155209
19	0.00002040079	0.156261	0.222261	**57**	0.00002040079	0.183489	0.249489
20	0.00002040079	0.036674	0.102674	**58**	0.00002040079	0.106487	0.172487
21	0.00002040079	0.151671	0.217671	**59**	0.00002040079	0.081997	0.147997
22	0.00002040079	0.167054	0.233054	**60**	0.00002040079	0.117012	0.183012
23	0.00002040079	0.174997	0.240997	**61**	0.00002040079	0.154554	0.220554
24	0.00002040079	0.146255	0.212255	**62**	0.00002040079	0.114942	0.180942
25	0.00002040079	0.187585	0.253585	**63**	0.00002040079	0.132616	0.198616
26	0.00002040079	0.195032	0.261032	**64**	0.00002040079	0.126639	0.192639
27	0.00002040079	0.20176	0.26776	**65**	0.00002040079	0.106524	0.172524
28	0.00002040079	0.213623	0.279623	**66**	0.00002040079	0.183364	0.249364
29	0.00002040079	0.297401	0.363401	**67**	0.00002040079	0.163663	0.229663
30	0.00002040079	0.319412	0.385412	**68**	0.00002040079	0.149433	0.215433
31	0.00002040079	0.766711	0.832711	**69**	0.00002040079	0.11094	0.17694
32	0.00002040079	0.117141	0.183141	**70**	0.00002040079	0.108684	0.174684
33	0.00002040079	0.148806	0.214806	**71**	0.00002040079	0.084027	0.150027
34	0.00002040079	0.143505	0.209505	**72**	0.00002040079	0.06504	0.13104
35	0.00002040079	0.120386	0.186386	**73**	0.00002040079	0.234608	0.300608
36	0.00002040079	0.123747	0.189747	**74**	0.00002040079	0.073402	0.139402
37	0.00002040079	0.194451	0.260451	**77**	0.00002040079	0.219345	0.285345
38	0.00002040079	0.268157	0.334157	**78**	0.00002040079	0.127834	0.193834
39	0.00002040079	0.700713	0.766713	**79**	0.00002040079	0.111983	0.177983
40	0.00002040079	0.252126	0.318126	**80**	0.00002040079	0.177957	0.243957
41	0.00002040079	0.26791	0.33391	**82**	0.00002040079	0.239389	0.305389
					Total		18.215(l/s)

Table 3: 3rd Trial

Nodes	C3=(C2+C1)/2	Qij (l/s)	0.066+Qij(l/s)	Nodes	C3=(C2+C1)/2	Qij (l/s)	0.066+Qij(l/s)
5	0.000024889	0.129492	0.195492	**42**	0.000024889	0.107525	0.17352467
6	0.000024889	0.232807	0.298807	**43**	0.000024889	0.153017	0.21901695
7	0.000024889	0.159739	0.225739	**44**	0.000024889	0.279099	0.34509883
8	0.000024889	0.15263	0.21863	**46**	0.000024889	0.187758	0.25375845
9	0.000024889	0.099335	0.165335	**47**	0.000024889	0.171896	0.23789635
10	0.000024889	0.165159	0.231159	**48**	0.000024889	0.212417	0.27841738
11	0.000024889	0.170285	0.236285	**49**	0.000024889	0.195629	0.26162897
12	0.000024889	0.156822	0.222822	**50**	0.000024889	0.165915	0.23191524
13	0.000024889	0.114708	0.180708	**51**	0.000024889	0.135573	0.20157252
14	0.000024889	0.114417	0.180417	**52**	0.000024889	0.142865	0.20886537
15	0.000024889	0.110188	0.176188	**53**	0.000024889	0.622376	0.68837581
16	0.000024889	0.113943	0.179943	**54**	0.000024889	0.086926	0.15292642
17	0.000024889	0.068254	0.134254	**55**	0.000024889	0.141638	0.207638
18	0.000024889	0.217594	0.283594	**56**	0.000024889	0.093299	0.15929871
19	0.000024889	0.156541	0.222541	**57**	0.000024889	0.192665	0.25866532
20	0.000024889	0.036464	0.102464	**58**	0.000024889	0.102655	0.16865473
21	0.000024889	0.151587	0.217587	**59**	0.000024889	0.084625	0.15062529
22	0.000024889	0.167856	0.233856	**60**	0.000024889	0.12082	0.18682006
23	0.000024889	0.176853	0.242853	**61**	0.000024889	0.150456	0.21645597
24	0.000024889	0.147902	0.213902	**62**	0.000024889	0.111864	0.17786364
25	0.000024889	0.189592	0.255592	**63**	0.000024889	0.129108	0.19510834
26	0.000024889	0.198241	0.264241	**64**	0.000024889	0.12329	0.18928982
27	0.000024889	0.206165	0.272165	**65**	0.000024889	0.103662	0.16966212
28	0.000024889	0.218181	0.284181	**66**	0.000024889	0.183931	0.24993079
29	0.000024889	0.300399	0.366399	**67**	0.000024889	0.165254	0.23125449
30	0.000024889	0.326281	0.392281	**68**	0.000024889	0.148836	0.21483576
31	0.000024889	0.81659	0.88259	**69**	0.000024889	0.104693	0.17069284
32	0.000024889	0.115688	0.181688	**70**	0.000024889	0.104746	0.17074576
33	0.000024889	0.15844	0.22444	**71**	0.000024889	0.081742	0.14774186
34	0.000024889	0.152291	0.218291	**72**	0.000024889	0.063266	0.12926607
35	0.000024889	0.108672	0.174672	**73**	0.000024889	0.223793	0.2897932
36	0.000024889	0.111707	0.177707	**74**	0.000024889	0.070041	0.13604105
37	0.000024889	0.183851	0.249851	**77**	0.000024889	0.209338	0.27533817
38	0.000024889	0.269486	0.335486	**78**	0.000024889	0.124372	0.19037194
39	0.000024889	0.782735	0.848735	**79**	0.000024889	0.107931	0.17393079
40	0.000024889	0.25293	0.31893	**80**	0.000024889	0.187564	0.25356383
41	0.000024889	0.273697	0.339697	**82**	0.000024889	0.232892	0.29889156
						Total	18.215

Table 4: 4th Trial

Nodes	C4=(C3-C2)/2	Qij (l/s)	0.066+Qij(l/s)	Nodes	C4=(C3-C2)/2	Qij (l/s)	0.066+Qij(l/s)
5	0.000002244	0.011675	0.077675	**42**	0.000002244	0.009695	0.075695
6	0.000002244	0.02099	0.08699	**43**	0.000002244	0.013796	0.079796
7	0.000002244	0.014403	0.080403	**44**	0.000002244	0.025164	0.091164
8	0.000002244	0.013762	0.079762	**46**	0.000002244	0.016929	0.082929
9	0.000002244	0.008956	0.074956	**47**	0.000002244	0.015499	0.081499
10	0.000002244	0.014891	0.080891	**48**	0.000002244	0.019152	0.085152
11	0.000002244	0.015353	0.081353	**49**	0.000002244	0.017638	0.083638
12	0.000002244	0.01414	0.08014	**50**	0.000002244	0.014959	0.080959
13	0.000002244	0.010342	0.076342	**51**	0.000002244	0.012224	0.078224
14	0.000002244	0.010316	0.076316	**52**	0.000002244	0.012881	0.078881
15	0.000002244	0.009935	0.075935	**53**	0.000002244	0.056115	0.122115
16	0.000002244	0.010273	0.076273	**54**	0.000002244	0.007838	0.073838
17	0.000002244	0.006154	0.072154	**55**	0.000002244	0.01277	0.07877
18	0.000002244	0.019619	0.085619	**56**	0.000002244	0.008412	0.074412
19	0.000002244	0.014114	0.080114	**57**	0.000002244	0.017371	0.083371
20	0.000002244	0.003288	0.069288	**58**	0.000002244	0.009256	0.075256
21	0.000002244	0.013667	0.079667	**59**	0.000002244	0.00763	0.07363
22	0.000002244	0.015134	0.081134	**60**	0.000002244	0.010893	0.076893
23	0.000002244	0.015946	0.081946	**61**	0.000002244	0.013566	0.079566
24	0.000002244	0.013335	0.079335	**62**	0.000002244	0.010086	0.076086
25	0.000002244	0.017094	0.083094	**63**	0.000002244	0.011641	0.077641
26	0.000002244	0.017874	0.083874	**64**	0.000002244	0.011116	0.077116
27	0.000002244	0.018588	0.084588	**65**	0.000002244	0.009346	0.075346
28	0.000002244	0.019672	0.085672	**66**	0.000002244	0.016584	0.082584
29	0.000002244	0.027085	0.093085	**67**	0.000002244	0.0149	0.0809
30	0.000002244	0.029418	0.095418	**68**	0.000002244	0.013419	0.079419
31	0.000002244	0.073626	0.139626	**69**	0.000002244	0.009439	0.075439
32	0.000002244	0.010431	0.076431	**70**	0.000002244	0.009444	0.075444
33	0.000002244	0.014285	0.080285	**71**	0.000002244	0.00737	0.07337
34	0.000002244	0.013731	0.079731	**72**	0.000002244	0.005704	0.071704
35	0.000002244	0.009798	0.075798	**73**	0.000002244	0.020178	0.086178
36	0.000002244	0.010072	0.076072	**74**	0.000002244	0.006315	0.072315
37	0.000002244	0.016577	0.082577	**77**	0.000002244	0.018874	0.084874
38	0.000002244	0.024298	0.090298	**78**	0.000002244	0.011214	0.077214
39	0.000002244	0.070574	0.136574	**79**	0.000002244	0.009731	0.075731
40	0.000002244	0.022805	0.088805	**80**	0.000002244	0.016911	0.082911
41	0.000002244	0.024677	0.090677	**82**	0.000002244	0.020998	0.086998
						Total	6.085959

Table 5: 5th Trial

Nodes	C5=(C4+C3)/2	Qij (l/s)	0.066+Qij(l/s)	Nodes	C5=(C4+C3)/2	Qij (l/s)	0.066+Qij(l/s)
5	1.35665E-05	0.070584	0.136584	**42**	1.35665E-05	0.05861	0.12461
6	1.35665E-05	0.126899	0.192899	**43**	1.35665E-05	0.083407	0.149407
7	1.35665E-05	0.087071	0.153071	**44**	1.35665E-05	0.152132	0.218132
8	1.35665E-05	0.083196	0.149196	**46**	1.35665E-05	0.102344	0.168344
9	1.35665E-05	0.054146	0.120146	**47**	1.35665E-05	0.093697	0.159697
10	1.35665E-05	0.090025	0.156025	**48**	1.35665E-05	0.115785	0.181785
11	1.35665E-05	0.092819	0.158819	**49**	1.35665E-05	0.106634	0.172634
12	1.35665E-05	0.085481	0.151481	**50**	1.35665E-05	0.090437	0.156437
13	1.35665E-05	0.062525	0.128525	**51**	1.35665E-05	0.073898	0.139898
14	1.35665E-05	0.062367	0.128367	**52**	1.35665E-05	0.077873	0.143873
15	1.35665E-05	0.060062	0.126062	**53**	1.35665E-05	0.339245	0.405245
16	1.35665E-05	0.062108	0.128108	**54**	1.35665E-05	0.047382	0.113382
17	1.35665E-05	0.037204	0.103204	**55**	1.35665E-05	0.077204	0.143204
18	1.35665E-05	0.118607	0.184607	**56**	1.35665E-05	0.050855	0.116855
19	1.35665E-05	0.085327	0.151327	**57**	1.35665E-05	0.105018	0.171018
20	1.35665E-05	0.019876	0.085876	**58**	1.35665E-05	0.055955	0.121955
21	1.35665E-05	0.082627	0.148627	**59**	1.35665E-05	0.046128	0.112128
22	1.35665E-05	0.091495	0.157495	**60**	1.35665E-05	0.065857	0.131857
23	1.35665E-05	0.0964	0.1624	**61**	1.35665E-05	0.082011	0.148011
24	1.35665E-05	0.080619	0.146619	**62**	1.35665E-05	0.060975	0.126975
25	1.35665E-05	0.103343	0.169343	**63**	1.35665E-05	0.070375	0.136375
26	1.35665E-05	0.108057	0.174057	**64**	1.35665E-05	0.067203	0.133203
27	1.35665E-05	0.112377	0.178377	**65**	1.35665E-05	0.056504	0.122504
28	1.35665E-05	0.118927	0.184927	**66**	1.35665E-05	0.100257	0.166257
29	1.35665E-05	0.163742	0.229742	**67**	1.35665E-05	0.090077	0.156077
30	1.35665E-05	0.17785	0.24385	**68**	1.35665E-05	0.081128	0.147128
31	1.35665E-05	0.445108	0.511108	**69**	1.35665E-05	0.057066	0.123066
32	1.35665E-05	0.063059	0.129059	**70**	1.35665E-05	0.057095	0.123095
33	1.35665E-05	0.086363	0.152363	**71**	1.35665E-05	0.044556	0.110556
34	1.35665E-05	0.083011	0.149011	**72**	1.35665E-05	0.034485	0.100485
35	1.35665E-05	0.059235	0.125235	**73**	1.35665E-05	0.121986	0.187986
36	1.35665E-05	0.060889	0.126889	**74**	1.35665E-05	0.038178	0.104178
37	1.35665E-05	0.100214	0.166214	**77**	1.35665E-05	0.114106	0.180106
38	1.35665E-05	0.146892	0.212892	**78**	1.35665E-05	0.067793	0.133793
39	1.35665E-05	0.426654	0.492654	**79**	1.35665E-05	0.058831	0.124831
40	1.35665E-05	0.137867	0.203867	**80**	1.35665E-05	0.102238	0.168238
41	1.35665E-05	0.149187	0.215187	**82**	1.35665E-05	0.126945	0.192945
						Total(l/s)	12.15048

Table 6: 6th Trial

Nodes	C6=(C5+C3)/2	Qij (l/s)	0.066+Qij(l/s)	Nodes	C6=(C5+C3)/2	Qij (l/s)	0.066+Qij(l/s)
5	0.000019228	0.100038	0.166038	**42**	0.000019228	0.083067	0.149067
6	0.000019228	0.179853	0.245853	**43**	0.000019228	0.118212	0.184212
7	0.000019228	0.123405	0.189405	**44**	0.000019228	0.215615	0.281615
8	0.000019228	0.117913	0.183913	**46**	0.000019228	0.145051	0.211051
9	0.000019228	0.076741	0.142741	**47**	0.000019228	0.132797	0.198797
10	0.000019228	0.127592	0.193592	**48**	0.000019228	0.164101	0.230101
11	0.000019228	0.131552	0.197552	**49**	0.000019228	0.151131	0.217131
12	0.000019228	0.121151	0.187151	**50**	0.000019228	0.128176	0.194176
13	0.000019228	0.088616	0.154616	**51**	0.000019228	0.104735	0.170735
14	0.000019228	0.088392	0.154392	**52**	0.000019228	0.110369	0.176369
15	0.000019228	0.085125	0.151125	**53**	0.000019228	0.480811	0.546811
16	0.000019228	0.088026	0.154026	**54**	0.000019228	0.067154	0.133154
17	0.000019228	0.052729	0.118729	**55**	0.000019228	0.109421	0.175421
18	0.000019228	0.168101	0.234101	**56**	0.000019228	0.072077	0.138077
19	0.000019228	0.120934	0.186934	**57**	0.000019228	0.148842	0.214842
20	0.000019228	0.02817	0.09417	**58**	0.000019228	0.079305	0.145305
21	0.000019228	0.117107	0.183107	**59**	0.000019228	0.065376	0.131376
22	0.000019228	0.129675	0.195675	**60**	0.000019228	0.093338	0.159338
23	0.000019228	0.136626	0.202626	**61**	0.000019228	0.116233	0.182233
24	0.000019228	0.11426	0.18026	**62**	0.000019228	0.086419	0.152419
25	0.000019228	0.146468	0.212468	**63**	0.000019228	0.099741	0.165741
26	0.000019228	0.153149	0.219149	**64**	0.000019228	0.095246	0.161246
27	0.000019228	0.159271	0.225271	**65**	0.000019228	0.080083	0.146083
28	0.000019228	0.168554	0.234554	**66**	0.000019228	0.142094	0.208094
29	0.000019228	0.232071	0.298071	**67**	0.000019228	0.127666	0.193666
30	0.000019228	0.252066	0.318066	**68**	0.000019228	0.114982	0.180982
31	0.000019228	0.630849	0.696849	**69**	0.000019228	0.080879	0.146879
32	0.000019228	0.089374	0.155374	**70**	0.000019228	0.08092	0.14692
33	0.000019228	0.122401	0.188401	**71**	0.000019228	0.063149	0.129149
34	0.000019228	0.117651	0.183651	**72**	0.000019228	0.048876	0.114876
35	0.000019228	0.083954	0.149954	**73**	0.000019228	0.172889	0.238889
36	0.000019228	0.086298	0.152298	**74**	0.000019228	0.05411	0.12011
37	0.000019228	0.142033	0.208033	**77**	0.000019228	0.161722	0.227722
38	0.000019228	0.208189	0.274189	**78**	0.000019228	0.096082	0.162082
39	0.000019228	0.604695	0.670695	**79**	0.000019228	0.083381	0.149381
40	0.000019228	0.195399	0.261399	**80**	0.000019228	0.144901	0.210901
41	0.000019228	0.211442	0.277442	**82**	0.000019228	0.179918	0.245918
						Total(l/s)	15.18274

Table 7: 7th Trial

Nodes	C7=(C6+C3)/2	Qij (l/s)	0.066+Qij(l/s)	Nodes	C7=(C6+C3)/2	Qij (l/s)	0.066+Qij(l/s)
5	0.000022058	0.114765	0.180765	**42**	0.000022058	0.095296	0.161296
6	0.000022058	0.20633	0.27233	**43**	0.000022058	0.135614	0.201614
7	0.000022058	0.141572	0.207572	**44**	0.000022058	0.247357	0.313357
8	0.000022058	0.135271	0.201271	**46**	0.000022058	0.166405	0.232405
9	0.000022058	0.088038	0.154038	**47**	0.000022058	0.152347	0.218347
10	0.000022058	0.146376	0.212376	**48**	0.000022058	0.188259	0.254259
11	0.000022058	0.150919	0.216919	**49**	0.000022058	0.17338	0.23938
12	0.000022058	0.138987	0.204987	**50**	0.000022058	0.147046	0.213046
13	0.000022058	0.101662	0.167662	**51**	0.000022058	0.120154	0.186154
14	0.000022058	0.101404	0.167404	**52**	0.000022058	0.126617	0.192617
15	0.000022058	0.097657	0.163657	**53**	0.000022058	0.551593	0.617593
16	0.000022058	0.100984	0.166984	**54**	0.000022058	0.07704	0.14304
17	0.000022058	0.060492	0.126492	**55**	0.000022058	0.12553	0.19153
18	0.000022058	0.192847	0.258847	**56**	0.000022058	0.082688	0.148688
19	0.000022058	0.138737	0.204737	**57**	0.000022058	0.170754	0.236754
20	0.000022058	0.032317	0.098317	**58**	0.000022058	0.09098	0.15698
21	0.000022058	0.134347	0.200347	**59**	0.000022058	0.075001	0.141001
22	0.000022058	0.148765	0.214765	**60**	0.000022058	0.107079	0.173079
23	0.000022058	0.15674	0.22274	**61**	0.000022058	0.133345	0.199345
24	0.000022058	0.131081	0.197081	**62**	0.000022058	0.099141	0.165141
25	0.000022058	0.16803	0.23403	**63**	0.000022058	0.114425	0.180425
26	0.000022058	0.175695	0.241695	**64**	0.000022058	0.109268	0.175268
27	0.000022058	0.182718	0.248718	**65**	0.000022058	0.091873	0.157873
28	0.000022058	0.193368	0.259368	**66**	0.000022058	0.163012	0.229012
29	0.000022058	0.266235	0.332235	**67**	0.000022058	0.14646	0.21246
30	0.000022058	0.289173	0.355173	**68**	0.000022058	0.131909	0.197909
31	0.000022058	0.72372	0.78972	**69**	0.000022058	0.092786	0.158786
32	0.000022058	0.102531	0.168531	**70**	0.000022058	0.092833	0.158833
33	0.000022058	0.140421	0.206421	**71**	0.000022058	0.072445	0.138445
34	0.000022058	0.134971	0.200971	**72**	0.000022058	0.056071	0.122071
35	0.000022058	0.096313	0.162313	**73**	0.000022058	0.198341	0.264341
36	0.000022058	0.099002	0.165002	**74**	0.000022058	0.062075	0.128075
37	0.000022058	0.162942	0.228942	**77**	0.000022058	0.18553	0.25153
38	0.000022058	0.238837	0.304837	**78**	0.000022058	0.110227	0.176227
39	0.000022058	0.693715	0.759715	**79**	0.000022058	0.095656	0.161656
40	0.000022058	0.224164	0.290164	**80**	0.000022058	0.166232	0.232232
41	0.000022058	0.242569	0.308569	**82**	0.000022058	0.206405	0.272405
				Total (l/s)			16.69887

Table 8: 8th Trial

Nodes	C8=(C7+C6)/2	Qij (l/s)	0.066+Qij(l/s)	Nodes	C8=(C7+C6)/2	Qij (l/s)	0.066+Qij(l/s)
5	2.0643E-05	0.107401	0.173401	**42**	0.000020643	0.089182	0.155182
6	2.0643E-05	0.193091	0.259091	**43**	0.000020643	0.126913	0.192913
7	2.0643E-05	0.132489	0.198489	**44**	0.000020643	0.231486	0.297486
8	2.0643E-05	0.126592	0.192592	**46**	0.000020643	0.155728	0.221728
9	2.0643E-05	0.082389	0.148389	**47**	0.000020643	0.142572	0.208572
10	2.0643E-05	0.136984	0.202984	**48**	0.000020643	0.17618	0.24218
11	2.0643E-05	0.141236	0.207236	**49**	0.000020643	0.162256	0.228256
12	2.0643E-05	0.130069	0.196069	**50**	0.000020643	0.137611	0.203611
13	2.0643E-05	0.095139	0.161139	**51**	0.000020643	0.112445	0.178445
14	2.0643E-05	0.094898	0.160898	**52**	0.000020643	0.118493	0.184493
15	2.0643E-05	0.091391	0.157391	**53**	0.000020643	0.516202	0.582202
16	2.0643E-05	0.094505	0.160505	**54**	0.000020643	0.072097	0.138097
17	2.0643E-05	0.056611	0.122611	**55**	0.000020643	0.117475	0.183475
18	2.0643E-05	0.180474	0.246474	**56**	0.000020643	0.077382	0.143382
19	2.0643E-05	0.129836	0.195836	**57**	0.000020643	0.159798	0.225798
20	2.0643E-05	0.030244	0.096244	**58**	0.000020643	0.085142	0.151142
21	2.0643E-05	0.125727	0.191727	**59**	0.000020643	0.070189	0.136189
22	2.0643E-05	0.13922	0.20522	**60**	0.000020643	0.100209	0.166209
23	2.0643E-05	0.146683	0.212683	**61**	0.000020643	0.124789	0.190789
24	2.0643E-05	0.122671	0.188671	**62**	0.000020643	0.09278	0.15878
25	2.0643E-05	0.157249	0.223249	**63**	0.000020643	0.107083	0.173083
26	2.0643E-05	0.164422	0.230422	**64**	0.000020643	0.102257	0.168257
27	2.0643E-05	0.170995	0.236995	**65**	0.000020643	0.085978	0.151978
28	2.0643E-05	0.180961	0.246961	**66**	0.000020643	0.152553	0.218553
29	2.0643E-05	0.249153	0.315153	**67**	0.000020643	0.137063	0.203063
30	2.0643E-05	0.270619	0.336619	**68**	0.000020643	0.123445	0.189445
31	2.0643E-05	0.677284	0.743284	**69**	0.000020643	0.086833	0.152833
32	2.0643E-05	0.095952	0.161952	**70**	0.000020643	0.086877	0.152877
33	2.0643E-05	0.131411	0.197411	**71**	0.000020643	0.067797	0.133797
34	2.0643E-05	0.126311	0.192311	**72**	0.000020643	0.052473	0.118473
35	2.0643E-05	0.090133	0.156133	**73**	0.000020643	0.185615	0.251615
36	2.0643E-05	0.09265	0.15865	**74**	0.000020643	0.058092	0.124092
37	2.0643E-05	0.152487	0.218487	**77**	0.000020643	0.173626	0.239626
38	2.0643E-05	0.223513	0.289513	**78**	0.000020643	0.103155	0.169155
39	2.0643E-05	0.649205	0.715205	**79**	0.000020643	0.089518	0.155518
40	2.0643E-05	0.209781	0.275781	**80**	0.000020643	0.155566	0.221566
41	2.0643E-05	0.227005	0.293005	**82**	0.000020643	0.193162	0.259162
					Total (l/s)		15.9408

Table 9: 9th Trial

Nodes	C9=(C8+C6)/2	Qij (l/s)	0.066+Qij(l/s)	Nodes	C9=(C8+C6)/2	Qij (l/s)	0.066+Qij(l/s)
5	0.000019935	0.10372	0.16972	**42**	0.000019935	0.086124	0.152124
6	0.000019935	0.186472	0.252472	**43**	0.000019935	0.122562	0.188562
7	0.000019935	0.127947	0.193947	**44**	0.000019935	0.223551	0.289551
8	0.000019935	0.122252	0.188252	**46**	0.000019935	0.150389	0.216389
9	0.000019935	0.079565	0.145565	**47**	0.000019935	0.137684	0.203684
10	0.000019935	0.132288	0.198288	**48**	0.000019935	0.170141	0.236141
11	0.000019935	0.136394	0.202394	**49**	0.000019935	0.156694	0.222694
12	0.000019935	0.12561	0.19161	**50**	0.000019935	0.132894	0.198894
13	0.000019935	0.091878	0.157878	**51**	0.000019935	0.10859	0.17459
14	0.000019935	0.091645	0.157645	**52**	0.000019935	0.114431	0.180431
15	0.000019935	0.088258	0.154258	**53**	0.000019935	0.498506	0.564506
16	0.000019935	0.091265	0.157265	**54**	0.000019935	0.069626	0.135626
17	0.000019935	0.05467	0.12067	**55**	0.000019935	0.113448	0.179448
18	0.000019935	0.174287	0.240287	**56**	0.000019935	0.07473	0.14073
19	0.000019935	0.125385	0.191385	**57**	0.000019935	0.15432	0.22032
20	0.000019935	0.029207	0.095207	**58**	0.000019935	0.082224	0.148224
21	0.000019935	0.121417	0.187417	**59**	0.000019935	0.067783	0.133783
22	0.000019935	0.134448	0.200448	**60**	0.000019935	0.096774	0.162774
23	0.000019935	0.141655	0.207655	**61**	0.000019935	0.120511	0.186511
24	0.000019935	0.118466	0.184466	**62**	0.000019935	0.0896	0.1556
25	0.000019935	0.151858	0.217858	**63**	0.000019935	0.103412	0.169412
26	0.000019935	0.158786	0.224786	**64**	0.000019935	0.098752	0.164752
27	0.000019935	0.165133	0.231133	**65**	0.000019935	0.083031	0.149031
28	0.000019935	0.174757	0.240757	**66**	0.000019935	0.147324	0.213324
29	0.000019935	0.240612	0.306612	**67**	0.000019935	0.132364	0.198364
30	0.000019935	0.261343	0.327343	**68**	0.000019935	0.119213	0.185213
31	0.000019935	0.654067	0.720067	**69**	0.000019935	0.083856	0.149856
32	0.000019935	0.092663	0.158663	**70**	0.000019935	0.083899	0.149899
33	0.000019935	0.126906	0.192906	**71**	0.000019935	0.065473	0.131473
34	0.000019935	0.121981	0.187981	**72**	0.000019935	0.050674	0.116674
35	0.000019935	0.087044	0.153044	**73**	0.000019935	0.179252	0.245252
36	0.000019935	0.089474	0.155474	**74**	0.000019935	0.056101	0.122101
37	0.000019935	0.14726	0.21326	**77**	0.000019935	0.167674	0.233674
38	0.000019935	0.215851	0.281851	**78**	0.000019935	0.099619	0.165619
39	0.000019935	0.62695	0.69295	**79**	0.000019935	0.08645	0.15245
40	0.000019935	0.20259	0.26859	**80**	0.000019935	0.150234	0.216234
41	0.000019935	0.219224	0.285224	**82**	0.000019935	0.18654	0.25254
				Total (l/s)			15.56177

Table 10: 10th Trial

Nodes	C10=(C9+C8)/2	Qij (l/s)	0.066+Qij(l/s)	Nodes	C10=(C9+C8)/2	Qij (l/s)	0.066+Qij(l/s)
5	0.000020289	0.10556	0.17156	**42**	0.000020289	0.087653	0.153653
6	0.000020289	0.189782	0.255782	**43**	0.000020289	0.124738	0.190738
7	0.000020289	0.130218	0.196218	**44**	0.000020289	0.227518	0.293518
8	0.000020289	0.124422	0.190422	**46**	0.000020289	0.153059	0.219059
9	0.000020289	0.080977	0.146977	**47**	0.000020289	0.140128	0.206128
10	0.000020289	0.134636	0.200636	**48**	0.000020289	0.17316	0.23916
11	0.000020289	0.138815	0.204815	**49**	0.000020289	0.159475	0.225475
12	0.000020289	0.12784	0.19384	**50**	0.000020289	0.135252	0.201252
13	0.000020289	0.093508	0.159508	**51**	0.000020289	0.110517	0.176517
14	0.000020289	0.093272	0.159272	**52**	0.000020289	0.116462	0.182462
15	0.000020289	0.089824	0.155824	**53**	0.000020289	0.507354	0.573354
16	0.000020289	0.092885	0.158885	**54**	0.000020289	0.070861	0.136861
17	0.000020289	0.05564	0.12164	**55**	0.000020289	0.115462	0.181462
18	0.000020289	0.177381	0.243381	**56**	0.000020289	0.076056	0.142056
19	0.000020289	0.12761	0.19361	**57**	0.000020289	0.157059	0.223059
20	0.000020289	0.029725	0.095725	**58**	0.000020289	0.083683	0.149683
21	0.000020289	0.123572	0.189572	**59**	0.000020289	0.068986	0.134986
22	0.000020289	0.136834	0.202834	**60**	0.000020289	0.098491	0.164491
23	0.000020289	0.144169	0.210169	**61**	0.000020289	0.12265	0.18865
24	0.000020289	0.120568	0.186568	**62**	0.000020289	0.09119	0.15719
25	0.000020289	0.154553	0.220553	**63**	0.000020289	0.105248	0.171248
26	0.000020289	0.161604	0.227604	**64**	0.000020289	0.100505	0.166505
27	0.000020289	0.168064	0.234064	**65**	0.000020289	0.084504	0.150504
28	0.000020289	0.177859	0.243859	**66**	0.000020289	0.149938	0.215938
29	0.000020289	0.244882	0.310882	**67**	0.000020289	0.134714	0.200714
30	0.000020289	0.265981	0.331981	**68**	0.000020289	0.121329	0.187329
31	0.000020289	0.665676	0.731676	**69**	0.000020289	0.085344	0.151344
32	0.000020289	0.094308	0.160308	**70**	0.000020289	0.085388	0.151388
33	0.000020289	0.129159	0.195159	**71**	0.000020289	0.066635	0.132635
34	0.000020289	0.124146	0.190146	**72**	0.000020289	0.051574	0.117574
35	0.000020289	0.088588	0.154588	**73**	0.000020289	0.182434	0.248434
36	0.000020289	0.091062	0.157062	**74**	0.000020289	0.057097	0.123097
37	0.000020289	0.149874	0.215874	**77**	0.000020289	0.17065	0.23665
38	0.000020289	0.219682	0.285682	**78**	0.000020289	0.101387	0.167387
39	0.000020289	0.638077	0.704077	**79**	0.000020289	0.087984	0.153984
40	0.000020289	0.206186	0.272186	**80**	0.000020289	0.1529	0.2189
41	0.000020289	0.223114	0.289114	**82**	0.000020289	0.189851	0.255851
					Total (l/s)		15.75129

Table 11: 11th Trial

Nodes	C11 =(C10+C9)/2	Qij (l/s)	0.066+Qij(l/s)	Nodes	C11= (C10+C9)/2	Qij (l/s)	0.066+Qij(l/s)
5	0.000020112	0.10464	0.17064	**42**	0.000020112	0.086889	0.152889
6	0.000020112	0.188127	0.254127	**43**	0.000020112	0.12365	0.18965
7	0.000020112	0.129082	0.195082	**44**	0.000020112	0.225535	0.291535
8	0.000020112	0.123337	0.189337	**46**	0.000020112	0.151724	0.217724
9	0.000020112	0.080271	0.146271	**47**	0.000020112	0.138906	0.204906
10	0.000020112	0.133462	0.199462	**48**	0.000020112	0.17165	0.23765
11	0.000020112	0.137604	0.203604	**49**	0.000020112	0.158084	0.224084
12	0.000020112	0.126725	0.192725	**50**	0.000020112	0.134073	0.200073
13	0.000020112	0.092693	0.158693	**51**	0.000020112	0.109554	0.175554
14	0.000020112	0.092458	0.158458	**52**	0.000020112	0.115447	0.181447
15	0.000020112	0.089041	0.155041	**53**	0.000020112	0.50293	0.56893
16	0.000020112	0.092075	0.158075	**54**	0.000020112	0.070244	0.136244
17	0.000020112	0.055155	0.121155	**55**	0.000020112	0.114455	0.180455
18	0.000020112	0.175834	0.241834	**56**	0.000020112	0.075393	0.141393
19	0.000020112	0.126498	0.192498	**57**	0.000020112	0.155689	0.221689
20	0.000020112	0.029466	0.095466	**58**	0.000020112	0.082953	0.148953
21	0.000020112	0.122494	0.188494	**59**	0.000020112	0.068384	0.134384
22	0.000020112	0.135641	0.201641	**60**	0.000020112	0.097632	0.163632
23	0.000020112	0.142912	0.208912	**61**	0.000020112	0.121581	0.187581
24	0.000020112	0.119517	0.185517	**62**	0.000020112	0.090395	0.156395
25	0.000020112	0.153206	0.219206	**63**	0.000020112	0.10433	0.17033
26	0.000020112	0.160195	0.226195	**64**	0.000020112	0.099628	0.165628
27	0.000020112	0.166598	0.232598	**65**	0.000020112	0.083767	0.149767
28	0.000020112	0.176308	0.242308	**66**	0.000020112	0.148631	0.214631
29	0.000020112	0.242747	0.308747	**67**	0.000020112	0.133539	0.199539
30	0.000020112	0.263662	0.329662	**68**	0.000020112	0.120271	0.186271
31	0.000020112	0.659871	0.725871	**69**	0.000020112	0.0846	0.1506
32	0.000020112	0.093485	0.159485	**70**	0.000020112	0.084643	0.150643
33	0.000020112	0.128032	0.194032	**71**	0.000020112	0.066054	0.132054
34	0.000020112	0.123063	0.189063	**72**	0.000020112	0.051124	0.117124
35	0.000020112	0.087816	0.153816	**73**	0.000020112	0.180843	0.246843
36	0.000020112	0.090268	0.156268	**74**	0.000020112	0.056599	0.122599
37	0.000020112	0.148567	0.214567	**77**	0.000020112	0.169162	0.235162
38	0.000020112	0.217766	0.283766	**78**	0.000020112	0.100503	0.166503
39	0.000020112	0.632514	0.698514	**79**	0.000020112	0.087217	0.153217
40	0.000020112	0.204388	0.270388	**80**	0.000020112	0.151567	0.217567
41	0.000020112	0.221169	0.287169	**82**	0.000020112	0.188195	0.254195
					Total (l/s)		15.65653

Table 12: 12th Trial

Nodes	C12= (C11+C9)/2	Qij (l/s)	0.066+Qij(l/s)	Nodes	C12= (C11+C9)/2	Qij (l/s)	0.066+Qij(l/s)
5	0.000020024	0.10418	0.17018	**42**	0.000020024	0.086507	0.152507
6	0.000020024	0.187299	0.253299	**43**	0.000020024	0.123106	0.189106
7	0.000020024	0.128514	0.194514	**44**	0.000020024	0.224543	0.290543
8	0.000020024	0.122795	0.188795	**46**	0.000020024	0.151057	0.217057
9	0.000020024	0.079918	0.145918	**47**	0.000020024	0.138295	0.204295
10	0.000020024	0.132875	0.198875	**48**	0.000020024	0.170896	0.236896
11	0.000020024	0.136999	0.202999	**49**	0.000020024	0.157389	0.223389
12	0.000020024	0.126168	0.192168	**50**	0.000020024	0.133483	0.199483
13	0.000020024	0.092285	0.158285	**51**	0.000020024	0.109072	0.175072
14	0.000020024	0.092052	0.158052	**52**	0.000020024	0.114939	0.180939
15	0.000020024	0.088649	0.154649	**53**	0.000020024	0.500718	0.566718
16	0.000020024	0.09167	0.15767	**54**	0.000020024	0.069935	0.135935
17	0.000020024	0.054913	0.120913	**55**	0.000020024	0.113952	0.179952
18	0.000020024	0.175061	0.241061	**56**	0.000020024	0.075061	0.141061
19	0.000020024	0.125941	0.191941	**57**	0.000020024	0.155004	0.221004
20	0.000020024	0.029337	0.095337	**58**	0.000020024	0.082589	0.148589
21	0.000020024	0.121956	0.187956	**59**	0.000020024	0.068083	0.134083
22	0.000020024	0.135044	0.201044	**60**	0.000020024	0.097203	0.163203
23	0.000020024	0.142283	0.208283	**61**	0.000020024	0.121046	0.187046
24	0.000020024	0.118991	0.184991	**62**	0.000020024	0.089997	0.155997
25	0.000020024	0.152532	0.218532	**63**	0.000020024	0.103871	0.169871
26	0.000020024	0.15949	0.22549	**64**	0.000020024	0.09919	0.16519
27	0.000020024	0.165866	0.231866	**65**	0.000020024	0.083399	0.149399
28	0.000020024	0.175533	0.241533	**66**	0.000020024	0.147977	0.213977
29	0.000020024	0.241679	0.307679	**67**	0.000020024	0.132952	0.198952
30	0.000020024	0.262502	0.328502	**68**	0.000020024	0.119742	0.185742
31	0.000020024	0.656969	0.722969	**69**	0.000020024	0.084228	0.150228
32	0.000020024	0.093074	0.159074	**70**	0.000020024	0.084271	0.150271
33	0.000020024	0.127469	0.193469	**71**	0.000020024	0.065764	0.131764
34	0.000020024	0.122522	0.188522	**72**	0.000020024	0.050899	0.116899
35	0.000020024	0.08743	0.15343	**73**	0.000020024	0.180048	0.246048
36	0.000020024	0.089871	0.155871	**74**	0.000020024	0.05635	0.12235
37	0.000020024	0.147913	0.213913	**77**	0.000020024	0.168418	0.234418
38	0.000020024	0.216809	0.282809	**78**	0.000020024	0.100061	0.166061
39	0.000020024	0.629732	0.695732	**79**	0.000020024	0.086833	0.152833
40	0.000020024	0.203489	0.269489	**80**	0.000020024	0.1509	0.2169
41	0.000020024	0.220196	0.286196	**82**	0.000020024	0.187368	0.253368
					Total (l/s)		15.60915

Table 13: 13th Trial

Nodes	C13= (C12+C11)/2	Qij (l/s)	0.066+Qij(l/s)	Nodes	C13= (C12+C11)/2	Qij (l/s)	0.066+Qij(l/s)
5	0.000020068	0.10441	0.17041	**42**	0.000020068	0.086698	0.152698
6	0.000020068	0.187713	0.253713	**43**	0.000020068	0.123378	0.189378
7	0.000020068	0.128798	0.194798	**44**	0.000020068	0.225039	0.291039
8	0.000020068	0.123066	0.189066	**46**	0.000020068	0.15139	0.21739
9	0.000020068	0.080095	0.146095	**47**	0.000020068	0.138601	0.204601
10	0.000020068	0.133168	0.199168	**48**	0.000020068	0.171273	0.237273
11	0.000020068	0.137302	0.203302	**49**	0.000020068	0.157736	0.223736
12	0.000020068	0.126446	0.192446	**50**	0.000020068	0.133778	0.199778
13	0.000020068	0.092489	0.158489	**51**	0.000020068	0.109313	0.175313
14	0.000020068	0.092255	0.158255	**52**	0.000020068	0.115193	0.181193
15	0.000020068	0.088845	0.154845	**53**	0.000020068	0.501824	0.567824
16	0.000020068	0.091873	0.157873	**54**	0.000020068	0.070089	0.136089
17	0.000020068	0.055034	0.121034	**55**	0.000020068	0.114203	0.180203
18	0.000020068	0.175447	0.241447	**56**	0.000020068	0.075227	0.141227
19	0.000020068	0.126219	0.192219	**57**	0.000020068	0.155347	0.221347
20	0.000020068	0.029401	0.095401	**58**	0.000020068	0.082771	0.148771
21	0.000020068	0.122225	0.188225	**59**	0.000020068	0.068234	0.134234
22	0.000020068	0.135343	0.201343	**60**	0.000020068	0.097418	0.163418
23	0.000020068	0.142598	0.208598	**61**	0.000020068	0.121313	0.187313
24	0.000020068	0.119254	0.185254	**62**	0.000020068	0.090196	0.156196
25	0.000020068	0.152869	0.218869	**63**	0.000020068	0.104101	0.170101
26	0.000020068	0.159842	0.225842	**64**	0.000020068	0.099409	0.165409
27	0.000020068	0.166232	0.232232	**65**	0.000020068	0.083583	0.149583
28	0.000020068	0.17592	0.24192	**66**	0.000020068	0.148304	0.214304
29	0.000020068	0.242213	0.308213	**67**	0.000020068	0.133245	0.199245
30	0.000020068	0.263082	0.329082	**68**	0.000020068	0.120007	0.186007
31	0.000020068	0.65842	0.72442	**69**	0.000020068	0.084414	0.150414
32	0.000020068	0.09328	0.15928	**70**	0.000020068	0.084457	0.150457
33	0.000020068	0.127751	0.193751	**71**	0.000020068	0.065909	0.131909
34	0.000020068	0.122793	0.188793	**72**	0.000020068	0.051012	0.117012
35	0.000020068	0.087623	0.153623	**73**	0.000020068	0.180445	0.246445
36	0.000020068	0.090069	0.156069	**74**	0.000020068	0.056474	0.122474
37	0.000020068	0.14824	0.21424	**77**	0.000020068	0.16879	0.23479
38	0.000020068	0.217288	0.283288	**78**	0.000020068	0.100282	0.166282
39	0.000020068	0.631123	0.697123	**79**	0.000020068	0.087025	0.153025
40	0.000020068	0.203938	0.269938	**80**	0.000020068	0.151233	0.217233
41	0.000020068	0.220683	0.286683	**82**	0.000020068	0.187781	0.253781
				Total (l/s)			15.63284

Table 14: 14th Trial

Nodes	C14= (13+C12)/2	Qij (l/s)	0.066+Qij(l/s)	Nodes	C14= (13+C12)/2	Qij (l/s)	0.066+Qij(l/s)
5	0.000020046	0.104295	0.170295	**42**	0.000020046	0.086602	0.152602
6	0.000020046	0.187506	0.253506	**43**	0.000020046	0.123242	0.189242
7	0.000020046	0.128656	0.194656	**44**	0.000020046	0.224791	0.290791
8	0.000020046	0.12293	0.18893	**46**	0.000020046	0.151224	0.217224
9	0.000020046	0.080006	0.146006	**47**	0.000020046	0.138448	0.204448
10	0.000020046	0.133022	0.199022	**48**	0.000020046	0.171084	0.237084
11	0.000020046	0.137151	0.203151	**49**	0.000020046	0.157563	0.223563
12	0.000020046	0.126307	0.192307	**50**	0.000020046	0.133631	0.199631
13	0.000020046	0.092387	0.158387	**51**	0.000020046	0.109192	0.175192
14	0.000020046	0.092153	0.158153	**52**	0.000020046	0.115066	0.181066
15	0.000020046	0.088747	0.154747	**53**	0.000020046	0.501271	0.567271
16	0.000020046	0.091772	0.157772	**54**	0.000020046	0.070012	0.136012
17	0.000020046	0.054973	0.120973	**55**	0.000020046	0.114077	0.180077
18	0.000020046	0.175254	0.241254	**56**	0.000020046	0.075144	0.141144
19	0.000020046	0.12608	0.19208	**57**	0.000020046	0.155176	0.221176
20	0.000020046	0.029369	0.095369	**58**	0.000020046	0.08268	0.14868
21	0.000020046	0.12209	0.18809	**59**	0.000020046	0.068159	0.134159
22	0.000020046	0.135193	0.201193	**60**	0.000020046	0.09731	0.16331
23	0.000020046	0.142441	0.208441	**61**	0.000020046	0.12118	0.18718
24	0.000020046	0.119123	0.185123	**62**	0.000020046	0.090097	0.156097
25	0.000020046	0.1527	0.2187	**63**	0.000020046	0.103986	0.169986
26	0.000020046	0.159666	0.225666	**64**	0.000020046	0.0993	0.1653
27	0.000020046	0.166049	0.232049	**65**	0.000020046	0.083491	0.149491
28	0.000020046	0.175727	0.241727	**66**	0.000020046	0.148141	0.214141
29	0.000020046	0.241946	0.307946	**67**	0.000020046	0.133099	0.199099
30	0.000020046	0.262792	0.328792	**68**	0.000020046	0.119875	0.185875
31	0.000020046	0.657695	0.723695	**69**	0.000020046	0.084321	0.150321
32	0.000020046	0.093177	0.159177	**70**	0.000020046	0.084364	0.150364
33	0.000020046	0.12761	0.19361	**71**	0.000020046	0.065836	0.131836
34	0.000020046	0.122657	0.188657	**72**	0.000020046	0.050955	0.116955
35	0.000020046	0.087526	0.153526	**73**	0.000020046	0.180247	0.246247
36	0.000020046	0.08997	0.15597	**74**	0.000020046	0.056412	0.122412
37	0.000020046	0.148077	0.214077	**77**	0.000020046	0.168604	0.234604
38	0.000020046	0.217048	0.283048	**78**	0.000020046	0.100171	0.166171
39	0.000020046	0.630427	0.696427	**79**	0.000020046	0.086929	0.152929
40	0.000020046	0.203714	0.269714	**80**	0.000020046	0.151067	0.217067
41	0.000020046	0.220439	0.286439	**82**	0.000020046	0.187575	0.253575
				Total (l/s)			15.621

Table 15: 15th Trial

Nodes	C15= (C14+C12)/2	Qij (l/s)	0.066+Qij(l/s)	Nodes	C15= (C14+C12)/2	Qij (l/s)	0.066+Qij(l/s)
5	0.000020035	0.104237	0.170237	**42**	0.000020035	0.086554	0.152554
6	0.000020035	0.187403	0.253403	**43**	0.000020035	0.123174	0.189174
7	0.000020035	0.128585	0.194585	**44**	0.000020035	0.224667	0.290667
8	0.000020035	0.122863	0.188863	**46**	0.000020035	0.15114	0.21714
9	0.000020035	0.079962	0.145962	**47**	0.000020035	0.138372	0.204372
10	0.000020035	0.132948	0.198948	**48**	0.000020035	0.17099	0.23699
11	0.000020035	0.137075	0.203075	**49**	0.000020035	0.157476	0.223476
12	0.000020035	0.126237	0.192237	**50**	0.000020035	0.133557	0.199557
13	0.000020035	0.092336	0.158336	**51**	0.000020035	0.109132	0.175132
14	0.000020035	0.092102	0.158102	**52**	0.000020035	0.115003	0.181003
15	0.000020035	0.088698	0.154698	**53**	0.000020035	0.500995	0.566995
16	0.000020035	0.091721	0.157721	**54**	0.000020035	0.069973	0.135973
17	0.000020035	0.054943	0.120943	**55**	0.000020035	0.114015	0.180015
18	0.000020035	0.175157	0.241157	**56**	0.000020035	0.075103	0.141103
19	0.000020035	0.126011	0.192011	**57**	0.000020035	0.15509	0.22109
20	0.000020035	0.029353	0.095353	**58**	0.000020035	0.082634	0.148634
21	0.000020035	0.122023	0.188023	**59**	0.000020035	0.068121	0.134121
22	0.000020035	0.135119	0.201119	**60**	0.000020035	0.097257	0.163257
23	0.000020035	0.142362	0.208362	**61**	0.000020035	0.121113	0.187113
24	0.000020035	0.119057	0.185057	**62**	0.000020035	0.090047	0.156047
25	0.000020035	0.152616	0.218616	**63**	0.000020035	0.103929	0.169929
26	0.000020035	0.159578	0.225578	**64**	0.000020035	0.099245	0.165245
27	0.000020035	0.165957	0.231957	**65**	0.000020035	0.083445	0.149445
28	0.000020035	0.17563	0.24163	**66**	0.000020035	0.148059	0.214059
29	0.000020035	0.241813	0.307813	**67**	0.000020035	0.133025	0.199025
30	0.000020035	0.262647	0.328647	**68**	0.000020035	0.119809	0.185809
31	0.000020035	0.657332	0.723332	**69**	0.000020035	0.084275	0.150275
32	0.000020035	0.093125	0.159125	**70**	0.000020035	0.084317	0.150317
33	0.000020035	0.12754	0.19354	**71**	0.000020035	0.0658	0.1318
34	0.000020035	0.12259	0.18859	**72**	0.000020035	0.050927	0.116927
35	0.000020035	0.087478	0.153478	**73**	0.000020035	0.180147	0.246147
36	0.000020035	0.089921	0.155921	**74**	0.000020035	0.056381	0.122381
37	0.000020035	0.147995	0.213995	**77**	0.000020035	0.168511	0.234511
38	0.000020035	0.216928	0.282928	**78**	0.000020035	0.100116	0.166116
39	0.000020035	0.630079	0.696079	**79**	0.000020035	0.086881	0.152881
40	0.000020035	0.203601	0.269601	**80**	0.000020035	0.150984	0.216984
41	0.000020035	0.220318	0.286318	**82**	0.000020035	0.187471	0.253471
				Total (l/s)			15.61507

Appendix XIV: Final simulated Pressure, volumetric and network leakage

Pipe ID	Length (m)	Start node Q_{ij} (l/s)	End node Q_{ji} (l/s)	ΣL_{ij} (m)	ΣL_{ji} (m)	Leakage (l/s)
1	75.53	0.084251489	0.121079336	250.33	305.52	0.0554
2	104.92	0.103899843	0.090022186	262.72	227.51	0.0830
3	42.36	0.180097418	0.056365483	500.96	156.52	0.0305
4	171.38	0.239321193	0.222365467	469.67	436.55	0.1746
6	266.85	0.00000	0.187351127	968.6	553.67	0.0903
7	92.45	0.187351127	0.128549949	553.67	382.18	0.0624
8	100.68	0.128549949	0.122828598	382.18	390.36	0.0655
9	100.65	0.122828598	0.079940132	390.36	390.36	0.0523
10	182.01	0.079940132	0.12620243	291.66	462.76	0.0995
11	89.58	0.12620243	0.132911621	462.76	378.5	0.0559
12	97.89	0.132911621	0.137037085	378.5	392.52	0.0685
13	181.03	0.137037085	0.122828598	378.5	390.36	0.1225
14	182.05	0.128549949	0.137037085	382.18	392.52	0.1248
15	188.37	0.187351127	0.175108916	553.67	357.35	0.1560
16	101.58	0.137037085	0.175108916	392.52	357.35	0.0852
17	49.4	0.175108916	0.125975929	357.35	248.28	0.0493
18	13.67	0.125975929	0.029344753	248.28	61.11	0.0135
19	137.12	0.119024192	0.121989285	226.68	248.73	0.1392
20	27.44	0.121989285	0.029344753	248.73	61.11	0.0266
21	65.56	0.119024192	0.152573995	226.68	292.38	0.0686
22	58.64	0.152573995	0.159534126	292.38	295.42	0.0623
23	62.76	0.159534126	0.165911301	295.42	297.4	0.0689
24	65.1	0.165911301	0.175581172	297.4	316.59	0.0724
25	65.26	0.175581172	0.657150428	316.59	898.5	0.0839
26	118.59	0.657150428	0.093099778	898.5	810.01	0.1004
27	59.42	0.093099778	0.127504396	810.01	164.68	0.0528
28	72.26	0.127504396	0.122555907	164.68	163.11	0.1102
29	56.85	0.122555907	0.657150428	163.11	898.5	0.0843
30	158.23	0.175581172	0.262574624	316.59	472.89	0.1756
31	142.54	0.165911301	0.241746017	297.4	469.67	0.1529
32	148.02	0.159534126	0.142322659	295.42	274.21	0.1568
33	143.18	0.152573995	0.135081629	292.38	269.19	0.1466
34	64.4	0.262574624	0.241746017	472.89	469.67	0.0689
35	62.35	0.241746017	0.142322659	469.67	274.21	0.0645

Pipe ID	Length (m)	Start node Q_{ij} (l/s)	End node Q_{ji} (l/s)	ΣL_{ij} (m)	ΣLji (m)	Leakage (l/s)
36	40.84	0.142322659	0.135081629	274.21	269.19	0.0417
37	63.17	0.135081629	0.121989285	269.19	248.73	0.0627
38	179.17	0.12620243	0.092310876	462.76	339.46	0.0976
39	93.73	0.092310876	0.088673852	339.46	326.32	0.0510
40	159.81	0.088673852	0.054927745	326.32	276.81	0.0751
41	53.56	0.092310876	0.092077012	339.46	338.6	0.0291
42	173.59	0.092077012	0.089895804	338.6	338.6	0.0933
43	98.91	0.087453902	0.091695589	308.5	300.12	0.0506
44	166.21	0.087453902	0.091695589	300.12	337.44	0.0936
45	57.78	0.091695589	0.088673852	337.44	326.32	0.0314
46	97.45	0.092077012	0.091695589	338.6	337.44	0.0530
47	309.82	0.147954107	0.168464743	423.79	466.22	0.2201
48	168.25	0.224604582	0.216868551	436.55	430.7	0.1713
49	220.26	0.262574624	0.220257088	472.89	400.29	0.2435
50	76.34	0.220257088	0.170942731	400.29	311.53	0.0839
51	66.57	0.170942731	0.157432273	311.53	287.25	0.0730
52	70.56	0.157432273	0.133520169	287.25	234.38	0.0789
53	21.28	0.133520169	0.109101886	234.38	191.59	0.0242
55	26.33	0.114970801	0.06810214	194.33	115.11	0.0312
56	29.78	0.06810214	0.097229858	115.11	164.16	0.0342
57	74.38	0.097229858	0.119775471	164.16	258.83	0.0785
58	67.51	0.180097418	0.119775471	500.96	258.83	0.0555
60	62.69	0.220257088	0.086530403	400.29	170.25	0.0664
61	60.59	0.086530403	0.123140282	227.51	305.52	0.0665
62	72.88	0.123140282	0.151098477	243.31	299.06	0.0737
63	59.56	0.151098477	0.138333466	299.06	286.17	0.0589
64	78.49	0.138333466	0.148018172	286.17	306.34	0.0759
65	69.31	0.148018172	0.132988431	306.34	263.44	0.0685
66	48.94	0.132988431	0.119775471	263.44	258.83	0.0474
67	120.62	0.170942731	0.151098477	311.53	299.06	0.1271
68	576.8	0.657150428	0.500856482	1398.5	789.01	0.6372
69	27.71	0.500856482	0.069953973	789.01	110.2	0.0352
70	28.49	0.069953973	0.11398308	110.2	179.56	0.0362
71	22.28	0.11398308	0.075082069	179.56	114.34	0.0288
72	36.06	0.075082069	0.155047276	179.56	228.47	0.0395
73	108.4	0.121079336	0.082611319	305.52	220.26	0.0836
75	105.8	0.100088231	0.084251489	249.68	250.33	0.0780
76	35.28	0.100088231	0.086857228	249.68	228.45	0.0276
77	114.17	0.086857228	0.084294078	228.45	222.31	0.0867
78	38.14	0.084294078	0.065781701	222.31	164.61	0.0308
82	135.41	0.155047276	0.150941854	228.47	215.41	0.1868
83	53.86	0.082611319	0.083422019	220.26	210.94	0.0415

Pipe ID	Length (m)	Start node Q_{ij} (l/s)	End node Q_{ji} (l/s)	ΣL_{ij} (m)	ΣL_{ji} (m)	Leakage (l/s)
84	92.08	0.099217389	0.083422019	250.88	210.94	0.0728
85	94.8	0.099217389	0.103899843	250.88	262.72	0.0750
87	73.79	0.11398308	0.06810214	179.56	115.11	0.0905
88	61.87	0.203545048	0.121946654	419.96	243.31	0.0610
89	101.12	0.157432273	0.138333466	287.25	286.17	0.1043
90	92.54	0.133520169	0.148018172	234.38	306.34	0.0974
91	78.19	0.114970801	0.132988431	194.33	263.44	0.0857
93	318.09	0.203545048	0.180097418	419.96	500.96	0.2685
94	166.21	0.125975929	0.216868551	248.28	430.7	0.1680
95	58.24	0.216868551	0.629905498	430.7	469.82	0.1074
96	245.61	0.629905498	0.187419315	469.82	466.57	0.4280
97	76.97	0.147954107	0.629905498	423.79	469.82	0.1301
98	79.4	0.168464743	0.187419315	466.22	466.57	0.0606
99	30.6	0.056365483	0.100088231	156.52	249.68	0.0224
100	52.92	0.224604582	0.086530403	436.55	170.25	0.0541
101	37.81	0.109101886	0.114970801	191.59	194.33	0.0439
102	9.56	0.187419315	0.056365483	466.57	156.52	0.0073
103	81.5	0.109101886	0.500856482	191.59	789.01	0.0981
104	60.59	0.090022186	0.121079336	227.51	305.52	0.0319
Real losses (l/s)						**8.6991**

Appendix XV: Calculation of real losses using SANFLOW

Description	**Calculation**	**Value (m^3/h)**
Domestic night use	4061 @ 6%/h @ 10 l	2.44
Small non-domestic use	30 @ 50l/h	1.50
Large non-domestic use	1 @1.2 m^3/h	1.20
Total normal night use		5.14
Description	**Calculation**	**Value (m^3/h)**
Mains losses	6.5 km @ 40 l/km × h	0.26
Connection losses	1442 @ 3 l/connection × h	4.33
Property losses	1442 @ 1 l/property × h	1.44
Total background leakage at 50 m pressure		6.03
Pressure correction factor		0.35
Total background leakage at 50 m pressure		2.103
Night use		7.24
MNF m^3/h		45.00
ENF (m^3/h)		37.76
Real losses m^3/month for 09/01/2016		**20,390.40**

Description	**Calculation**	**Value (m^3/h)**
Domestic night use	4061 @ 6%/h @ 10 l	2.44
Small non-domestic use	50 l/h	1.50
Large non-domestic use	1 @1.2 m^3/h	1.20
Total normal night use		5.14
Description	**Calculation**	**Value (m^3/h)**
Mains losses	6.5 km @ 40 l/km × h	0.26
Connection losses	1442 @ 3 l/connection ×h	4.33
Property losses	1442 @ 1 l/property ×h	1.44
Total background leakage at 50 m pressure		6.03
Pressure correction factor		0.36
Total background leakage at 50 m pressure		2.18
Night use		7.32
MNF m^3/h		47.00
ENF (m^3/h)		39.68
Real losses m^3/month for 10/01/2016		**21,429.32**

Appendix XV continued

Description	**Calculation**	**Value (m^3/h)**
Domestic night use	4061 @ 6%/h @ 10 l	2.44
Small non-domestic use	50 l/h	1.50
Large non-domestic use	1 @1.2 m3/h	1.20
Total normal night use		5.14
Description	**Calculation**	**Value (m^3/h)**
Mains losses	6.5 km @ 40 l/km × h	0.26
Connection losses	1442 @ 3 l/connection × h	4.33
Property losses	1442 @ 1 l/property × h	1.44
Total background leakage at 50 m pressure		6.03
Pressure correction factor		0.35
Total background leakage at 50 m pressure		2.10
Night use		7.24
MNF (m^3/h)		47.00
ENF (m^3/h)		39.76
Real losses m3/month for 11/01/2016		**21,469.57**

Description	**Calculation**	**Value (m^3/h)**
Domestic night use	4061 @ 6%/h @ 10 l	2.44
Small non-domestic use	50 l/h	1.50
Large non-domestic use	1 @1.2 m3/h	1.20
Total normal night use		5.14
Description	**Calculation**	**Value (m^3/h)**
Mains losses	6.5 km @ 40 l/km × h	0.26
Connection losses	1442 @ 3 l/connection× h	4.33
Property losses	1442 @ 1 l/property × h	1.44
Total background leakage at 50 m pressure		6.03
Pressure correction factor		0.34
Total background leakage at 50 m pressure		2.08
Night use		7.22
MNF (m^3/h)		50.00
ENF (m^3/h)		42.78
Real losses m3/month for 12/01/2016		**23,103.30**

Appendix XV continued

Description	**Calculation**	**Value (m^3/h)**
Domestic night use	4061 @ 6%/h @ 10 l	2.44
Small non-domestic use	50 l/h	1.50
Large non-domestic use	1 @1.2 m3/h	1.20
Total normal night use		5.14
Description	**Calculation**	**Value (m^3/h)**
Mains losses	6.5 km @ 40 l/km × h	0.26
Connection losses	1442 @ 3 l/connection × h	4.326
Property losses	1442 @ 1 l/property × h	1.442
Total background leakage at 50 m pressure		6.028
Pressure correction factor		0.34
Total background leakage at 50 m pressure		2.06
Night use		7.20
MNF (m^3/h)		49.00
ENF (m^3/h)		41.80
Real losses m^3/month for 13/01/2016		**22,573.83**

Description	**Calculation**	**Value (m3/h)**
Domestic night use	4061 @ 6%/h @ 10 l	2.44
Small non-domestic use	50 l/h	1.50
Large non-domestic use	1 @1.2 m3/h	1.20
Total normal night use		5.14
Description	**Calculation**	**Value (m^3/h)**
Mains losses	6.5 km @ 40 l/km × h	0.26
Connection losses	1442 @ 3 l/connection × h	4.33
Property losses	1442 @ 1 l/property × h	1.44
Total background leakage at 50 m pressure		6.03
Pressure correction factor		0.36
Total background leakage at 50 m pressure		2.14
Night use		7.28
MNF (m^3/h)		48.00
ENF (m^3/h)		40.72
Real losses m^3/month for 14/01/2016		**21,990.19**

Appendix XV continued

Description	**Calculation**	**Value (m^3/h)**
Domestic night use	4061 @ 6%/h @ 10 l	2.44
Small non-domestic use	50 l/h	1.50
Large non-domestic use	1 @1.2 m^3/h	1.20
Total normal night use		5.14
Description	**Calculation**	**Value (m^3/h)**
Mains losses	6.5 km @ 40 l/km × h	0.26
Connection losses	1442 @ 3 l/connection ×h	4.33
Property losses	1442 @ 1 l/property × h	1.44
Total background leakage at 50 m pressure		6.03
Pressure correction factor		0.35
Total background leakage at 50 m pressure		2.14
Night use		7.28
MNF (m^3/h)		49.00
ENF (m^3/h)		41.72
Real losses m^3/month for 15/01/2016		**22,531.40**

Appendix XVI: Questionnaire

Questionnaire No………….

UNIVERSITY OF ZIMBABWE

DEPARTMENT OF CIVIL ENGINEERING

MASTERS IN INTEGRATED WATER RESOURCE MANAGEMENT

2015/2016

1.0 INTRODUCTION

I am ***Goodson Masheka*** a student from the University of Zimbabwe, currently undertaking a Master's Degree in Integrated Water Resources Management (IWRM). As part of the programme, I am currently carrying out a study on the water service which is being provided in this area of Dambwe Central. The research work will go a long way in capturing important information that will help in improving water services delivery in the research area. You are kindly requested to contribute to the research by answering questions on this questionnaire. Your responses will be treated confidentially. Further, note that participation in this survey is not compulsory but based on your willingness. The information provided in this questionnaire will not be used for any other purposes other than this academic purpose.

Appendix XVI continued

2.0 HOUSEHOLD BASIC INFORMATION

Customer's Name:

…………………………………………………………………………………………

Name of Suburb:

……………………………………………………………………………………………

House Address:

……………………………………………………………………………………………

Date: ……………………Start Time: …………………………Finish Time: …………

3.0 DETAILED INFORMATION

3.1. Are you the landlord or the tenant of the house? Landlord ☐ Tenant ☐

3.2. How many people are leaving in this house? ....

3.3. Are you a connected customer to SWSC?

Yes ☐ No ☐

3.4. How many days in a week do you receive water from SWSC?

Less than 3 days ☐ 3-5 days ☐ 6 - 7 days ☐

3.5. How many hours in a day do you experience continuous water supply during the time you have water

12 - 24 Hours ☐ 6-12 Hours ☐ 3 – 6 Hours ☐ Less than 3 Hours ☐

3.6. Do you have a pour flush or flush toilet?

Pour flush toilet ☐ Flush toilets ☐ Pit latrines ☐

Appendix XVI continued

3.7. Have you ever reported any pipe burst/leakages case to Southern Water and Sewerage Company? Yes ☐ No ☐

3.8. How long does it take for SWSC to fix pipe bursts/leakages from the day it starts?

1-2 Days ☐ 3-5 Days ☐ 6-7 Days ☐ More than 7 days ☐

3.9. What do you think can be the cause for frequent pipe bursts/leakages?

High Pressures ☐ Vandalism ☐ Ageing Infrastructure ☐ Poor workmanship ☐

3.10. In your opinion, how do you rate the level of service for Southern Water and Sewerage?

Poor ☐ Good ☐ Very Good ☐ Excellent ☐

3.11. Do you receive bills for your water consumption from SWSC?

Yes ☐ No ☐

3.12. What is the average bill which you pay per month? ....

3.12. If yes in Question 3.11, are you satisfied with the billed consumption you receive

Yes ☐ No ☐

3.13. Do you experience any meter problems

Yes ☐ No ☐

3.14. Have you ever reported your problem to SWSC, if yes, have they ever come to rectify the problem

Yes ☐ No ☐

Appendix XVI continued

3.15. In your own view what is the water quality status of the water you receive in your area?...

....

3.16. Any suggestions which can help to improve the water supply service in this by SWSC?

....

....

....

....

Appendix XVII: t-test on measured and simulated flow to Lizuma Ward

XLSTAT 2016.02.27444 - Two-sample t-test and z-test - Start time: 4/28/2016 at 2:08:21 PM / End time:4/28/2016 at 2:08:23 PM
Hypothesized difference (D): 0
Significance level (%): 5
Summary statistics
Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Measured	24	0	24	50.000	66.000	58.458	4.314
Simulated	24	0	24	53.964	62.280	57.378	2.692

z-test for two independent samples / Two-tailed test:
95% confidence interval on the difference between the means:
] -0.954 , 3.115 [

Difference	1.080
z (Observed value)	1.041
|z| (Critical value)	1.960
p-value (Two-tailed)	0.298
alpha	0.05

Test interpretation:
H0: The difference between the means is equal to 0.
Ha: The difference between the means is different from 0.

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The risk to reject the null hypothesis H0 while it is true is 29.79%.

t-test for two independent samples / Two-tailed test:

95% confidence interval on the difference between the means:
] -1.009 , 3.169 [

Difference	1.080
t (Observed value)	1.041
|t| (Critical value)	2.013
DF	46
p-value (Two-tailed)	0.303
alpha	0.05

Test interpretation:
H0: The difference between the means is equal to 0.
Ha: The difference between the means is different from 0.
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 30.34%.

Appendix XVIII: Summary of calculated p-value for pressure logging points

Pressure Logging Points			
Location ID	Location	Coordinates	p-value
1	Inlet to Lizuma Ward 150mm pipe line	17 51' 26.58"S 25 50' 55.26"E	0.842
2	Near Kazugula Road on a 75mm pipe line	17 51' 18.60"S 25 50' 33.61"E	0.18
3	Sambono Road 75mm pipe line	17 51' 31.20"S 25 50'20.69"E	0.131
4	Undi Street Near the Market 63mm	17 51' 32.92"S 25 50'39.30"E	0.247
5	Mongu Road 63mm Pipe line	17 51' 35.57"S 25 50' 28.75"E	0.66

Appendix XIX: Unmetered accounts

	Name	**Address**	**Length of connection in meter**
Liv0003453	Moyo E	1711 Dambwa Central	15
Liv0003468	Kakinga	1349Nakatindi	5
Liv0003494	Sianziba	1570 Kalanga Rd	10
Liv0003521	Josephine Musole Chikonba	2872 Nakatindi	11
Liv0003558	Mr Nkunika	2613/1425 Dambwa Central	10
Liv0003562	Aaron Mazhita	2613/2095 Dambwa Cental	20
Liv0003585	Mrs Nawa	2613/1402 Nakatindi	10
Liv0010899	Rodwell Mutukwa	ZSM 5 Zambia Railways	6
Liv0010908	R. Bbonga	ZSM 16	6
Liv0010910	Mr Mulonda G	ZSM 18	6
Liv0010917	Kahongo G	ZSM 27	6
Liv0010926	Muntumuswana	ZSM 42	6
Liv0010929	Shikanyanga D	ZSM 48	10
Liv0010949	Simon Malunga	105 ZSM	4
Liv0010953	Kasuka A	140 Z/Sawmills	5
Liv0010953	Josephine Simate	ZSM 142	4
Liv0004360	Kabele G	DB 30	11
Liv0004491	Banda J	DB 161	12
Liv0004518	Kongwa E	DB188	13
Liv0004521	Chibwe IM	DB 191	9
Liv0003463	Nkhoma SK	2613/1426 Dambwa Central	6
Liv0003473	Sinonge Kam	1383 Dambwa Central	50
Liv0003526	Limwanya A	2613/1345 Nakatindi	6
Liv0003527	Makosa RN	2613/1409 Dambwa Central	5
Liv0003535	(Z.Army) GQ Hatyoka	2613/1377 Nakatindi Rd	10
Liv0003540	Josephat Liswaniso	2613/1445 Dambwa Central	103
Liv0003566	Mhongo I.G	2613/1436 Dambwa Central	8
Liv0003570	Felix Siwila	1392 Villa Estate	50
Liv0003574	New Fairmount Hotel	2613/1352 Nakatindi Rd	6
Liv0003577	Gworge Kaunda	2613/1358 Dambwa Central	10
Liv0003675	ZAF(WOI JERE)	1344 Nakatindi Rd	6
Liv0003682	Masamu Innocent	A11 Mulwani	5
Liv0003685	Mr Maponda Habuuka	Mulwani compond Dambwa Central	5
Liv0003686	Chlamba M. Goodwell	Mulwani compond Dambwa Central	5
			454

Appendix XX: Metering testing results

Value ID	Meter ID	Age	Volume passed	Measured volume	Error	Volume passed	Measured volume	Error	Volume passed	Measured volume	Error
		1.5	25l/h			500l/h			1000l/h		
28039129	20006149	1.5	10	10	0.0	100	100	0.00	100	104	0.04
28038910	20007946	1.5	10	11	0.1	100	111	0.11	100	109	0.09
28037758	20006216	1.5	10	10	0.0	100	104	0.04	100	100	0.00
28038755	20007568	1.5	10	10	0.0	100	104	0.04	100	105	0.05
28038905	20007818	1.5	10	10	0.0	100	104	0.04	100	102	0.02
28038122	20006188	1.5	10	11	0.1	100	109	0.09	100	111	0.11
28038122	20007485	1.5	10	11	0.1	100	105	0.05	100	112	0.12
28039023	20007289	1.5	10	10	0.0	100	100	0.00	100	100	0.00
28038995	20007525	1.5	10	10	0.0	100	103	0.03	100	102	0.02
28038425	20007214	1.5	10	11	0.1	100	105	0.05	100	103	0.03
28039030	20007108	1.5	10	10	0.0	100	101	0.01	100	102	0.02
28038408	20006209	1.5	10	10	0.0	100	102	0.02	100	100	0.00
28038409	20007786	1.5	10	10	0.0	100	100	0.00	100	100	0.00
28039383	20007734	1.5	10	11	0.1	100	106	0.06	100	108	0.08
28037740	20006073	1.5	10	10	0.0	100	100	0.00	100	100	0.00
28038696	20007398	1.5	10	10	0.0	100	100	0.00	100	102	0.02
28039123	20008393	1.5	10	10	0.0	100	102	0.02	100	104	0.04
28038860	20006212	1.5	10	9	-0.1	100	105	0.05	100	106	0.06
28038293	20006441	1.5	10	10	0.0	100	100	0.00	100	100	0.00
28039565	20007872	1.5	10	10	0.0	100	101	0.01	100	100	0.00
28038969	20007788	1.5	10	10	0.0	100	102	0.02	100	103	0.03
28038140	20006836	1.5	10	10	0.0	100	100	0.00	100	102	0.02
28037808	20006330	1.5	10	10	0.0	100	101	0.01	100	100	0.00
28039316	20007684	1.5	10	10	0.0	100	100	0.00	100	100	0.00
					0.50			0.67			0.76
Average % meter Error					**2.2%**			**2.9%**			**3.3%**

Appendix XXI: Meter reading for 71 customers

	Meter reading as at 25th January 2016		Meter reading as at 25th February 2016			
House Number	**Readings taken by the researcher**	**Reading taken by the meter reader**	**Readings taken by the researcher**	**Reading taken by the meter reader**	**Billed consumption by the researcher**	**Billed consumption by the meter reader**
DA35	417	417	441	440	24	23
1326/1328 Dambwa Central	1254	0	1272	1	18	1
1326/1329 Dambwa Central	478	479	492	492	14	13
1326/1332	451	453	480	480	29	27
1326/1331	184	185	200	199	16	14
1333	539	541	557	559	18	18
1372	215	215	215	215	0	0
1351	1036.83	1036	1065	1064	28.17	28
1353	402.44	405	414	414	11.56	9
1416	2256.36	2256	2301	2300	44.64	44
1415	328.68	495	417	416	88.32	0
1414	787	787	811	810	24	23
412	3753	3753	3771	3753	18	0
1429	649.77	649	676	675	26.23	26
1419	1394.09	1394	1414	1413	19.91	19
1340	111	114	162	164	51	50
1326/1476	600	589	618	617	18	28
DB226	402	401	421	421	19	20
DB225	128	128	132	132	4	4
DB203	511	510	535	535	24	25
DB224	379	378	402	402	23	24

DB194	1013	995	1040	1040	27	45
DB223	362	362	380	380	18	18
DB222	218	218	230	230	12	12
DB221	74	74	84	84	10	10
DB220	461	461	479	479	18	18
DB219	565	563	600	600	35	37
DB242	449	449	464	464	15	15
DB196	176	176	185	185	9	9
DB197	255	255	265	265	10	10
DB214	186	186	191	191	5	5
DB101	180	179	192	192	12	13
DB49	126	125	133	133	7	8
DB48	392	392	416	416	24	24
DB47	1015	1014	1054	1054	39	40
DB46	356	351	408	408	52	57
DB203	425	510	535	535	110	25
DB45	224	224	230	230	6	6
DB44	320	319	345	345	25	26
DB81	646	646	671	671	25	25
DB87	206	205	215	215	9	10
DB93	169	168	178	178	9	10
DB92	208	206	224	224	16	18
DB91	356	356	374	374	18	18
DB98	259	259	276	276	17	17
DB97	202	202	215	215	13	13
DB99	400	399	420	420	20	21
DB108	202	201	216	216	14	15
DB116	194	194	204	204	10	10

DB115	178	178	188	188	10	10
DB114	270	269	284	284	14	15
DC81	146	147	151	157	5	10
DC82	157	154	165	165	8	11
ZSM01	101	102	106	106	5	4
ZSM 91	309	302	314	304	5	2
ZSM 02	99	101	105	105	6	4
ZSM 03	95	102	112	112	17	10
ZSM88	71	73	90	90	19	17
ZSM04	275	279	286	286	11	7
1330 Villa	0	0	18	0	18	0
DA1	417	418	429	430	12	12
DA2	284	284	306	307	22	23
DA3	369	370	390	389	21	19
DA4	276	276	290	290	14	14
DA5	255	254	273	273	18	19
DA6	385	385	408	409	23	24
DA7	285	284	300	299	15	15
DA10	339	339	357	357	18	18
DA11	237	237	254	254	17	17
DA13	571	571	588	590	17	19
DA14	1020	1020	1040	1041	20	21
DA15	366	366	397	397	31	31
					1425.83	1230

Appendix XXII: Photos of data collections

Pressure Measuring at the inlet to Lizuma Ward along Kafubu Road

Setting up flow meter at the inlet to Lizuma Ward along Kafubu Road

Pipe Verification along Kanzugula – Livingstone Road

Collection of meters from Lizuma Ward

Meter testing in Progress at SWSC water audit Laboratory

Recording of bulk meter reading along Kanzungula Livingstone Road