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AN ASSESMENT OF NON-REVENUE WATER FOR NORTON TOWN IN ZIMBABWE

By

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MASTER OF SCIENCE THESIS IN INTEGRATED WATER RESOURCES MANAGEMENT

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

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DECLARATION

I, Bester Maramba, declare that this research report is my own work. It is being submitted for the Master of Science Degree in Integrated Water Resources Management (IWRM) at the University of Zimbabwe. It has not been submitted before for any other degree for examination at any other university. The findings, interpretations and conclusions expressed in this study neither reflect the views of the University of Zimbabwe, Department of Civil Engineering nor those of the individual members of the MSc Examination Committee, nor of their respective employers

Signature ____

Date ____

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LIST OF ABBREVATIONS AND ACRONYMS

AZP	Average Zone Pressure
CARL	Current Annual Real Losses
DMA	District Metered Area
GIZ	Deutsche Gesellschaft Fuer Internationale Zusammenarbeit
ILI	Infrastructure Leakage Index
IWA	International Water Association
MCA	Multi Criteria Analysis
MNF	Minimum Night Flow
NDF	Night Day Factor
NGO	Non-Governmental Organisation
NRW	Non-Revenue Water
NTC	Norton Town Council
NWASCO	National Water Supply and Sanitation Council of Zambia
SDG	Sustainable Development Goal
UARL	Unavoidable Annual Real Losses
UFW	Unaccounted For Water
UN	United Nations
UNICEF	United Nations Children’s Fund
WHO	World Health Organisation
ZIMASSET	Zimbabwe Agenda for Sustainable Socio-Economic Transformation
ZINWA	Zimbabwe National Water Authority

DEDICATION

To Tonderai, for your patience and love.

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ABSTRACT

Water is an important natural resource and urban water utilities in Southern Africa are facing challenges in the provision of potable water supply. Non-Revenue Water (NRW) is one of the challenges affecting water provision in developing countries. Norton Town Council is mandated by the government to provide safe and adequate water to the residents of Norton. The town is faced with a challenge of limited water supply, with a supply of 7 500m^3/day against an estimated demand of 15 000 m^3/day. This is against a background of high NRW in the region. Therefore, this study sought to assess the extent of NRW for Norton and its components. An evaluation of possible strategies to control NRW was also done. To determine NRW for the town, historical data from 2004 to 2015 was collected and analysed. From the historical data comparison of the bulk water received and billed consumption volume was done to determine overall NRW. Partitioning of water losses was done through Minimum Night Flow (MNF) analysis focusing on two distinct zones of the town which are Galloway and Katanga-Ngoni. Norton town is characterised by intermittent supply, therefore to perform MNF the water supply system was manipulated in order to create continuous flows as recommended. The results obtained were true for the testing period and to correct for intermittent supply correction factors were applied. Correction factors were determined based on the leakage theory which relates pressure to leakage. To evaluate the operating practices in the water supply system qualitative and quantitative data was collected through key informant interviews, questionnaires and meter testing. Multi-Criteria Decision Analysis (MCDA) was used to evaluate strategies to control NRW. MCDA used the data and information collected in the study to determine criterion and objectives in the analysis. Results from the study showed that the average NRW for the town from 2004 to 2015 was 34 % which is above regional benchmarks of 20 % to 25 %. This was attributed to absence of active leakage management, high metering inaccuracies, partial water billing in some areas of the town and manual meter reading instead of use of available automated data loggers. Partial billing suggests that residents in those areas may have free access to water contributing to NRW. Meter testing showed that 73 % of the tested meters were under registering consumption. The average NRW for the two areas were 65 % for Galloway and 76 % for Katanga-Ngoni. Partitioning of water losses for Galloway revealed that real losses were 26 % and apparent losses 74 %. In Katanga-Ngoni, real losses were 35 % and apparent losses 65%. The apparent losses for both areas are above recommended limit range of 20 % to 40 %, indicating a poorly managed system in terms of billing and metering. Apparent losses were attributed to a poor metering system characterised by use of non-functional meters and absence of a regulatory policy on metering and billing. Management of the water supply system by the local authority is fragmented between the departments responsible for water supply. This has resulted in inefficient use of equipment and infrastructure provided for improving water management. Controlling commercial losses was ranked first as a strategy to control NRW followed by integrated management and reduction of physical water losses respectively. The recommendations were to update the customer database and improve on metering. It was also recommended that utilisation of available zonal meters and data loggers be done so that both apparent and real losses are controlled. The study also suggested integrated management of the water system so that departmental goals on water services are the same.

Key words: non-revenue water, apparent and real losses, minimum night flow analysis, billing, metering

CHAPTER 1: INTRODUCTION

1.1. Background

The United Nations in 2015 set up the Sustainable Development Goals (SDGs) and Goal Number 6 is on ensuring the availability and sustainable management of water and sanitation for all (Loewe and Rippin, 2015). This is against a background of water utilities facing more obstacles and challenges today than they have in the past in terms of resources and funding as highlighted by Mohd *et al*. (2009) and Raj (2013). Many urban areas of the world are facing a water challenge, which is a threat to the daily lives of the inhabitants (Mortada, 2015). As water resources have become less accessible and available and less acceptable in terms of water quality, reduction of network losses and enhancement of distribution efficiency represent preferred options to meet water demands (Motiee *et al*., 2007). Water loss is a major component of the problem and it is a significant challenge in many developing countries (Mutikanga *et al.*,2009; Raj, 2013; Gongera, 2015).

Water losses occur when there is a difference between net production and consumption (Bell, 2006 and Sharma, 2008). However, there are many water and revenue losses that are preventable and should not occur (Sharma, 2008). A global water supply and sanitation assessment in 2000 by WHO-UNICEF, averages NRW values of 39 % for African cities, whilst for Asia, Latin America and the Caribbean are at 42 % and North America 15 % (Sharma, 2008 andMutikanga *et al*., 2009). A case study of eight African cities by Gumbo (2004) revealed that Bulawayo, Windhoek and Hermanus achieved less than 20 % (UFW), whilst Johannesburg, Maputo, Maseru, Lusaka and Mutare had UFW from 40 to 60 %. Marunga *et al.*(2006) found an average UFW value of 57 % for Mutare City in Zimbabwe. In 2013 the National Water Supply and Sanitation Council of Zambia (NWASCO) reported a sector performance of 42 % against a minimum national acceptable sector benchmark of 25 % (NWASCO, 2013). A study of 237 water utilities in South Africa estimated NRW for the country to be 36.8 % (Mckenzie *et al*. 2012). The causes of NRW in African cities have been attributed to reactive asset management, poor meter management, poor pressure management etc. (Gumbo and van der Zaag, 2002 and Mutikanga *et al*., 2009).

According to Gumbo (2004) the acceptable figure for Southern African water utilities is 20 %. Higher values of water losses translate into extra costs in terms of energy extraction, treatment and distribution of higher volume of water to meet the same demand (Frauendorfer and Liemberger, 2010). Identification and elimination of water losses should be the goal of every water utility because water losses also have a financial cost to the water utility (Sastry, 2006 and Sharma, 2008a)

The Government of Zimbabwe in partnership with the World Bank took an initiative from 2012 to assess service levels in urban local authorities. NRW is one of the components used to assess performance of local authorities. In the first consolidated report of the project, the key findings were that NRW for urban water utilities in Zimbabwe was averaging 43 % (Nhapi, 2013). The report, however, considered the fact that data accuracy was affected by estimations due to non-functional meters as well as poor record keeping. The recommendation was for water utilities to have water audits and implement water loss reduction measures. The report estimated NRW for Norton to be 62 %. Norton Town council already experiences intermittent water supplies because it relies on water supply from City of Harare at a peak delivery rate of 7 800 m^3/day against an estimated demand of 15 000 m^3/day (Richards *et al.*,2009). As at the close of the 2014 financial year, Norton Town Council owed City of Harare in excess of US$ 7 million in unpaid bulk water charges (NTC, 2015).

1.2 Problem statement

Water losses directly affects the capacity of water utilities to become financially viable (Frauendorfer and Liemberger, 2010). Regional studies have recommended acceptable limits of NRW of 20 % to 25 % (McKenzie *et al.*, 2006 and NWASCO, 2013). The basic problems of water and revenue losses are most effectively addressed when identification and quantification of losses are determined (Sastry, 2006). Extensive studies on NRW for Norton town have not been done to determine the causes and components. This is against a background of limited water supplies for the town. It is for this reason that a study focusing on determination of NRW was done for Norton Town in order to determine its causes and components. The determination will assist in identifying appropriate interventions to control NRW for the town.

1.3 Justification

Norton Town Council has limited water supplies, it depends on supplies from the City of Harare with a supply of 7 800 m^3/day against a demand of 15000 m^3/day (Richards *et al.*, 2009). City of Harare charges Norton Town Council for all water delivered, therefore, the need to quantify and control NRW. The World Bank in 2013 estimated NRW for Norton to be 62 % (Nhapi, 2013). Deutsche Gesellschaft fuer Internationale Zusammenarbeit (GIZ) in

2014 estimated UFW for Norton to be 42 % (Tafangombe and Madyiwa, 2014). Despite the figures being conflicting they are both above acceptable limits. The limited water supply and indications of high NRW justifies a study which focuses on estimation of NRW so that appropriate strategies are identified to improve management of the system. NRW reduces water coverage in terms of physical losses. Coverage for water supply in Norton was determined as 66 % in 2013 against an expected benchmark of 100 % (Nhapi, 2013). NRW reduces revenue inflows as the water lost does not bring returns to a water utility (Farley *et al.*, 2008). Norton Town Council owes City of Harare on bulk water purchases and has a collection efficiency of 35 % and this is exacerbated by water losses. Use of unreliable data results in difficult water management and quantification of water losses creates a platform for improvement on water management and positively affects other sectors such as infrastructure development, housing, health etc.

1.4 Objectives

The main objective of the study was to assess the extent of non-revenue water in Norton town in order to identify areas of intervention to control NRW.

1.4.1Specific objectives

The specific objectives were;

i. To determine NRW trends for the water supply system from 2014 to 2015
ii. To partition the water losses into real and apparent losses
iii. To evaluate the town's water supply system operating practices
iv. To evaluate possible strategies to control non-revenue water.

CHAPTER 2: LITERATURE REVIEW

2.1 Water supply and Sustainable Development Goals

The importance of improved water supply, sanitation and hygiene has been recognised by their inclusion as specific targets in the framework of SDGs (Loewe and Rippin, 2015). As such Goal Number 6 and its specific targets emphasize the need for universal and equitable access to water, adequate and equitable sanitation, water use efficiency, integrated water resources management and protection and restoration of water resources systems (Loewe and Rippin, 2015). Therefore, reduction and quantification of water losses ensures sustainability of water resources in light of achieving SDGs.

2.2 Occurrence and variation of non-revenue water

Annually, more than 32 billion m^3 of water are lost through leakage from distribution networks and a further 16 billion m^3 is delivered to customers but not invoiced due to theft, poor metering or corruption (Farley *et al*., 2008). Non-revenue water occurs in all distribution systems, but the volume of loss varies depending on the characteristics of the pipe network and other local factors (McKenzie and Seago, 2005 and Motiee *et al*., 2007). Table 2-1 shows the variation in unaccounted for water in some Southern African cities according to Sharma (2008).

Table 2-1: UFW in some Southern African cities (Sharma, 2008a)

City	**Unaccounted For Water (%)**
Luanda, Angola	60
Gaborone, Botswana	20
Kinshasa, Democratic republic of Congo	47
Maseru, Lesotho	32
Port Louis, Mauritius	45
Maputo, Mozambique	34
Windhoek, Namibia	11
Great Victoria, Seychelles	26
Mbabane Swaziland	32
Dar es Salaam, Tanzania	60
Lusaka, Zambia	56
Harare, Zimbabwe	30

From Table 2-1 an average of more than 35 % of the water produced is lost in Southern Africa. The variation depends on the different characteristics of the distribution systems.

2.3 Components of non-revenue water

Non-revenue water in distribution systems is attributed to leakage from pipes, thefts and overflows, improper recording of consumed water by meters, illegal connections and under registration of water meters (Sharma, 2008a). By typology, these sources of water loss can be classified into real losses and apparent losses (Sastry, 2006). Commercial losses are the apparent losses and physical losses are the real losses (Lee and Schwab, 2005). It is recommended as a standard practise to split water losses into real and apparent losses when studying water losses (McKenzie *et al.*, 2005). Real losses are attributed to the technical problems involving physical water loss such as pipe breaks and leaks, storage over flows and house connection leaks. They are an indication of the actual water supplied to the system that is lost into the ground (McKenzie *et al.*, 2005). Real losses are also attributed to varying pressure, inefficient leak detection system, poor workmanship and maintenance of distribution network (Sharma, 2008a). Real losses are therefore the physical water losses in the distribution system.

Apparent losses are commercial losses which are from improper recording of total water consumed due to meter errors, inaccurate assumptions of unmeasured and unauthorised consumption and these deficiencies are attributed to administrative inefficiencies of the water utility (Motiee *et al.*, 2007 and Frauendorfer and Liemberger, 2010). Xin *et al*. (2014) acknowledge that apparent losses consist of four primary components such as customer meter inaccuracy, unauthorised consumption (theft, meter bypass, illegal connections, misuse of fire hydrants, etc.), meter reading errors as well as data handling and billing errors. Customer meter inaccuracy is the major reason for the apparent water losses in a water supply system (Xin *et al*., 2014a). Water losses are therefore composed of real and apparent losses and it is standard practise to split the two when studying water losses.

2.4 Causes of non-revenue water

2.4.1 Causes of Real losses

Real losses are water volumes lost within a given period through all types of leaks, bursts and overflows (Sastry, 2006). They can be classified according to their location within the system and their size and runtime (Fallis *et al.*, 2011). Leakage from the transmission main and distribution mains may occur at pipes (bursts due to extraneous causes or corrosion), joints (disconnection, damaged gaskets) and valves (operational or maintenance failure) and usually have medium to high flows rates and short to medium runtimes (McKenzie and Seago, 2005 and Fallis *et al*., 2011). Runtime is short to medium because when a leakage occurs it is generally obvious and so serious such that it is repaired within the shortest time possible (McKenzie *et al*., 2006; Fallis *et al*., 2011). A case study of Nakuru Water and Sanitation Services Company in Kenya by Gongera (2015) revealed that mechanical damages and vandalism were the main causes of pipeline leakages in water supply systems. Therefore, real losses from transmission and distribution mains have medium to short runtime as they are normally visible and promptly attended to.

Leakage from service connections up to the point of the customer are sometimes referred to as the weak points of water supply networks, because their joints and fittings exhibit high failure rates and tends to exceed all other leakages (McKenzie *et al*., 2006). They further highlight that these leakages are difficult to detect due to their comparatively low flow rates and thus often have long runtimes as they are often unreported. Leakages can also be on storage tanks due to deficient or damaged level controls or overflows and seepage from pervious walls and it is often difficult to assess since it normally occurs at night and may run undetected for years (McKenzie *et al*. 2006 and Fallis *et al*., 2011). Therefore, leakages from service connections up to the point of customer and on storage tanks are difficult and may have long run times.

Considering size and run time there are visible or reported leaks which are primarily from sudden bursts or raptures of joints on pipes and leaking water visibly appears on the surface (Fallis *et al*., 2011). McKenzie *et al*. (2006) and Fallis *et al*. (2011) highlight that there are also unreported or hidden leaks with flow rates greater than 250 l/hr at 50m pressure, but due to unfavourable conditions do not appear on the surface and are referred to as bursts and background leakages with flow rates less than the 250 l/hour which do not appear on the surface. The threshold used between bursts and background leakages is not fixed as it varies from country to country, for instance in South Africa the threshold is 250 l/hour and in the UK it is 500 l/hour (McKenzie *et al*., 2006). There are therefore bursts and background leakages which are differentiated by their flow rates.

While apparent losses can be totally eliminated, a certain level of real losses always remain in the water supply system and this is known as Unavoidable Annual Real Losses (UARL)

(Sharma, 2008a). These water losses cannot be avoided from a technical point of view and are, therefore, considered acceptable from an economic point of view (Bell, 2006; Lambert and Taylor, 2010; Sharma, 2008a). This means that in any water distribution system, real losses cannot be eliminated completely as some form of leakages will exist.

2.4.2 Causes of Apparent losses

Appparent losses are caused by other factors which can be grouped based on their origin such as meter inaccuracies due to broken or incorrect customer and bulk water meters, data handling and accounting errors and pooor customer accountability in billing systems and unauthorised consumption due to water theft and illegal connections (Frauendorfer and Liemberger, 2010; Sturm *et al*., 2013; Xin *et al.*, 2014b). Apparent losses may be considered as all water that is successfully delivered to the consumer but which is not metered or recorded correctly and thus causes an error of consumer consumption (Thornton and Lambert, 2005 and Lambert and Taylor, 2010). According to Seago *et al*. (2004) apparent losses recommended limit is 20 % of total losses from a study of typical water distribution systems in South Africa. Xin *et al*. (2014b) and Lambert and Taylor, (2010) also support that apparent losses are 30 to 40 % of the total losses.

Metering inaccuracies are the most common form of apparent losses and occurs when water is not metered correctly due to measuring errors or losses in water meters (Fallis *et al*., 2011 and Gongera, 2015). Data handling errors may occur during the taking of readings and data may get lost or changed due to systematic errors in data processing and billing procedure (Fallis *et al*., 2011). Unmetered consumption may be underestimated while unmetered production maybe overestimated (Lundqvist *et al.*, 2005 and Lambert and Taylor, 2010). Unauthorised consumption appears in many different ways such as illegal connections, vanadalised, manipulated or bypassed customer meters, illegal water abstraction from fire hydrants as well as bribery and corruption of utlity personnel (Sastry, 2006; Sharma, 2008a; Fallis *et al*., 2011). Consequently, Gongera (2015) in Kenya found out that non-reading of meters and lack of access to customer meters were the key factors contributing to billing errors. Causes of apparent losses therefore include metering inaccuracies, data handling errors and unauthorised consumption.

2.5 Effects of non-revenue water

2.5.1 Physical loss

The main concern of NRW is the physical loss of water after a huge investment involved in the whole process from withdrawing the water, treatment and delivery to the distribution network in addition to the revenue loss (Sastry, 2006). Fallis *et al*. (2011) supports the same that amount of water lost must be provided again in order to meet customer demands. NRW reduction is a priority issue to save the scarce water resources, besides improving efficiency and finances of water utilities (Sastry, 2006).

2.5.2 Additional financial costs

Higher values of real losses translate into extra costs and energy for extraction, treatment and distribution of higher volume of water to meet the same demand. This is also supported by Fallis *et al*. (2011) who classify water lost on its way to consumers as an economic cost as the lost amount of water must be provided again and technically the production capacities of installations must be increased. This is a huge financial burden on the water utilities, in light of the increasing financial scarcity (Frauendorfer and Liemberger, 2010). Kuma and Ewusi (2009) considered water losses as a source of revenue loss. This was revealed during their study of Tarkwa town in Ghana where NRW was 34 % to 65 % of the water produced and the main causes were illegal water connections, pipe leaks and bursts.

The increasing cost in the production of water makes it imperative for water utilities to improve water management, as water provision can pay for itself (Bell, 2006). Apparent losses do not only reduce the income of a water utility directly but also result in errors of basic data, which may further bring difficulties in water supply management (Xin *et al.*, 2014b). Apparent losses therefore result in additional financial cost as additional water is required to meet the same demand reducing the income of a water utility.

2.5.3 Route for contamination

Real losses have also been identified as a route of contamination in the water distribution systems (Lee and Schwab, 2005 and Mutikanga *et al*., 2009). They highlight that if a leak occurs in a pipeline and faecal contamination is in the environment because of reasons such as inadequate sewage collection, leaking waste water pipes then a route exists for the contaminants to be introduced in the water supply system.

2.5.4 Water losses and sustainable development

Water losses are considered an obstacle to sustainable development by Fallis *et al*. (2011) with a number of potential impacts such as economic, technical, social and ecological.

Economic effects: Economic effects occur as a result of the costs incurred for exploiting, treating and transporting water which is lost on its way to the customer without generating any revenue for the water utility (Sastry, 2006 and Frauendorfer and Liemberger, 2010). Pipe bursts and leaks necessitate expensive repair works and may also cause considerable damage to nearby infrastructure (Fallis *et al*., 2011). Martins *et al*. (2012) reiterates that water production for human consumption has very exacting quality requirements, which results in high production and treatment costs to meet the stringent quality standards.

Technical impacts: They occur as leakages lead to reduced coverage of the existing water demand, possibly so much that the system can no longer operate continuously (Lee and Schwab, 2005 and Lahnsteiner and Lempert, 2007). Intermittent supply will cause further technical problems by air intruding into the pipes and will tempt customers to install private storage tanks (Fallis *et al*., 2011).

Social impacts: They are observed when customers are being adversely affected by supply failures, such as low pressure, service interruptions and unequal supply and also health risks which may arise from the infiltration of sewage and other pollutants into pipe systems under low pressure or intermittent supply (Lee and Schwab, 2005 and Besner *et al*., 2010). Frauendorfer and Liemberger (2010) further support that in the case of intermittent supply, which is frequently caused by excessive leakages, the urban poor often suffer most as they cannot afford proper storage facilities and often have to buy overpriced water from vendors during non-supply hours.

Ecological impacts: They are experienced when water losses are compensated for by further increasing water extraction rates on sources, this requires additional energy and thus carbon dioxide emission that could be avoided (Fallis *et al*., 2011). Water losses have environmental consequences, related to the seasonal and spatial scarcity of water (Martins *et al*., 2012). Surface water resources are being depleted as more new dams are being developed and groundwater in some countries is effectively being extracted to such an extent that there are problems in quantity and quality (McKenzie and Seago, 2005). These effects demonstrate that water loss impairs all aspects of sustainability of a water supply system therefore water utilities should strive to analyse, quantify, and control physical and apparent water losses from their water supply systems.

2.6 Benefits of reducing non-revenue water

Faced with acute water shortages caused by contamination and over extraction and when it is also difficult to search for new water sources, it is apparent that water utilities and communities reduce drinking water losses in their various forms (McKenzie and Seago, 2005; McKenzie *et al*., 2006; Xin *et al*. 2014a). Considering the crisis of water supply issues in large cities owing to increase in population, quantifying the water losses in terms of both physical and non-physical losses of water in the network to improve the system efficiency represents an important issue that managers need to consider (Motiee *et al*., 2007). According to Tortajada (2006) Singapore is a water scarce country and between 1990 and 2004 NRW was below 9.5 % and is consistently around 5 % and there are no illegal water connections to its water supply system. From the Singapore study it is apparent that water losses should be seriously controlled and reduced.

2.6.1 Increased coverage of water supply

For many cities, reducing NRW should be the first option to pursue when addressing low service coverage levels and increased demand for piped water supply (Otieno and Ochieng, 2004 and Motiee *et al.*, 2007). As such, NRW reduction should be the aim of every water utility since it leads to improved economic and ecological efficiency and better service for clients (Fallis *et al.*, 2011). Expanding water networks without addressing water losses leads to a cycle of waste and inefficiency (Frauendorfer and Liemberger, 2010). About 45 billion m^3 of water are lost annually through leakages corresponding to 35 % of the total water supplied and if half of this water was saved 200 million people would have access to safe water without any further investment (Kanakoudis *et al.*, 2015). Therefore, reduction and control of NRW increases coverage without the need for huge investments in the system.

2.6.2 Increased revenues

When treated water is lost, raw water abstraction, treatment and distribution costs increase, water sales decrease, and substantial capital expenditure programs are often promoted to meet the ever-increasing demand (Otieno and Ochieng, 2004). This does not address the core problem as water delivered to customers' taps has a large amount of embedded energy

(Frauendorfer and Liemberger, 2010). Reducing physical losses will not only help postpone capital investments for developing new water sources, it will also help reduce a utility's energy bill (Sastry, 2006 and Kanakoudis *et al.*, 2015). Baird (2011) highlights that NRW reduction results in saving water, reducing operational costs through the water energy nexus and this improves the financial position by netting uncaptured revenue and lowering production costs. The increasing cost in production makes it imperative for water utilities to improve water management through measures such as reduction of water loss as this may result in financial sustainability through improvement of internal revenues (Mugisha *et al*., 2005 and Gongera, 2015). This is further supported by Fallis *et al.* (2011) who also highlight that energy is saved in water treatment and pumping increases the revenues generated by water.

The focus need not only be on real losses but also apparent loses (Xin *et al.*, 2014b). According to Lambert and Taylor (2010) apparent losses accounts for 30 to 40 % of the total leakage, therefore strengthening the management of apparent losses will pose a notable and direct effect on the reduction of pipe network loss. McKenzie *et al*. (2005) support that the reduction of apparent losses results in increased income for the water utility.

2.6.3 Environmental sustainability

Water loss is also a priority issue to save the scarce water resources, besides improving efficiency and finances of water utilities (Sastry, 2006). Fallis *et al.* (2011) also highlight that it is not only essential for ethical reasons to increase coverage of supply of safe drinking water to reduce the spread of water borne diseases but reducing water losses mitigate environmental problems and alleviate the stress on scarce water resources.

2.6.4 Effective use of facilities and equipment

NRW reduction also results in extended life span of pumps and equipment due to reduced pumping (Bell, 2006). Gongera (2015)also support that reduction of NRW results in the need for less water production, translating into cost savings in operation and maintenance. NRW results in increased pumping hours to meet the same demand resulting in early replacement of pumping equipment (Sastry, 2006).

2.6.5 Reduced water borne diseases

High levels of physical losses cause intermittent supply and pose a significant public health risk therefore a reduction in water loss assists in the reduction of potential contamination to drinking water (Lee and Schwab, 2005). Fallis *et al.* (2011) highlight that less water bursts, increased security of supply and hygienic conditions enhances the public's perception of the water utility and this positively affects the consumers' willingness to pay. In essence reducing water losses in their various forms will make more water available and enable water utilities to increase coverage, including to poor communities and a reduction of commercial losses or the existence of extensive losses results in more water being billed, and in addition revenue for the utility.

2.7 Determination of non-revenue water

Various types of water losses exist and there are many different causes and factors influencing the amount of water lost in a distribution network such that without proper knowledge of the nature of the water losses it is thus impossible to find the appropriate and most efficient interventions to reduce them (Fallis *et al*., 2011). NRW should be accurately determined with the first step being a water audit to determine exactly how much water is being lost and a water utility should know the amount of water being used by all its customers and the amount produced from treatment plants or amount purchased (Bell, 2006).

Audits are also used to estimate the cost associated with these losses to the water system by balancing the amount of water produced with the amounts billed (Baird, 2006). Comprehensive audits can provide the water system with a detailed profile of the distribution system and water users, allowing for more effective management of resources and improved reliability (O'Malley *et al*., 2013). Benefits of an audit include improved knowledge and documentation of the distribution system including the identification of problem or risk areas (Otieno and Ochieng, 2004). They further emphasize that identification of risk areas assists utilities in focusing on areas that require remedial action and efficient use of resources. A basic water audit includes the following three elements which are meter testing, leak detection and quantification and system inventory (Mutikanga *et al*., 2009).

2.7.1 District metering in non-revenue water analysis

The process of auditing a water network involves activities such as diving the town/city into small enumerable areas called District Metering Areas (DMAs) and installation of bulk meters at several strategic points in each DMA to measure water flow and recording of the bulk meter readings over time (Sastry, 2006). Through the monitoring of the inflow and outflow in each area, the DMAs method can effectively find out leakage problem (Xin, *et al*., 2014b). The delineation of zones of the water network represents an effective strategy to inspect, quantify and subsequently control NRW (Motiee *et al*., 2007). An analysis of the results using the International Water Association (IWA) standard water balance table and terminology will show the magnitude of water losses in the different areas which will inform corrective action and policy (Mutikanga *et a*l., 2009).

2.7.2 Water balance analysis

A water balance is used to assess the volumes of NRW and the management of water losses in a distribution system (Sharma, 2008a and Mutikanga *et al.,* 2009).The water balance has been and is recognised and adopted by an increasing number of countries in the world (Sastry, 2006). At the consumer ends the activities involved are testing of consumer meters for correct measurements, identification of unauthorised measurements and usage of water in each DMA and preparation of the water balance charts for all DMAs (McKenzie and Seago, 2005). According to (Sharma 2008a; Lambert and Taylor, 2010; Fallis *et al*., 2011) IWA published in July 2000 a standard international best practise water balance as shown in Table 2-2.

Table 2-2: IWA Standard water balance (Sharma, 2008a; Lambert and Taylor, 2010;Fallis et al., 2011)

System input volume	Authorised consumption	Billed authorised consumption	Billed water exported	Revenue water
			Billed metered consumption	
			Billed unmetered consumption	
		Unbilled authorised consumption	Unbilled metered consumption	Non-revenue water
			Unbilled unmetered consumption	
	Water losses	Apparent losses	Unauthorised consumption	
			Customer meter inaccuracies	
		Real losses	Leakage on transmission and distribution mains	
			Leakage and overflows at storage tanks	
			Leakage on service connection up to point of customer meter	

An analysis of the results of the water balance will show the magnitude of water losses in the different areas for the purposes of improving efficiency, management and cost recovery (Sastry, 2006).The elements of the water balance are defined as follows;

The System input volume: It is the measured volume of water supplied to a defined part of the water supply system from the utility's own sources as well as purchased from other sources (Lambert and Taylor, 2010; Mckenzie *et al*., 2012; Xin *et al*., 2014b).

Authorised consumption: It is the volume of metered and/or un-metered water taken by registered customers, the water utility and other authorised parties (Sturm *et al*., 2013). It includes billed authorised consumption and unbilled authorised consumption and also comprises leaks and overflows after the point of customer metering as well as own requirements of the water utility (Lambert and Taylor, 2010 and Fallis *et al*., 2011).

Revenue water: This refers to billed authorised consumption which is the volume of water successfully delivered and billed to the customer which generates revenue for the water utility (Fallis *et al.*, 2011).On the other hand non-revenue water is the difference between system input volume and billed authorised consumption, consisting of unbilled authorised consumption and water losses (Lambert and Taylor, 2010). Water losses is estimated as the difference between system input volume and authorised consumption and consists of real and apparent losses (McKenzie *et al*., 2005).

Water losses is expressed as a percentage of net water production (delivered into the distribution system) in m^3/day/km of water distribution pipe network system and other use m^3/day per connection or, m^3/day/connection/m pressure (Sharma, 2008a). Water loss expressed as a percentage of net water production is the most common however it could be misleading for systems with different net productions with the same amount of real and apparent losses (Sharma, 2008a and Lambert and Taylor, 2010).

2.7.3 Assessing and quantifying real losses

Leakages that lead to real losses can occur in storage tanks, transmission mains and the distribution network and the majority of leakages occur within the distribution system (Lambert and Taylor, 2010 and Fallis *et al.*, 2011). Leakages from reservoir tanks may be attributed to physical leaks caused by cracks or poor seals on the structure and they are difficult to detect since the leaks can run unnoticed for years (McKenzie *et al*., 2006).

Volume of water leaking from a storage reservoir maybe detected by a volumetric or drop test analysis (McKenzie *et al.*, 2006; Fallis *et al*., 2011; Sturm *et al*., 2013). The test is normally performed at night by filling the tank to a maximum level before closing the inlet and outlet valves and fluctuations in the water level are observed over a period of 4 to 12 hours, the tanks leakage rate can be derived by dividing the volume of water lost by the duration of the test (McKenzie e*t al*., 2006 and Fallis *et al*., 2011).

Transmission mains losses are usually measured through simultaneous measurements upstream and downstream end of a pipe section under steady state conditions with the pipe fully filled and all lateral connections to the section closed (Fallis *et al*., 2011). The results are a good indication of the overall losses along the entire transmission mains. McKenzie and Seago (2005) suggest that losses on the distribution network can be measured through separation of a supply area into discrete zones and appropriate methods based on supply system applied to measure leakage. There are different methods to measure leakage which are the Minimum Night Flow (MNF), stop tap and continuous measurement (Fallis *et al*., 2011).

Minimum night flow analysis (in systems with continuous supply: It is a method used to identify leakage problems in a defined area (McKenzie *et a*l., 2005). It is defined by Sturm *et al*. (2013) as the lowest flow entering a defined area in a 24 hour period, with the assumption that the available water during that period is sufficient to meet water demand .This method is suitable for systems that are operated continuously based on the assumption that authorised consumption drops to a minimum during night hours (Fallis *et al*., 2011 and Lambert and Taylor, 2010). Minimum night flow analysis is a bottom up approach used in real loss assessment in urban water utilities (Sturm *et al*., 2013). Between 0200 and 0400 hours, very few customers use water such that sudden variations in water consumption can reflect the real leakage (Xin *et al*., 2014a). They further went on to suggest that residential consumption is low at night and flow over 3 m^3/hr should be carefully examined for detection of leaks.

The amount of water fed into a discrete zone during this time period is continuously measured and the share of legitimate consumption and losses is analysed (Sturm *et al*., 2013). According to McKenzie *et al*. (2005) and Fallis *et al*. (2011) Equation 1 is used to do the analysis.

Q_{in}=Q_{dom}+Q_{bulk} + Q_{trans} + Q_{loss} ……………………………………………..Equation 1

Where Q_{in} (m^3/hr) is system input volume

Q_{dom} (m^3/hr) is domestic night consumption

Q_{bulk}(m^3/hr) is non-domestic night consumption

Q_{trans}(m^3/hr) is transfer of water to neighbouring zones

Q_{loss} (m^3/hr) is water losses

Legitimate consumption consists of domestic night consumption Q_{dom} (mainly for flushing toilets) and non-domestic Q_{bulk} (administrative, industrial, commercial or agricultural users) which may represent a large percentage of minimum night flow (Fallis et al., 2011). Bulk consumers should be correctly identified and their night consumption determined and water exports and transfers, Q_{trans} to neighbouring zones have to be measured or must be ceased during MNF assessments (McKenzie *et al.*, 2006 and Fallis *et al*., 2011).

In order to determine the daily water losses from an assessed zone, the ratio of night and day zonal pressures must be taken into account by calculating the Night Day Factor (NDF) (Lambert and Taylor, 2010). Pressure profiles must be measured at the Average Zone Point (AZP) and the system's leakage exponent, α must be ascertained in order to calculate NDF, then the volume of real daily losses $Q_{loss,d}$ can then be determined using Equations 2 and 3(Lambert and Taylor, 2010 and Fallis *et al*., 2011).

$Q_{loss,d} = NDF \times Q_{loss}$……………………………………………………Equation 2

And

$NDF = \sum_{i=1}^{i=24} (\frac{Pi}{Pmnf}) P^{\propto}$…………………………………………..........Equation 3

Where $Q_{loss,d}$ (m^3/d)is the daily real loss volume

NDF (h/d) is the night to day factor

Q_{loss} (m^3/hr) average minimum night flow rate

P_i (m) average pressure at AZP during 24 hours

P_{mnf} (m) Average pressure at AZP during MNF conditions

α is the leakage exponent

Typical values of the NDF range from 20 or less in gravity fed systems to over 30 hours per day in pressure management areas with flow modulated systems (Fallis *et al*., 2011). For zones supplied by gravity NDF varies between 18 to 23 hours and for pumped systems or pressure modulated systems NDF ranges from 24 to 30 as pressures at night and leak flow rates are lower at night than during the day (Lambert and Taylor, 2010).

Stop tap method: It is applied in systems with intermittent supply since MNF cannot be used in those systems as it is distorted due to the common use of private storage which distorts night flow characteristics (McKenzie *et al.*, 2006 and Fallis *et al*., 2011). The stop tap method is an alternative, and requires that all connections have to be stopped in order to prevent filling of private receptacles (Fallis *et al*., 2011). However they have pointed out that this method has a disadvantage of considerable volumes of water being lost at the leak points and all leaks cannot be identified during the short testing period and customers are without supply for several hours.

Continuous measurements: According to Fallis *et al.* (2011) continuous measurement is the best method to assess real losses in the distribution network through a constant arrangement of the network into discrete zones, with bulk meters installed at all entry points and customers meters at households. Through this method a water utility obtains a good over view of the condition of its water supply system and can detect pipe breaks almost instantaneously by continuously monitoring the system input and regularly reading customer meters (Fallis *et al.*, 2011).

The Infrastructure Leakage Index (ILI): This is a performance indicator for making comparisons of real losses (Lambert, 2012). The World Bank Institute (WBI) provides an internationally applicable description of ILIs and corresponding relative leakage management activities for each WBI Band (Delgado, 2008 and Lambert, 2012). ILI is a better indicator for losses and describes the quality of infrastructure management (Sharma, 2008b). According to Sharma (2008b), Delgado (2008) and Lambert and Taylor (2010) ILI is calculated as a ratio of Current Annual Real Losses (CARL) to Unavoidable Annual Real Losses (UARL) thus Equation 4.

$$ILI = \frac{CARL}{UARL} \qquad \text{...Equation 4}$$

Where CARL = current annual real losses obtained from MNF analysis

Where UARL = unavoidable annual real losses (l/d)

UARL is determined using Equation 5

$$UARL = (18 \times L_m + 0.80 \times N_c + 25 \times L_p) \times P \qquad \text{.Equation 5}$$

L_m = length of mains

N_c= number of service connection

L_p= length of unmetered underground pipe from street edge to customer meters (km)

P= average operating pressure at average zone point

ILI is classified into Bands A to D by the World Bank with different limits for developed and developing countries. Table2-3 shows the banding system used to interpret ILIs.

Table 2-3: WBI Banding system to interpret ILIs (Fantozzi *et al*., 2006; Sharma, 2008b; Lambert and Taylor, 2010)**.**

Developing countries ILI Range	**Developed countries** ILI Range	**Band**	**General description of real loss performance management categories**
<4	< 2	A	Further loss reduction maybe uneconomic unless there are shortages: careful analysis is needed to identify cost effective improvement
4 to < 8	2 to < 4	B	Potential for marked improvements: consider pressure management, better active leakage control practise and better network maintenance
8 to < 16	4 to < 8	C	Poor leakage record; tolerable only if water is plenty and cheap; even then analyse level and nature of leakage and intensify leakage reduction efforts
16 or more	8 or more	D	Very inefficient use of resources; leakage reduction programs imperative and high priority

2.7.4 Assessing and quantifying apparent water losses

The three main sources of apparent losses were identified as meter inaccuracies, unauthorised consumption and data handling errors (Lambert and Taylor, 2010; Xin *et al*., 2014a). Apparent losses due to meter inaccuracies can be estimated by selecting a representative group of domestic meters while taking into account the different meter types, brands, sizes and age groups and checking them on a test bench (Farley *et al*., 2008). The average meter inaccuracies for each group of meters can then be applied to the whole area under study. A value of +/-2 % is recommended for apparent losses due to water meter under-registration (Lambert and Taylor, 2010).

Errors caused by data handling mistakes can be detected and quantified by means of reduction of human error by training, standardising, reporting and auditing (Sastry, 2006).

Farley and Liemberger (2005) and Farley *et al*. (2008) also support that data handling errors can be reduced by continuous training of meter readers and having standardised working routines.

Unauthorised consumption can be estimated through estimation of unauthorised connections so that unauthorised water use can be quantified (Fallis *et al*., 2011). The estimation of the connections maybe achieved through property surveys in a pilot zone and the estimated number of illegal connections is then multiplied by the average household size and per capita water consumption (Fallis *et a*l., 2011).

2.8 Controlling non-revenue water

In 2003 The IWA water loss task force defined the four principal intervention methods to combat real water losses as illustrated in Figure 2-1, which are pressure management, active leak detection, speed and quality of repairs and infrastructure management (McKenzie and Seago, 2005; Lambert and Taylor, 2010; Fallis *et al*., 2011).

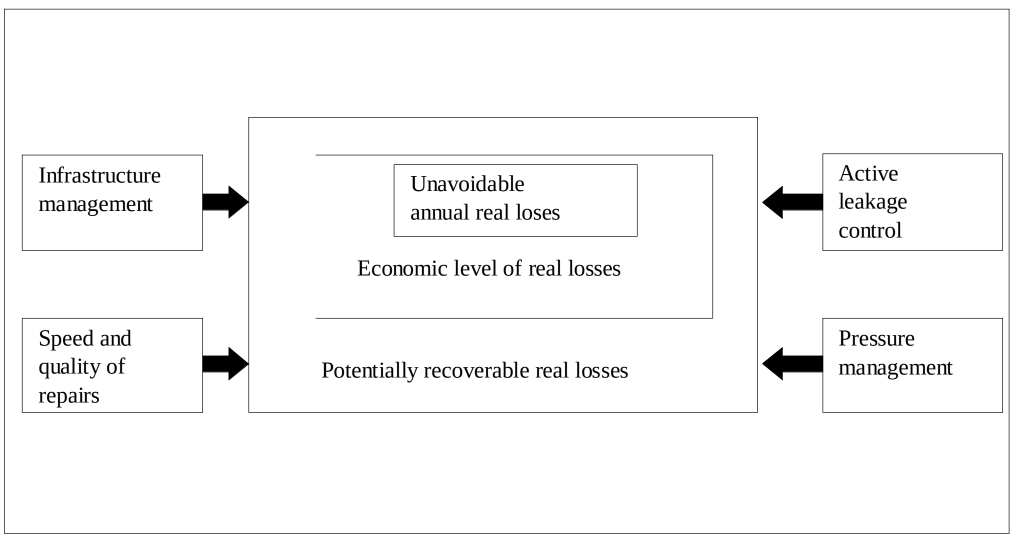

Figure 2-1:Four components of active real loss management(McKenzie and Seago, 2005; Lambert and Taylor, 2010; Fallis *et al*., 2011).

Pressure management can be defined as the practise of managing system pressures to the optimum levels of service while ensuring sufficient and efficient supply to legitimate uses (Thornton and Lambert, 2005). Pressure management has the effect of reducing real water losses by reducing unnecessary or excess pressures as well as eliminating strong pressure fluctuations (Motiee *et al*., 2007 and Fallis *et al*., 2011). The leak flow rate is directly proportional to the pressure which means that pressure management is the only intervention method to have a positive impact on all three components of real water losses which are background leakages, reported and unreported leakages (Motiee *et a*l., 2007). An increasing number of countries and utilities are now recognising that good pressure management is the fundamental foundation of good leakage and infrastructure management (Thornton and Lambert, 2005).

Apparent losses are also an important component of non-revenue water and they exist in all kinds of water distribution systems (Xin *et al.*, 2014b). Utilities therefore need not only focus on real loss management since apparent losses also have a commercial cost to the utility (Frauendorfer and Liemberger, 2010).It is generally acknowledged that apparent losses consists of four primary components which are meter inaccuracy, unauthorised consumption, metre reading errors as well as data handling and billing errors (Xin *et al.*, 2014b). As such the IWA water loss task force also defined the four principal intervention methods to combat apparent water losses as shown in Figure 2-2.

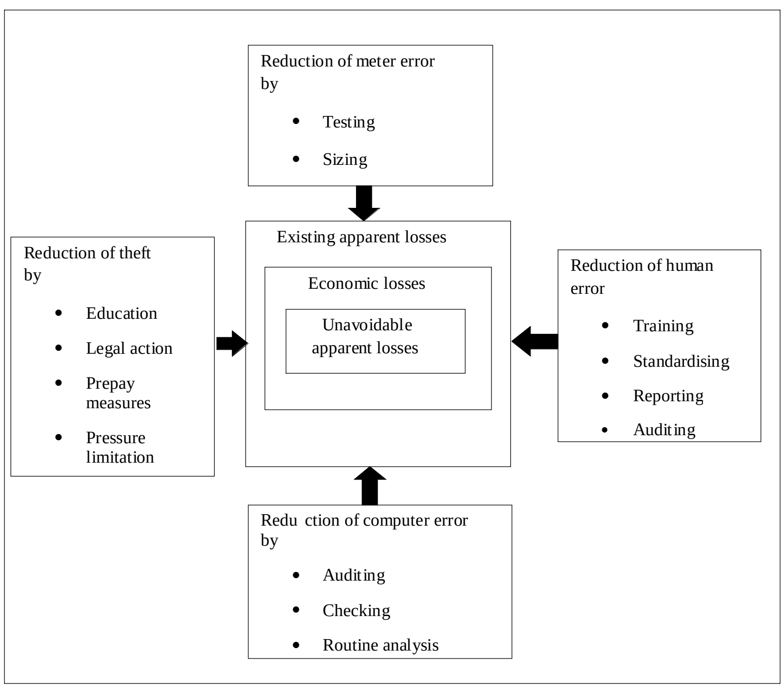

Figure 2-2: Four components of an active apparent loss management (Mckenzie *et al.*, 2006)

The four components are reduction of meter errors, reduction of human error, reduction of theft and reduction of computer error. Reduction of meter error is through meter replacement programmes, testing and sizing as accurate and complete metering is fundamental to any water loss control programme (O'Malley *et al*., 2013). Reduction of human error is through training, standardising operations, reporting and auditing, as human error is present during the processes of meter reading and data capturing (Farley *et al*., 2008). Reduction of computer error is achieved through auditing, checking, routine analysis and upgrading of systems and software and reduction of theft is achieved through education, flow control, pressure limitation, prepayment measures and legal action (Xin *et al*., 2014b). Customer education is critical for auditing and water loss reduction purposes (Farley *et al*., 2008 and O'Malley *et al*., 2013).

Apparent losses are more difficult to investigate and quantify such that researchers have much of the time looked at ways of combating real losses (Xin *et al*., 2014b). They constitute 30 to 40 % of the total leakage (Lambert and Taylor, 2010). Utilities are urged to strengthen the management of apparent losses as this results in an immediate effect on the reduction of pipe network loss (Farley *et al*., 2008 and Xin *et al*., 2014b). Addressing apparent losses results in an immediate revenue increase which is based on the water sales (Fallis *et al*., 2011).

2.9 Review of network operating practices

After determination of NRW and its components, the recommended next step is assessing the reasons for the presence of NRW in a network and what strategies may be implemented to control it (Fallis *et al*., 2011). A review of network operating practices reflects a water utility's management of its network and is necessary in order to address why there is non-revenue water in a system (Farley and Liemberger, 2005). In order to achieve this there is need to investigate historical reasons, poor practices, quality management procedures, infrastructure, local or political influences and cultural or social or financial factors (Farley *et al*., 2008). Therefore, identification of NRW and its components alone is not adequate on a network there is need to investigate the presence of NRW in order to propose applicable strategies for control.

2.10 Development of strategies to reduce non-revenue water

Strategies to control non-revenue water are required in order to improve performance of a water utility (Farley and Liemberger, 2005). Proposed strategies should be feasible in terms of physical application and financial requirements (Farley *et al*., 2008). The strategy development team should comprise members from the various departments of the water utility who will be involved in implementation of the strategy and to also ensure consensus by senior management (Farley *et al*., 2008 and Mutikanga *et al*., 2011). Strategies should address both apparent and real losses (Xin *et al*., 2014b). When real losses are attended to the resultant savings are in the form of a reduction in variable operational costs (Farley *et al*., 2008 and Fallis *et al.*, 2011). When apparent losses are addressed, the savings are an immediate revenue increase which is based on the water sales (Fallis *et al*., 2011). In Johor, Malaysia within a year of implementing a major customer meter replacement plan, installation of a new customer billing software package and spot billing to improve meter reading practices, profits improved (Farley *et al.*, 2008). Within two years revenues had increased by 60 % due to the strategies.

According to Fallis *et al*. (2011) water utilities should focus first on strategies that generate the highest rate of return. However, Mutikanga *et al.* (2011) highlight that evaluating water loss reduction strategies based on a single criterion of maximising revenue is unrealistic as water services management takes place in a multiple criteria environment. According to Lasage (2007), Mutikanga *et al*. (2011) and Mateo (2012) Multi-Criteria Decision Analysis (MCDA) is a tool developed in the field of decision making for resolving operational research problems with a finite number of decision options amongst which decision makers have to evaluate and rank based on weights of a finite set of evaluation criteria.

2.10.1 The process of multi-criteria decision analysis

MCDA was used in Kampala, Uganda in assessing water loss reduction options (Mutikanga *et al*., 2011). In Kenya the method was used to assess water management strategies in Kitui (Lasage, 2007). According to Dodgson *et al*. (2009) and Mutikanga *et al*. (2011) the process of multi-criteria analysis may apply the following steps

a) Identifying objectives

b) Identifying options for achieving the objectives

c) Identifying criteria to be used to compare the options

d) Analysing the options

e) Making the choices

Goals and objectives maybe derived for the utility's vision and mission statement and should include sustainability dimensions such as economic, environmental and social aspects (Mutikanga *et al*., 2011). NRW reduction options are selected after carrying out a water balance because the water balance reveals the nature and magnitude of the problem and provides guidance on which strategy options to adopt (Farley and Liemberger, 2005 and Farley *et al*., 2008). Identification of evaluation criteria involves selecting criteria for evaluating performance of options and should be meaningful, relevant and cover all aspects of the objectives (Lasage, 2007 and Mutikanga *et al*., 2011).

In Kampala the most important criterion was reducing the physical water leakage ahead of reduction of metering errors (Mutikanga *et al*., 2011). Water utilities tend to rank replacement of pipe networks and zoning least on the basis of the huge capital requirements for implementation (Fallis *et al*., 2011 and Mutikanga *et al*., 2011). According to Mutikanga *et al*. (2011) decision makers can assign weights for each criterion as a reflection of its relative importance to the decision. The total criterion score is then converted to a weighted score using Equation 6 which expresses the score as a function of the total score of other criterion (Dodgson *et al*., 2009).

$$S_i = \frac{x_i}{\sum_{i=1}^{n} x_i} \quad \text{…………………………………………………………………..Equation 6}$$

Where S_i is the weighted score and x is the criterion score.

Strategies may be scored on a Likert Scale as a measure of their relative importance in achieving results for the objectives (Mutikanga *et al*.,. 2011). Scoring is done by decision makers wherein they are required to rank the strategies on the Likert Scale (Lasage, 2007 and Mutikanga *et al*., 2011). According to Mateo (2012) the individual weighted scores of the criterion should be multiplied by the rating of each strategy before being added up in order to express the preference of the importance of a certain criteria over other criteria. The summation is then referred to as the utility function of a strategy as shown in Equation 7

$$U_K = Y_1 \times W_{K1} + Y_2 \times W_{K2} + \cdots Y_m \times W_{Km} \quad \text{………………………………...Equation } \mathbf{7}$$

Where U_k is the utility function of strategy K

Y_m is the rating of a strategy against a criterion J for 1 to m criteria

W_{km} is the weighted score of alternative K for criterion J

The strategy with the highest sum of scores which represents a high value of utility function is considered to be the most preferred intervention that may be implemented.

CHAPTER 3: STUDY AREA

3.1 Location of study area

The study was conducted in Norton, Mashonaland West Province of Zimbabwe. It lies between latitudes 17° 50’ S and 17° 54’ S and between longitudes 30° 38’ E and 30° 45’ E. (Dorner and Kasanga, 2014). It is a town 40km South West of Harare on the Harare to Bulawayo Road. It has expanded over the years by incorporating and subdividing surrounding farms (NTC, 2015). Figure 3-1 shows the location of Norton.

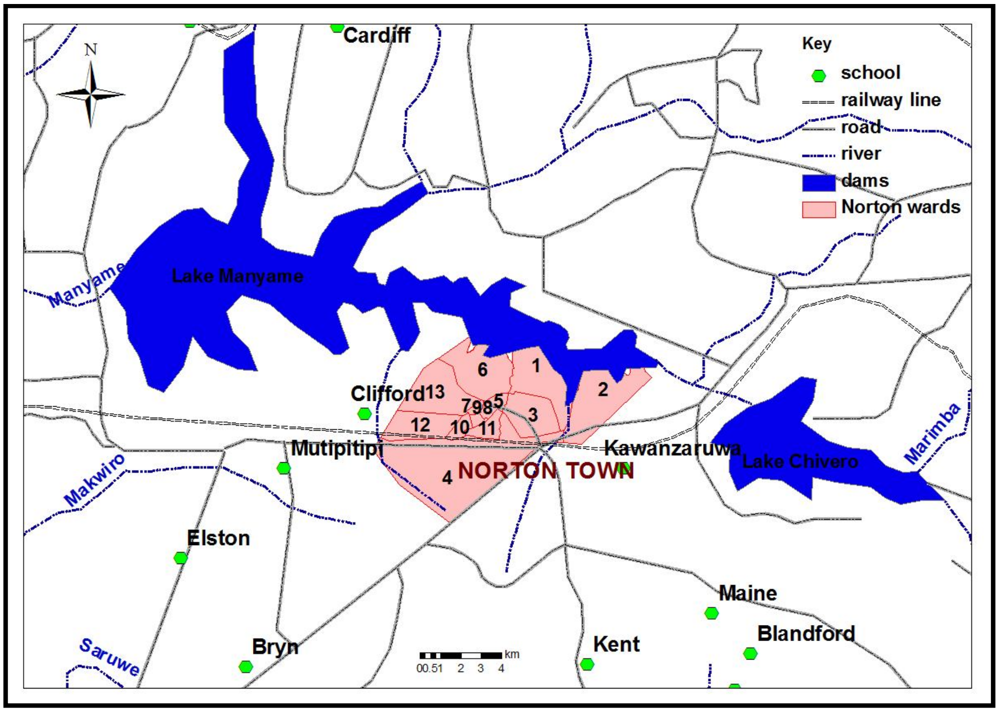

Figure 3-1: Locality map of Norton (Nhapi, 2013).

The town is bordered by rural district areas of Chegutu and Zvimba and also by Lake Manyame. There are 13 wards in Norton composed of the suburbs of Twinlakes, Galloway, Katanga, Ngoni, Maridale, Johannesburg, Marshlands, Knowe and Trafalgar. Figure 3-2 shows the location of the different suburbs in Norton. Twinlakes, Galloway, Nharira and Knowe are low density residential areas whilst Katanga, Garikai, Maridale, Johannesburg. Marshlands are high density residential areas.

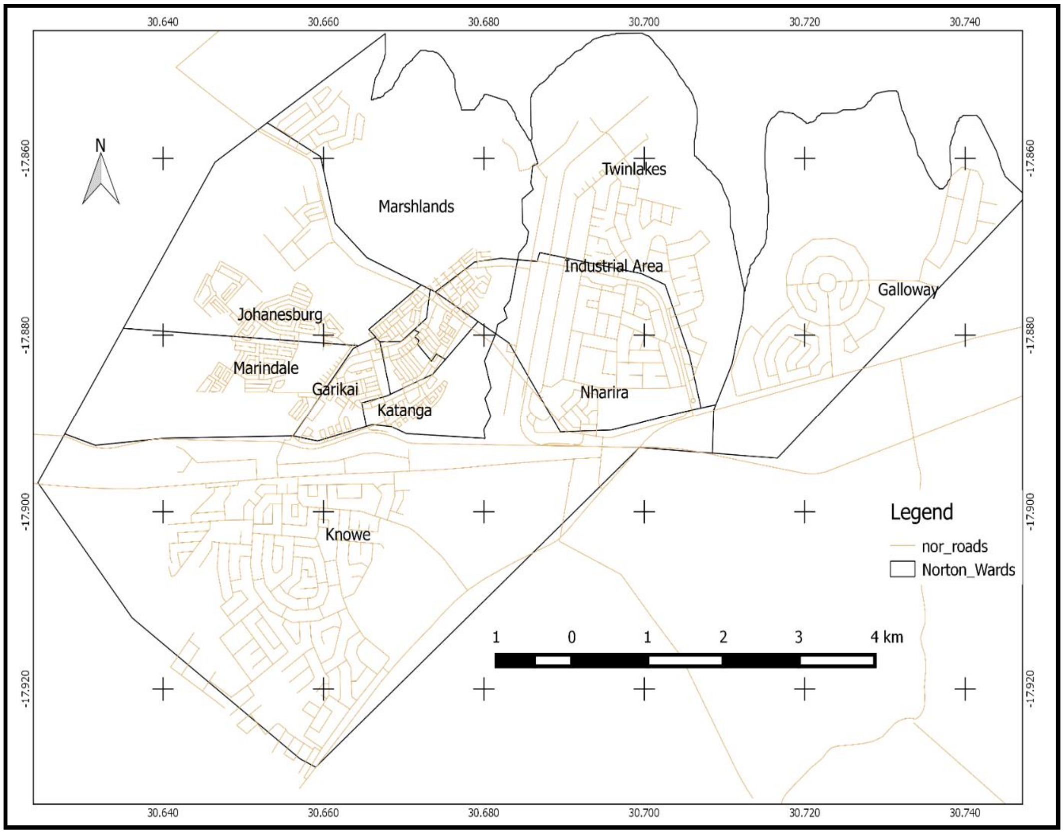

Figure 3-2: Study area map (Findlay, 2013)

3.2 Climate

Norton is in the greater Harare area which has a subtropical highland climate with average annual temperature is 18 ^{o}C (Dorner and Kasanga, 2014).According to the town's Master Plan of I995 the area experiences three main seasons a warm wet season from November to March/ April (rainy season); a cool dry season from May to August (winter); and a hot dry season in September and October (summer). Norton is in the agro-ecological Region IIa which has an average rainfall between 800 to 900 mm per annum (NTC, 1995).

3.3 Topography and geology

The initial developments in the town were placed on a watershed with a maximum height of 1658 m above sea level (NTC, 1995). The Master Plan indicates that the area has gentle slopes towards streams running northwards to Lake Manyame whose altitude is 1 344 meters. The general geology consists of the Bulawayan Group, older gneisses and granites of the basement complex, Great dyke mafics and ultra mafics, dolerites and gabbroic dykes (Dorner and Kasanga, 2014). The area has moderately shallow to moderately deep reddish brown to greyish brown, relatively silky sandy clay loams over reddish brown to yellowish similar clay loams and clays (NTC, 1995). The soil surrounding Lake Manyame is black clay which in some places is not more than 450 mm below the surface, is wet and impervious (NTC, 1995). The landscape is covered by natural vegetation of open woodland and most common tree of the region is the Msasa *(BrachystegiaSpiciformis)* (Dorner and Kasanga, 2014).

3.4 Land use

Norton was originally a farming and industrial town but has since developed significantly as a dormitory town to Harare and was established in 1914 and initially administered under Selous Rural District Council (NTC, 2015). It was upgraded to town status in 1994. Council area is made up of residential and industrial developments with a total area of 19 km^2 (NTC, 2014). Areas such as Knowe, Galloway, Maridale, Marshlands and Johannesburg have been subdivided from farms into residential properties (Richards *et al*,. 2009). According to Richards *et al.* (2009) the subdivisions were done by private developers, who are responsible for the phenomenal expansion of Norton in the last 10 years, targeting the working population in Harare. The proximity to Harare makes the town attractive for investments in residential housing and agro processing industry (Dorner and Kasanga, 2014).

3.5 Background on water supply

Norton is bordered by Lake Manyame and is 8 km away from Lake Chivero, both Lakes are jointly owned by the Zimbabwe National Water Authority, (ZINWA) and City of Harare; These dams have a combined 10 % yield of 196 520 000 m^3that is shared between ZINWA and City of Harare on the basis of 20 % / 80 % (Richards *et al*., 2009). While Norton Town Council's share is drawn from ZINWA's share of the yield, there is no formal agreement in place yet between the two organisations and based on the estimated water demand of 15000 m^3/day this represents 12 % of ZINWA's allocation (Richards *et al.*, 2009).

NTC depends on potable water supply from City of Harare with an average delivery of 7 500 m^3/day (NTC, 2014). Water is delivered from City of Harare's Morton Jaffray water treatment plant to the town's reservoirs on the slopes of Hunyani Hills through 4 km of 30 0mm diameter steel pipes with a peak delivery rate 7 800 m^3/day(Richards *et al*., 2009 and NTC 2014). Therefore, City of Harare supplies bulk water and Norton Town Council is responsible for the distribution of the water, maintenance of the network and collection of related charges. Figure 3-3 shows the systematic layout diagram for major water supply components in Norton.

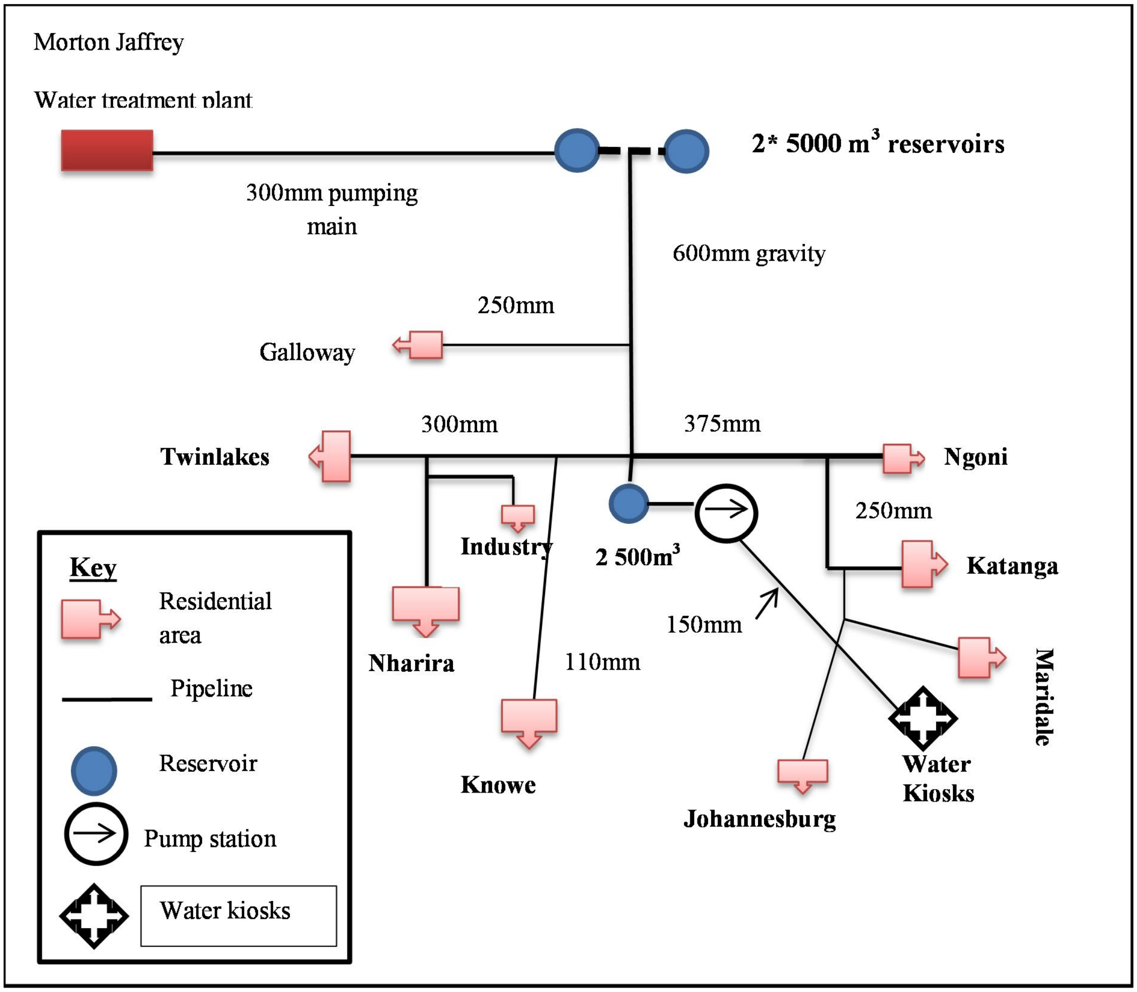

Figure 3-3: Schematic layout of the water supply system

In 1996 NTC started construction of a new 40 000 m^3/day water treatment plant (Richards *et al.*, 2009). Construction was stopped as a result of the lack of funding and the site is currently abandoned (Richards *et al.*, 2009). A June 2012 estimate indicated that the total cost of the new water treatment plant, including downstream facilities such as metering, treated water pumping station, reservoirs primary distribution mains and engineering fees is approximately US$ 20 million (NTC, 2014).

The present storage reservoirs comprise of two 5000 m^3 reinforced concrete tanks located on the western slopes of Hunyani Hills Range and they provide a static head varying of 45 to 80 m to the distribution system (Richards *et al.*, 2009 and Dorner and Kasanga, 2014). The distribution networks in the new residential areas of Knowe, Maridale, Johannesburg and Marshlands are significantly undersized (Richards *et al.*, 2009). In spite of an adequate head, there are areas in these townships that do not receive water even if the entire delivered water is directed to those areas (Richards *et al*., 2009 and NTC, 2014). The water distribution networks in these areas were installed by the developers for Norton Town Council (Richards *et al*., 2009).

The remainder of Norton consisting of the high density townships of Ngoni and Katanga are serviced by a network whose pipe sizes range from 75 mm to 350 mm in diameter and the water pressures is quite high (Richards *et al.,* 2009). With the considerable water shortages that Norton has been experiencing the Council has an ongoing programme to supply water through strategically located water points, 11 prepaid water kiosks were commissioned in 2015 to augment supplies from 21 communal boreholes in the high density areas (NTC, 2015).

The average supply of 7 500 m^3/day is against an estimated demand of 15 000 m^3/day (Richards *et al*., 2009). Residents are therefore accustomed to intermittent water supply in the town. In the suburbs of Knowe, Maridale and Johannesburg residents depend to a large extent on private wells and boreholes, communal boreholes and prepaid water kiosks (NTC, 2015). Reticulated water network was installed in those areas however water supply is not reliable (Richards *et al*., 2009). In the areas of Marshlands, Kingsdale and Trafalgar water pipe network was not installed, therefore residents have their own means of getting water (NTC, 2014 and NTC, 2015). A study by Oxfam in 2009 revealed that the communal boreholes and wells in Maridale, Katanga and Johannesburg revealed that these water sources were contaminated with coliforms which is a health risk to the communities (NTC, 2014)

Deutsche Gesellschaft fuer Internationale Zusammenarbeit (GIZ) in 2014 estimated UFW for Norton to be 42 % (Tafangombe and Madyiwa, 2014). The World Bank estimated a collection efficiency of 42 % against an agreed benchmark of 75 % by urban local authorities in Zimbabwe (Nhapi, 2013). The same study estimated water supply coverage for Norton was of 66 %. The estimates for NRW and collection efficiency are beyond acceptable limits. This is not sustainable for the organisation since the City of Harare charges for total water delivered including losses. Because coverage is less than 100 % and continuity of water supply is less than 24 hours, residents use other water supply sources during periods of non-supply. In 2008/2009 there were 50 deaths due to cholera and 1 954 cases were reported (NTC, 2014). The outbreak was attributed to use of unsafe water.

CHAPTER 4: MATERIALS AND METHODS

4.1 Study design

4.1.1 Selection of specific study areas

The study was carried out in Norton Town. The town was selected because it is among one of the towns in Zimbabwe that depend on potable water supply from another water utility. Such towns and cities are characterised by challenges of inadequate water supply and poor collection efficiency and inabilities to pay for the bulk water (Dorner and Kasanga, 2014). The water supplied in Norton town does not meet the demand (Dorner and Kasanga, 2014 and NTC,2015). The study focused on two specific study areas of the town. The areas that were used are Galloway and Katanga-Ngoni. These two areas were considered on the basis that they have zonal meters which were required in data collection. Zonal meters were also installed in Maridale, Johannesburg and Knowe, however there is no water billing for Maridale and Johannesburg and for Knowe there is selected water billing. The non-billing and selected water billing is based on assumed end points of water coverage. Therefore for these areas data on billing was not available.

Galloway is a low density residential area with a reticulated water supply system. There are 2300 stands/properties in the area with 304 connected to the water supply system as some stands are still vacant (NTC, 2015). The area is low lying and has the first take-off from the main gravity delivery line, hence receives more water than other areas (Richards *et al*. 2009). Katanga-Ngoni is a residential area incorporating the two high density suburbs of Katanga and Ngoni into one zone. Combined there are 5024 properties in the area and at least 3078 of these have access to water (NTC, 2014). The remaining properties in the area are in the newer higher altitude extension of the high density suburb.

4.1.2 Selection of data to be analysed

The selection of data to be analysed was based on literature on similar studies. For determination of NRW trends for the town, the data that was used was yearly bulk water received and billed consumption records for the years 2004 to 2015. This is according to water balance requirements as highlighted by McKenzie and Seago (2005), Thornton and Lambert (2005) and Mutikanga *et al.*(2009). They suggest that NRW is determined on the basis of the difference between the system input volume and the billed consumption.

To partition NRW, zonal readings were taken for 6 days continuously in each of the specific study areas. This was according to guidelines for determining real losses in a system by Lambert and Taylor (2010) and Fallis et *al*. (2011) when using the minimum night flow method.

Farley and Liemberger (2005) and Fallis *et al*.(2011) suggest that it is not sufficient to determine NRW and its components without further looking at the reasons why NRW exists in a system and coming up with strategies for its control. Therefore the study further looked at the network operating practices in order to get a reflection of the water utility's management of its network in order to clarify the presence of non-revenue water in the system. Farley *et al*. (2008) highlighted the need to investigate historical reasons, poor and good practices, quality management procedures, infrastructure, local or political influences and cultural or social or financial factors that may have an effect on NRW. Therefore, qualitative and quantitative data was collected through review of available information, meter testing, questionnaires and key informant interviews.

Meter testing was done on a sample of domestic water meters. According to Farley *et al*. (2008) water meters are the basic instruments in managing a water supply system. In addition, qualitative data was also collected from council management and workers to determine their understanding and influence on NRW. Council internal documents such as strategic plans and reports were also considered in order to get an insight on how the water system is managed.

To evaluate possible strategies for NRW control both the qualitative and quantitative data collected in the study was analysed using Multi-Criteria Decision Analysis (MCDA). According to Lasage (2007) and Mutikanga *et al.* (2011) MCDA may be used to assess water management strategies.

4.1.3 Methods of sampling for meter testing

In this study a sample of water meters was collected from the properties in Galloway and Katanga-Ngoni areas for meter testing and. Table 4-1 shows the distribution of stands in these areas.

According to Teddlie and Yu (2007) probability sampling may be used to select a relatively large number of units from subgroups in a random manner with the application of systematic random sampling method to select properties.

Table 4-1: Distribution of stands in the specific study areas

DMA	Number of stands
Galloway	304
Katanga-Ngoni	3078
Total	**3382**

Systematic sampling involves arranging the target population according to some ordering scheme and then selecting elements at regular intervals through that ordered list (Teddlie and Yu, 2007). In this study the population was from Galloway and Katanga-Ngoni areas. Systematic random sampling was applied to the housing list of the properties to select meters for testing. In each area the first property to be selected was chosen randomly in the first 30 on the housing list, thereafter every 30th property was selected also dependant on willingness by the property owner. For properties were the owners or tenants were not willing to have their meter removed the next property was considered. The results of the sampling are presented in Table 4-2.

Table 4-2: Sample size determination for meter testing in specific study areas

Area / Group	Number of properties	Sample size
Galloway	304	10
Katanga-Ngoni	3078	90
Total	3382	100

4.2 Data collection methods

4.2.1 Zonal readings

DMA readings were taken from the two specific study areas to determine system input volume which is required in NRW determination. The readings were taken from December 2015 to May 2016. Previous DMA readings were not regularly taken hence could not be used in the study. Figure 4-1 shows the distribution of DMAs in Norton. The study focused on DMAs 6 and 2 which are Galloway and Katanga-Ngoni respectively. The readings were taken monthly because billing is also done monthly. This was done to assess the overall water losses in a specific area through comparison of billed consumption and volume delivered into the area.

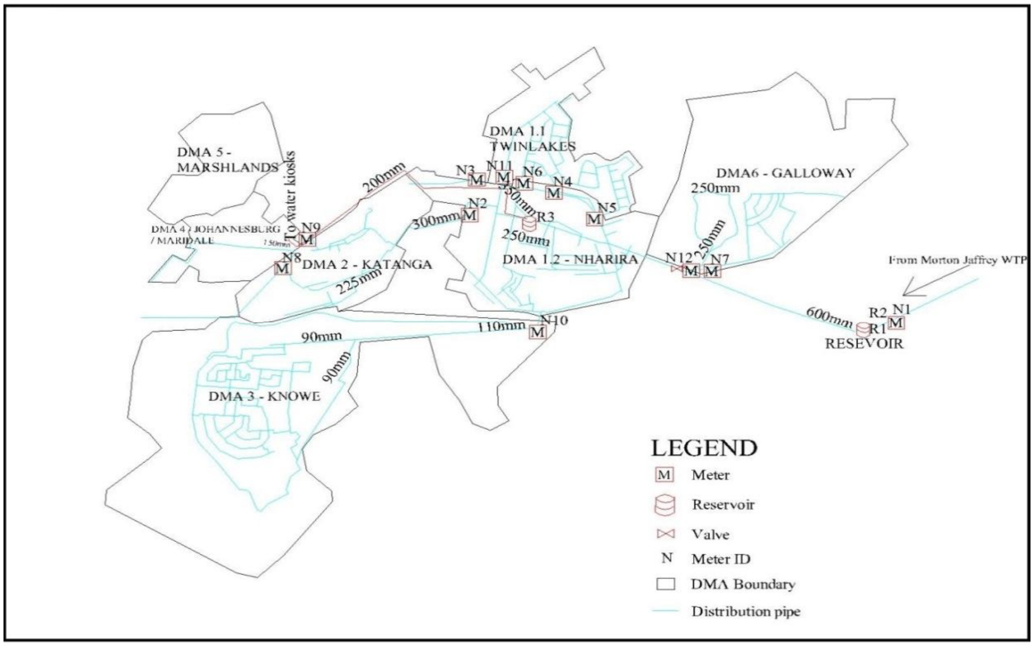

Figure 4-1: Norton Town reticulation and DMA layout (Findlay, 2013)

4.2.2 Measurement of continuous flows

Continuous flow readings were taken in Galloway and Katanga-Ngoni to determine real losses using the Minimum Night Flow (MNF) method. According to Fallis *et al*. (2011) the method is suitable for use in systems which have continuous water supplies. Water supply had to be manipulated in Norton in order to create continuous flow conditions in the specific study areas and to keep storage into private receptacles at a minimum. The water supply system had to be manipulated without the knowledge of the customers. This meant isolating other areas from water supply during the MNF measurements period. On the first 24 hour period no readings were taken to allow for customers to adjust to continuous water supply and filling in of receptacles. For six consecutive days in the two specific areas hourly flow measurements were recorded manually as there are no flow loggers for the water system in Norton. Maximum storage was first obtained without supplying any area with water, thereafter the stored and incoming supply was directed continuously to one area for six days.

4.2.3 Review of available information

Review of available information was done through a desk study. According to Farley and Liemberger (2005) and Farley *et al*. (2008) investigation of the presence of NRW in a system involves looking at both historical and current information as well as practices, social, cultural and local factors. Historical billing data from 2004 to 2015 was analysed. Monthly bulk water received and billed data was compiled for use in analysing yearly non-revenue water. Internal documents such as consultants' reports, council's strategic plans, and financial reports were also studied. Current billing records were looked at in order to determine NRW in the specific two study areas.

4.2.4 Meter testing

Meter testing was done to determine the level of meter accuracy. Meter testing was done because they are an essential tool for measuring water consumption and should be as accurate as possible (Farley *et al*., 2008). A fixed meter testing bench was used. Figure4-2 is a sketch of the meter testing bench.

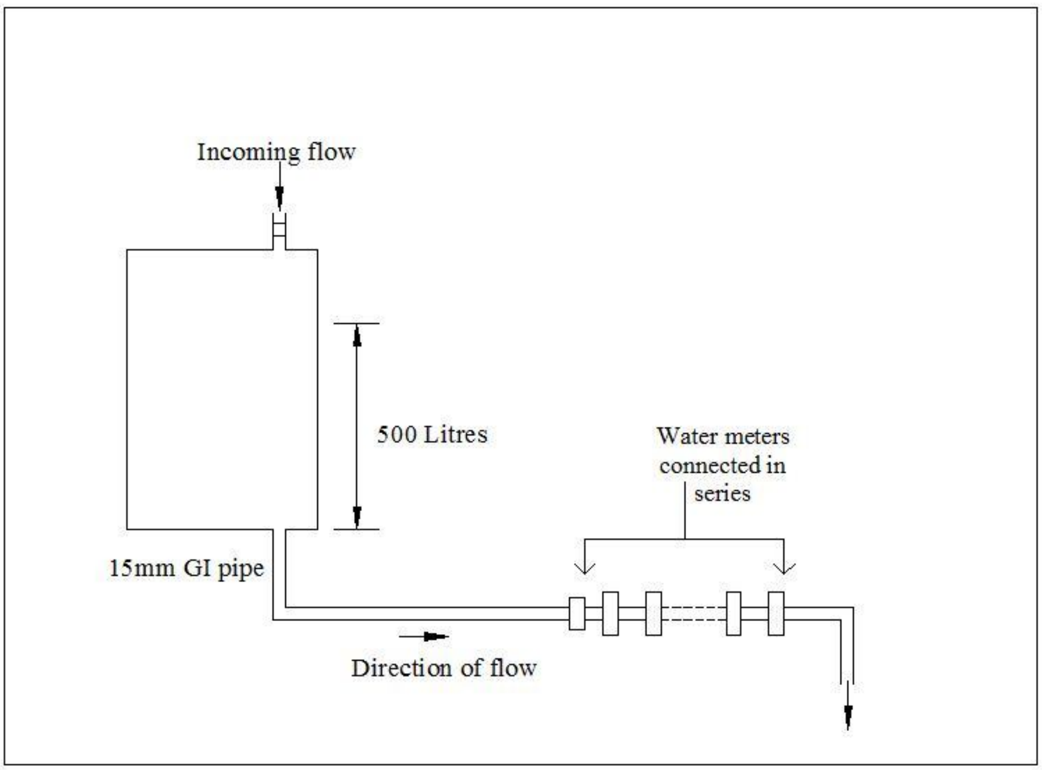

Figure 4-2: Sketch of the meter testing bench

The bench used is designed such that eight domestic water meters maybe tested at once. To conduct the test a water tank is filled with water up to the 500 liter mark. Water meters are connected in series and connected to the water tank through a 15 mm galvanised iron pipe. Water was then allowed to flow through the series of meters. For each meter the initial meter reading was taken and a final meter reading was taken when 500 liters of water had passed through the meters. The test was repeated three times for each series of meters and an average volume of water that passed through each meter was calculated from the three sets of readings.

4.2.5 Collection of qualitative data

Farley *et al*. (2008) suggest that awareness and understanding of NRW is essential at all levels in a water utility. They further state that all employees should understand their roles and responsibilities in NRW reduction since this involves long term combined effort from all departments in the utility. Questionnaires were administered on meter readers from Norton Town Council. This was done on all the six meter readers and Appendix I presents the sample questionnaire that was used. The data that was collected from meter readers was on how they handle meter reading in terms of non-functional meters and how the process of meter reading is done. Meter reading was focused on because commercial losses occur mostly through faulty meters and errors committed during the reading or processing in the billing system (Farley *et al*., 2008 and Xin *et al*., 2014b). The data was used in assessing effects of the current meter reading practice on NRW.

Key informant interviews were done with Norton Town Council senior management in order to evaluate their understanding of the council's water management system as well as understanding of NRW management. The interview checklist used is in Appendix II. Senior managers who were interviewed are the Finance Director, Director of Housing and Community Services, Town Secretary, Director of Health Services, and the Water Superintendent. According to Farley and Liemberger (2005) and Farley *et al*. (2008) all staff including senior management and operations employees need to understand NRW and their roles to achieve set targets in NRW reduction, hence the inclusion of all managers in the key informant interviews. The information collected was on the roles of the departments in relation to water management. The data collected was used to assess how management practices affect NRW.

4.3 Methods of data analysis and checking

The collected data was subjected to a thorough scanning and sifting processes in order to organise and summarise it. In scanning and sifting all the data was checked for completeness, accuracy, consistence and relevance to the study.

4.4 Trends for non-revenue water

According to Lambert and Taylor (2010) NRW trends were calculated based on the water balance method. The difference between water delivered into the system and the total billed consumption was determined according to Equation 8 (Sharma, 2008a and Fallis *et al.*, 2011)

$Q_{loss} = Q_{syt} - Q_{cons}$ ……………………………………………………..Equation 8

Where Q_{loss} is the total loss per unit time all in m^3.

Q_{syst} is the system input volume

Q_{cons} is the authorised billed consumption

The determination of NRW employed use of historical yearly volumes delivered into the system and billed consumption figures for the years 2004 to 2015. NRW was expressed as a percentage of net water production (delivered into the distribution system) (Sharma, 2008a).

4.5 Partitioning non-revenue water

4.5.1 Determination of real losses

Data from continuous flow recording was used in the Minimum Night Flow (MNF) analysis method. MNF analysis was used to estimate real losses volumes (Fallis *et al.*, 2011). From the hourly readings flow per hour was calculated through Equation 9.

$Q_{sh} = R_2 - R_1$……………………………………………………………Equation 9

Where Q_{sh} is flow per hour (m^3/hr)

R_2 is the meter reading at the end of the hour in m^3

R_1 is the meter reading at the beginning of the hour in m^3

The minimum flow was determined as the lowest flow during a 24 hour period (Xin, *et al.*, 2014b). MNF can be determined directly from the flow graph (Farley *et al.*, 2008). According to Lambert and Taylor (2010) Equations 2 and 3 were used to determine real loss.

$Q_{loss,d} = NDF \times Q_{loss}$………………………………………………Equation 2

And

$NDF = \sum_{i=1}^{i=24} (\frac{Pi}{Pmnf})P^{\propto}$…………………………………….......Equation 3

Where $Q_{loss,d}$ (m^3/d) is the daily real loss volume

NDF (h/d) is the night to day factor. It is the ratio of night and day zonal pressures (Fallis *et a*l. 2011). NDF is used as a factor because the average pressure in distribution systems is normally not constant but varies over 24 hour periods (Fallis $et\ al$. 2011).

Q_{loss} (m^3/hr) average minimum night flow rate

P_i (m) average pressure at AZP during 24 hours

P_{mnf} (m) Average pressure at AZP during MNF conditions

α is the leakage exponent

In this study, due to the absence of pressure measuring equipment P_i, P_{mnf} and α could not be measured, therefore a value for NDF was assumed. For gravity fed systems average zone pressure is highest at night, but is lower during the day, this result in reduced leakage for most of the day (Lambert and Taylor, 2010). Therefore NDF for gravity fed systems is normally less than 24 hours/day. According to Lambert and Taylor (2010) for gravity systems NDF ranges from 18 to 23 hours. According to Fallis $et\ al$. (2011) typical NDF values for gravity fed systems range from 20 or less. From the provided ranges the average between 18 to 20 hours was determined as 19. NDF for this study was taken as 19. Therefore multiplication of the observed average MNF with NDF gives the average daily leakage rate in m^3/day (Fallis *et al.*, 2011 and Xin *et al.*, 2014b).

As the system was manipulated to have continuous flows instead of intermittent supply, this renders the data true only for the period of testing, the calculated $Q_{loss,d}$ is for a normal continuous supply of 24 hours, therefore an over estimate of real losses. To estimate real losses for intermittent supply ratios of the average volume supplied per day to average flows during MNF analysis were applied as correction factors. The average volumes per day were 671 m^3/day and 1 709 m^3/day for Galloway and Katanga-Ngoni respectively from the monthly zonal readings from December 2015 to May 2016. The use of volumes ratio as a correction factor is based on studies that link leakage to pressure. The higher or lower the pressure, the higher or lower the leakage (Farley *et al.*, 2008). The volume of water per unit time in a pipe is determined from Equation. 10

Q = vA…………………………………………………………………..Equation10

Where Q is the volume of water per unit time, v is the velocity and A is the area. v is dependent on pressure in the system. From Equation 10, flow rate is directly proportional to pressure. Rising pressure will increase leakage according to the power function equation (Equation 11) and conversely leakage decreases at reduced pipe pressure (Fallis *et al*. 2011).

$$q = ch^{\alpha} \text{ ....Equation 11}$$

Where q is the leakage flow rate, c is the leakage coefficient, h is the pressure head and α is the leakage exponent. Therefore from the leakage theory, the correction factor for intermittent supply was determined based on ratio of volume per unit time given in Equation 12. Average intermittent supply volume was obtained from the monthly volumes *(converted to daily)* recorded from December 2015 to May 2016. Average daily volume during flow logging was obtained from the total of hourly volumes per day during flow logging.

$$correction\ factor = \frac{average\ intermitttent\ volume\ supplied}{average\ daily\ volume\ supplied\ during\ flow\ logging} \text{ ....Equation 12}$$

= 671/5660

= 0.12 (for Galloway)

And for Katanga-Ngoni = 1709/9051

=0.18 (for Katanga-Ngoni)

The calculated daily losses from MNF were multiplied by the correction factors to estimate real losses for the system under intermittent supply as this is the current operational regime in Norton.

4.5.2 Determination of apparent losses

According to (Xin *et al*., 2014b) apparent losses were obtained as the difference between the average zone water loss and the real losses. They were determined according to Equation 13.

$$AL\ (m^3/month) = Average\ water\ loss - RL \text{ ....Equation 13}$$

Where AL is the average loss per month and RL is the real losses per month.

4.6 Evaluation of the water system operating practices

To evaluate the water system operating practices the qualitative and quantitative data and results obtained in the study was used. This included review of historical and current information available as recommended by Farley and Liemberger (2005) when investigating the presence of NRW in a water system.

4.6.1 Meter testing

Meter testing gave the percentage of under/over-registration of the tested meters. Meter testing was done because they are essential tools for measuring water consumption and should be as accurate as possible (Farley *et al*., 2008). The percentage error of a meter was determined using Equation 14.

$$Error = \frac{500-V}{500} \times 100 \quad \text{……………………………………………………Equation 14}$$

Where V was the average recorded volume that passed through the meter and 500 was the volume allowed to pass through the meter and the error is the over/under-registration by the meter.

4.6.2 Analysis of working procedures

Information from meter readers was used to interpret the meter reading process. The method of comparing responses from the respondents was used to sort the responses into their various categories and ranks and to make meaning of the same. Information from key informant interviews was also categorised to give meaning to the data. The interviewees were the three Directors, Water Superintendent and the Town Secretary.

4.7 Evaluation of possible strategies

Multi-Criteria Decision Analysis (MCDA) was used to evaluate strategies. Strategy options were selected from recommendations provided by the International Water Association (IWA) and the American Water Works Association (AWWA). The process of MCDA was according to the steps recommended by Dodgson *et al*. (2009) and Mutikanga *et al*. (2011) which are;

a) Identifying objectives
b) Identifying options for achieving the objectives
c) Identifying criteria to be used to compare the options
d) Analysing the options
e) Making the choices

The objectives stemmed from the study of Norton Town Council's Water Sanitation and Hygiene (WASH) Strategic Plan for 2014 to 2018, Norton Town Council's Strategic Plan for 2015 to 2020 and results from this study on NRW estimates and key informant interviews. The evaluation criteria were generated through information from key informant interviews and data from NRW analysis.

4.7.1 Prediction of performance

An evaluation matrix was prepared to rate the strategies against each criterion. Scoring of options was based on MCDA studies of water management (Mutikanga *et al*., 2011). Since the criteria were qualitative in nature the strategies were measured on a Likert Scale as recommended by Mutikanga *et al*. (2011). The Likert Scale ranged from 1 (poor performance) to 5 (very good performance.) as shown in Table 4-3.

Table 4-4: Transformation of linguistic terms to interval scale

Term	**Interval**
Very poor	1
poor	2
Fair	3
Good	4
Very good	5

4.7.2 Determination of criteria weights:

The relative importance of each criterion was derived from subjective judgements by the managers as suggested by Mutikanga *et al.* (2011) and Saarikoski*et al*. (2015). All managers assigned weights for each criterion on a 1 to 10 scale. A score of 1 represented least importance and a 10 represented the most important. The total criterion score was converted to a weighted score as recommended by Dodgson *et al.* (2009) using Equation 15 which expresses the score as a function of the total score of other criterion.

$$S_i = \frac{x_i}{\sum_{i=1}^{n} x_i} \quad \text{..........Equation 15}$$

Where S_i is the weighted score and x is the criterion score.

According to Mateo (2012) the individual weighted were multiplied by the rating of each strategy before being added up in order to express the preference of the importance of a certain criteria over other criteria. The summation was then referred to as the utility function of a strategy using Equation16.

$$U_K = Y_1 \times W_{K1} + Y_2 \times W_{K2} + \cdots Y_m \times W_{Km} \quad \text{..........Equation 16}$$

Where U_K is the utility function of strategy K

Y_J is the rating of a strategy against a criterion J for 1 to m criteria

W_{KJ} is the weighted score of alternative K for criterion J

The strategy with the highest sum of scores which represents a high value of utility function is considered to be the most preferable intervention.

CHAPTER 5: RESULTS AND DISCUSSION

5.1 Assessment of non-revenue water trends

Non-revenue water trends were assessed using historical billing and consumption data collected from 2004 to 2015. The monthly data collected is shown in Appendices III and IV. The bulk water received represents the system input volume, which is bulk water received from City of Harare. The billed consumption is from Norton Town Council billing data for the respective years. NRW was expressed in volumetric terms according to McKenzie and Seago (2005) and Lambert and Taylor (2010). Appendix V presents the yearly NRW for the town from 2004 to 2015. Figure 5-1 presents results of total water received, billed and non-revenue water for Norton town from 2004 to 2015.

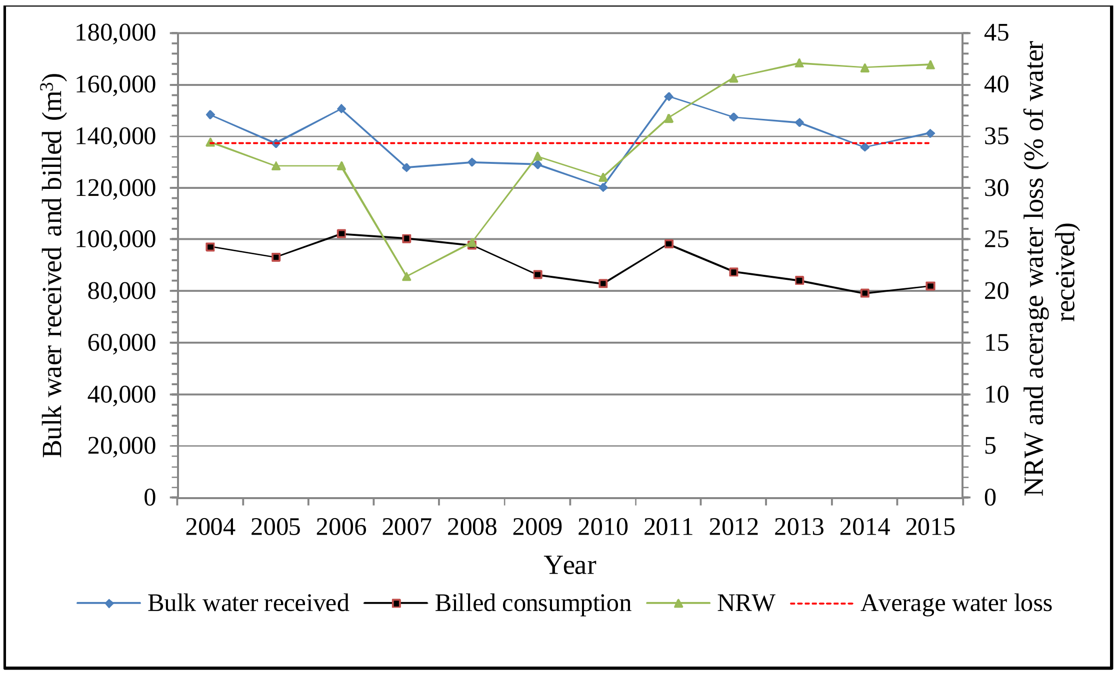

Figure 5-1: Total water received, billed and non-revenue water for Norton Town from 2004 to 2015

From Figure 5-1 the bulk water received does not show a defined pattern while billed consumption over the 12 year period was decreasing. The average NRW for the 12 year period was established as 34 %. The coefficient of variation for NRW is 20 %. The trend for NRW is increasing with an R^2 value of 0.48. The highest non-revenue water was 42 % in 2013, 2014 and 2015 with the lowest occurring in 2007 at 21 %. The high NRW may be as a result of passive leakage management in the council area. New suburbs and extensions have been connected to the water supply network with no immediate occupation of stands and leakages could have taken a long run time before attendance. Galloway area is one such suburb with a size of 285 hectares and was connected to the water supply system but the uptake of the serviced stands was not immediate (NTC, 2015). In the year 2013 Council also serviced a total of 306 stands with water in Katanga (Cabs extension and infills) and Twinlakes extension (NTC,2015). New customers could have been connected to the water supply but not immediately updated on the customer data base, therefore the water used by such customers was non-revenue water.

From interviews with meter readers and also study of billing reports in areas of the town such as Maridale, Johannesburg and Katanga extension meter readings are not taken based on the acceptable view that there is no water coverage in those areas yet water supplies could be there. According to billing reports in Knowe suburb, 60 properties out of 3124 are billed for water consumption on the basis of assumed end points for coverage. Water that goes beyond the assumed points is unbilled and has the effect of increasing NRW.

Gumbo (2004) did a study on eight Southern African countries and the range of NRW was from 20 % to 60 %. In the study Bulawayo City in Zimbabwe had NRW of 20 %, it can be seen that NRW for Norton is higher than that of Bulawayo. Mutare City NRW was 57 % from a study by Marunga *et al*. (2006) which is higher than that for Norton Town. Kuma and Ewusi (2009) revealed during their study of Tarkwa Town in Ghana that non-revenue water was 34-65 % of the water produced. In 2013 the National Water Supply and Sanitation Council of Zambia (NWASCO) reported a sector performance of 42 % against a minimum acceptable sector benchmark of 25 % (NWASCO, 2013). Mckenzie *et al*. (2012) reported average NRW for South African water utilities at 37 % against a global average of 37 %. Gumbo (2004) recommends NRW of 20 % for well performing utilities in Southern Africa. Urban local authorities in Zimbabwe agreed on a benchmark of 25 % for non-revenue water (Nhapi, 2013). It can be concluded that NRW for Norton was within the ranges reported in literature (20 % to 65 %) but higher than the recommended limits for the region.

5.2. Non-revenue water trends for the specific study areas

The non-revenue water for Galloway and Katanga-Ngoni was estimated based on the difference of the bulk meter readings and the billed consumption, following the water balance as recommended by Lambert and Taylor, (2010) and Fallis *et al*. (2011). The zonal bulk meter readings are shown in Appendix VI. Galloway is fed from two lines hence the two meter readings. The water supplied to each area was determined as the difference between the monthly readings. Both areas are supplied with water by gravity from the two reservoirs in Norton. The results of the water supplied to the two specific study areas are presented in Table 5-1.

Table 5-1: Water supplied to the two specific study areas

Area	Number of connections	m^3 Supplied					
		Dec-15	Jan-16	Feb-16	Mar-16	April-16	May-16
Galloway	304	15,278	18,895	15,654	16,325	14,387	15,338
Katanga-Ngoni	3,078	48,850	43,350	41,325	40,265	41,025	40,648

Galloway has a high volume supplied to the area with respect to the number of connections. Katanga-Ngoni is high density with a larger number of customers, hence the high value of water supplied. The billed consumption for each area was established and is presented in Table 5-2.

Table 5-2: Billed water consumption for the specific two study areas.

	m^3 Billed water					
Area	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16
Galloway	6,516	5,600	4,956	7,003	6,790	6,985
Katanga-Ngoni	22,304	23,787	18,754	22,478	19,802	22,305

Galloway has a high consumption as it has larger stand sizes and it has the first take off from the 600 mm delivery main and it is low lying.

5.2.1 Non-revenue water for the specific study areas

The non-revenue water for the two specific study areas was determined as the difference between the water supplied and the billed consumption for that area (Lambert and Taylor, 2010 and Fallis *et al.*, 2011). Based on the average water supplied and billed consumption for the five month period, NRW for the two areas was determined and the results are presented in Table 5-3.

.

Table 5-3: Average NRW for the two specific areas for December 2015 to May 2016

				NRW	
Area	**Average water supplied m^3/month**	**Average billed consumption m^3/month**	**connections**	**m^3/month**	**%**
Galloway	15,980	6,308	304	9,672	61
Katanga-Ngoni	42,557	18,367	3,078	24,167	56

Non-revenue water losses percentage was 61 % in Galloway. Katanga-Ngoni had non-revenue water of 56 %. Katanga-Ngoni is the largest zone in terms of area coverage and number of customers. In Mutare City, Zimbabwe a study of two specific study areas in the city UFW was 47 % and 32 % (Marunga *et al.*, 2006). In Malawi for Zomba City four specific study areas were studied and UFW was 13 %, 62 %, 51 % and 6 % (Chipwaila, 2009). For Zomba, NRW was attributed to pipe bursts and an old water network. The NRW for the two areas in Norton is within the ranges reported in literature of 6 % to 62 %; however it is on the extreme higher end of the results. The acceptable limits for the region are within the range 20 to 25 % (Gumbo, 2004; Mckenzie *et al*. 2012; NWASCO, 2013). It can be concluded that NRW for the two areas is above acceptable limits but within ranges reported in literature.

5.2.2 Partitioning of non-revenue water

Non-revenue water was further partitioned into real and apparent losses.

Real losses: Real losses were determined using MNF. Hourly meter readings are provided on Appendix VII for Galloway. Figure 5-2 presents the flow pattern for Galloway. From Figure 5-2 the average minimum night flow was determined. According to Thornton and Lambert (2005), Lambert and Taylor (2010) and Fallis *et al*. (2011) MNF is the lowest flow over a 24 hour period and for Galloway it was 34 m^3/hour. To determine daily real losses Equations 2 and 3 were used as recommended by Lambert and Taylor (2010) and Fallis *et al*. (2011).

Therefore Galloway Daily loss = 34 m^3/hr x 19 hr/day = 646 m^3/day.

The daily loss of 646 m^3/day was true for the testing period and to correct for intermittent conditions the correction factor was applied.

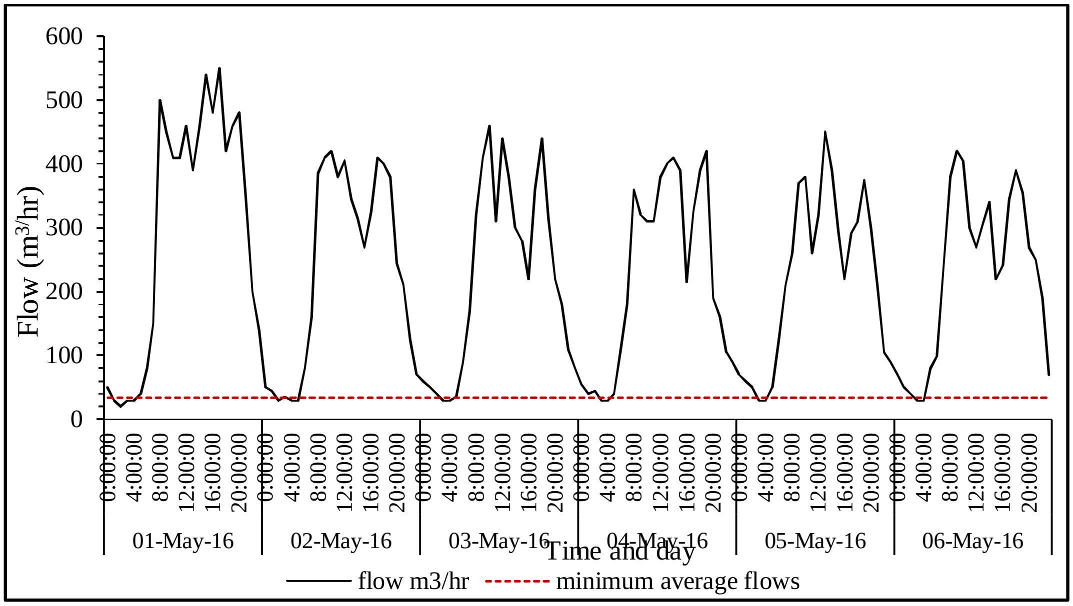

Figure 5-2: Galloway flow pattern from 1 to 6 May 2016.

The same procedure was also done for Katanga-Ngoni area. Data on Katanga readings on recorded flows is presented in Appendix VII. The results for flow readings were plotted and are presented in Figure 5-3.

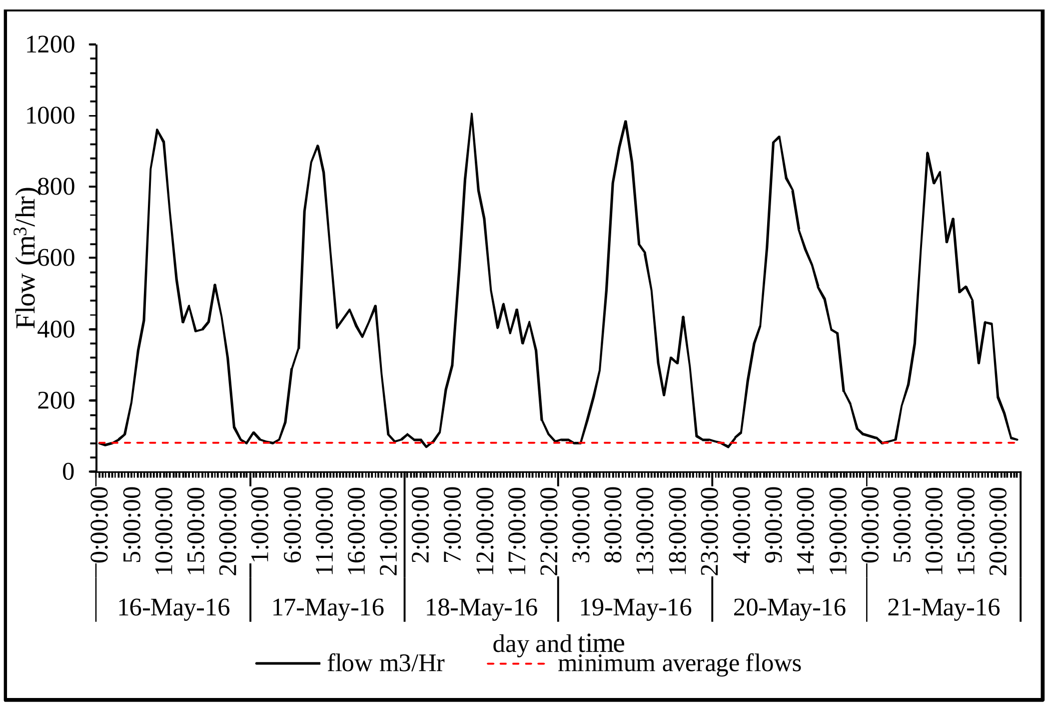

Figure 5-3: Katanga-Ngoni flow pattern from 16 to 21 May 2016

From Figure 5-3 the average minimum night flow is 82 m^3/hour.
Katanga-Ngoni daily real loss = 82 m^3/hr x 19hr/day = 1 558 m^3/day

The MNF for Galloway and Katanga-Ngoni were 34 m^3/hr and 82 m^3/hour respectively. A study in Malawi for Blantyre City which focused on two specific study areas had excess night flows of 1.26 m^3/hour to 3.54 m^3/hour (Chiipanthenga, 2008). Xin *et al*. (2014b) recommends an acceptable limit of 3 m^3/ hour. MNFs above recommended limits are an indication of unexplained leakages in the distribution system which must be attended (Xin *et al*., 2014b).

Katanga-Ngoni area has a higher area of service coverage than Galloway, therefore the higher value of MNF. The network in Katanga-Ngoni is older than in Galloway. Katanga-Ngoni was established in the early 1950s (NTC, 1995 and NTC, 2014). Therefore, the age of the network can have an effect on the amount of real losses. It can be concluded that for Norton in the specific study areas there are excess flows which can be attributed to leakages in the system as observed in Blantyre City.

Table 5-4 shows real losses for Katanga-Ngoni and Galloway after application of correction factors.

Table 5-4: Real losses for the two specific areas

Area	**Real losses**			
	Daily real loss (m^3/day)	**Correction factor**	**Corrected daily Real losses (m^3/day)**	**m^3/month**
Galloway	646	0.12	78	2,340
Katanga-Ngoni	1,558	0.18	280	8,400

Apparent losses: The Apparent Losses (AL) for the two areas was calculated according to Equation 13 which defines apparent losses as the difference between NRW and real losses (Lambert and Taylor, 2010 and Fallis *et al*., 2011). Table 5-5 shows the results on partitioning of real and apparent losses for the two areas

Table 5-5: Partitioning of non-revenue water for Galloway and Katanga-Ngoni

Area		**Real losses**		**Apparent losses**	
	NRW (m^3)	**m^3/month**	**%**	**m^3/month**	**%**
Galloway	9,672	2,340	24	7,332	76
Katanga-Ngoni	24,167	8,400	35	15,767	65

From Table 5-5 the real losses for Galloway were 24 % and apparent losses were 76 %. Katanga-Ngoni had real losses of 35 % and 65 % apparent losses. A study of four specific study areas in Zomba, Malawi had results for apparent losses of 27 %, 25 %, 60 % and 77 % (Chipwaila, 2009). The results for Norton are similar to two of the areas and contradict the remaining two areas. Norton had real losses of 24 % and 35 %, this is similar to the study in Zomba were real loses of 23 % to 40 % were observed.

According to Seago *et al.* (2004) apparent losses acceptable limit is 20 % of total losses from a study of typical water distribution systems in South Africa. Xin *et al*. (2014b) and Lambert and Taylor (2010) also support that apparent losses are 30 to 40 % of the total losses. The high apparent losses may be attributed to high metering inaccuracies of 73 % obtained from the meter testing as shown in Table 5-6.

Table 5-6: Status of water meters

Status of meter	**%**
Under registering	73
over registering	4
Within range	23
Total	100

Inaccurate meters tend to under register consumption resulting in increased commercial losses (Farley *et al.*, 2008). The age range of meters was also a factor to consider. In the Zomba city study apparent losses were also attributed to both metering inaccuracies caused by under registering and age. Table 5-7 presents results on the age of water meters from the two specific study areas.

Table 5-7: Age range of water meters from Galloway and Katanga-Ngoni

Age range (Years)	number of meters	%
0 to 10	43	43
11 to 20	32	32
over 20	25	25

From meter testing results presented in Table 5-7, it can be seen that 57 % of the meters tested were above the age of 10 years. Meters with age greater than 10 years are considered to have a poor accuracy according to Sharma (2008b). This may also contribute to the above limit apparent loses. It can be concluded that apparent losses for Norton are higher than acceptable limits recommended in literature but is within ranges of similar studies in the region of 60 % to 77 %. According to McKenzie *et al.* (2006) apparent losses in well managed systems tend to be below 20 % or less and when they are in excess of 50 % that maybe an indication of a poorly managed system.

5.3. Evaluation of the operating practices by the Local Authority

Evaluation of the operating practices of Norton Town Council for water supply included investigation through use of historical and current records, enquiries into current policies and procedures and meter testing. The aspects that were evaluated were condition of water meters, meter reading process and management of the water supply system.

5.3.1 Meter testing in the specific study areas

Meter testing results have been presented in Tables 5-6 and 5-7. Appendix IX presents data on individual age of meters and results from meter testing. The results showed that the water system has 57% of the meters being above 10 years of age. Meters above 10 years of age are considered to have a poor accuracy and average acceptable age is 5 to 10 years and less than 5 years is considered good (Sharma, 2008b). A water meter was considered to be under or over registering when the measured volume through the meter was ±2 % of the expected volume (Lambert and Taylor, 2010). Therefore the acceptable range in this study was 490 liters to 510 liters. From the test 73 % of the meters under registered flow by an average of 67 %. When meters under register there is an increase in NRW. Metering inaccuracies were identified as a key factor in commercial losses resulting in apparent losses according to Xin *et al.* (2014b) and Gongera (2015). From key informant interviews it was revealed that Norton Town Council does not do meter calibration before installation of meters as prescribed by

IWA nor is there a meter replacement programme in place (Farley *et al.*, 2008). It can be concluded that Norton town has a poor metering system in terms of calibration of meters and meter replacement programmes which is contributing to apparent losses

5.3.2 Meter reading process and billing

Meter readers have fixed routes for meter reading. This is a bad practice according to Farley *et al*. (2008) as this promotes familiarity with customers and there maybe collusion to record lower meter readings in exchange for monetary incentives. This has an effect of increasing NRW in terms of apparent losses in the form of water theft. They recommend rotation of meter readers to different routes on a regular basis as is the case in Johor were meter readers do not read a particular meter more than once every four months. Meter reading as well as billing is not done in certain areas on the basis of predefined end points of water coverage. In Maridale and Johannesburg suburbs residents are not billed, whilst in Knowe 60 out of above 3000 are billed, the same applies to Katanga extension area there is no water billing. This assumption is not true as records have shown attendance to water bursts in the same areas where water coverage is deemed absent. This has an effect of increasing non-revenue water in terms of unbilled consumption. It can be concluded that NRW is exacerbated by partial meter reading and billing.

It is a policy of the local authority from 2011 that absence of a water meter attracts a penalty of $50 per month; however there are no measures in place to ensure that a meter's condition is satisfactory. This translates to an estimated consumption of 103 m^3/month and has an effect of reducing NRW as this is an above average consumption for residential consumption (Ministry of Local Government, Public Works and National Housing, 1982). Non-functional meters are defined by the local authority as those meters that are continuously stuck on the same reading. This is not correct according to Farley *et al*. (2008) who highlight that water meters do not exactly register the total amount of water consumed since they have a limited range of operation.

5.3.3 Management of the water supply system

From the interviews it was revealed the water supply system is mainly managed by the Engineering Services Department and the Finance Department. The roles of the departments are clearly defined as per departmental organograms and goals (NTC, 2015). However, there is minimum cooperation between departments towards achieving set goals because on the council structure departments are interdependent. Other departments also support water supply management but at a much less extent. The Finance Department focuses on maximising revenue and minimising expenditure on repairs and maintenance of the system. However, the Engineering Department depends on resources from Finance Department to operate and maintain the system. According to Mckenzie *et al*. (2012) fragmented management is a key problem in municipalities with the most common issue being the water services division where both the technical and finance departments have certain responsibility but different goals. Farley and Liemberger (2005) and Farley *et al*. (2008) highlight that all senior managers have a role to play in NRW reduction.

A review of existing documents within the local authority revealed that under the water loss reduction programme initiative by GIZ, zonal meters were installed through the Engineering Department for use by the Finance Department. The zonal meters are currently not being read for the purposes of performing water audits at the end of each billing cycle. Meter readers confirmed that they do not read the zonal meters. Water audits are recommended for determination of the amount of water lost in a distribution system and they begin with a measurement of the system input volume in DMAs (Sastry, 2006 and O'Malley *et al*., 2013). Under the same program data loggers and software for meter reading and billing were purchased, however these are not in use such that meter reading is being done manually. The data loggers were for reducing data handling errors and also monitored the meter readers through a Geographical Information System (GIS) platform as meter readings are being taken. It can be concluded that the departments which manage water supply in Norton are fragmented resulting in inefficient use of available resources.

The Ministry of Local Government, Public Works and National Housing in their routine audit commented that the town's water account was showing a negative variance between bulk water received and billed consumption. The formal response from the local authority attributed the variance to high physical water losses only which were not quantified. Aspects of possible apparent losses in the system were not mentioned. This means that there is no appreciation of water loss components by the local authority. Farley *et al*. (2008) acknowledge that appreciation of NRW is usually limited to the technical personnel, however everyone in a water utility should understand the importance NRW and how it affects their daily work and the utility.

It can be concluded that there are some bad practices in the same system which intensify the NRW challenge. Such challenges are non-rotation of meter readers, selective meter reading and water billing, ineffective use of water management equipment, limited appreciation of NRW components and lack of an effective regulatory policy on metering.

5.4 Evaluation of possible strategies

Analysis of strategies was done through Multi-Criteria Decision Analysis (MCDA). According to Farley *et al.* (2008) and Mutikanga *et al.*(2011) the key requirements for strategies were identified as

i. Strategy options that address real losses
ii. Strategy options that address apparent losses
iii. Cost of implementation
iv. Strategies that lead to integrated water management

The main objectives were established from the mission statement and strategic planning documents of Council. Results of NRW and its components also contributed to the formulation of objectives which are;

i. Improve revenues and minimise costs
ii. Improve water savings
iii. Improve water affordability

5.4.1 Proposed strategies to control NRW

Strategies were derived from recommendations from a variety provided by International Water Association (IWA) and American Water Works Association (AWWA) as recommended by Mutikanga *et al*. (2011). Table 5-8 shows the proposed strategies and complimentary actions.

Table 5-8: Proposed strategies and actions

Code	Strategy	Actions
S1	Controlling commercial water losses	a) Introduce meter testing b) Systematic meter replacement programme with the local authority purchasing meters on behalf of customers so that standard high quality meters are used. c) Use of data loggers and the complimentary software d) Rotation of meter readers e) Avoid selective meter reading and water billing f) Performing water balance through use of zonal meters and segregating bills according to zones
S2	Reducing physical water losses	a) Active leakage control through analysis of DMA flow data b) Efficient organisation and procedures to improve the speed and quality of repairs c) Asset management through replacement of aged pipe networks
S3	Integrated management of the water system	a) Combined effort from management and staff throughout the local authority b) Setting performance targets including scheduled reporting and monitoring

5.4.2 Criterion for rating

Criterion were determined from the objectives and weighted as recommended by Dodgson *et al*. (2009) and Saarikoski *et al*. (2015) to get the relative importance of each by the managers. Weighted score was determined according to equation 14. Results of the weighting derived from key informant interviews are presented in Table 5-9.

Table 5-9: Criterion weighting

Criteria	Weight values by managers					Total	Weighted score
	Manager 1	Manager 2	Manager 3	Manager 4	Manager 5		
EC 1 Revenue	9	10	7	7	6	39	0.25
EC2 Cost of implementation	9	10	8	8	8	43	0.28
EC3 Water Saved	7	8	8	9	6	38	0.24
EC4 Socio Economic	8	5	9	6	8	36	0.23
Total						156	1

From Table 5-9 cost of implementing a strategy has the highest importance according to the senior managers of the local authority. This is due to the need to reduce expenditure since rates are the only source of funding for the local authority (NTC, 2015). According to Farley *et al.* (2008) development and implementation of a strategy to reduce NRW incurs financial cost and managers favour strategies that are financially viable. Therefore the expenditure items should be at a minimum. Improved revenues is second in importance because the collection efficiency for water for the town is at 35 % according to GIZ (Tafangombe and Madyiwa, 2014). According to Fallis *et al*. (2011) managers favour components of NRW where investments will generate the highest rate of return. Managers therefore tend to compare components of NRW not only by their volumes but also by their financial impacts.

Water saved is third. This is attributed to the capital costs involved in implementing water saving strategies. For water utilities like Norton where there are water shortages reduction in physical losses would effectively create an additional water supply improving coverage (Farley *et al*., 2008). However, the objective of increasing water supply in the town is overshadowed by the need to minimise cost and capitalising on high returns. Socio-economic aspects have the least weight because the focus is on improving revenues regardless of the impacts on customers.

5.4.3 Rating of strategies against criterion

Using the Likert Scale presented in Table 4-3 the strategies were rated against each criterion and the results are presented in Table 5-10. The rating considers the effect of a strategy on the criterion.

Table 5-10: Rating of strategies against criterion

Objective	Criteria	Desired Direction	Strategy options		
			S1	S2	S3
Financial-Economic	EC1 Revenue	Maximise	4	3	3
	EC2 Investment Cost	Minimise	3	2	5
Environmental	EC3 Water Saved	Maximise	3	4	3
Affordability	EC4 Socio-Economic	Maximise	4	4	2

According to Mateo (2012) the individual weighted scores of the criterion were multiplied by the rating of each strategy before being added up in order to express the preference of the importance of a certain criteria over other criteria. Weighted scores have already been presented in Table 5-9. The summation was done using Equation14 to determine the utility function of a strategy. The results are presented in Table 5-11.

Table 5-11: Ranking of strategies

Criteria	Weight	S1 (Controlling commercial losses)		S2 (Reducing physical losses)		S3 (Integrated management)	
		Rating	Score	Rating	Score	Rating	Score
EC1	0.25	4	1	3	0.75	3	0.75
EC2	0.28	3	0.83	2	0.55	5	1.38
EC3	0.24	3	0.73	4	0.97	3	0.73
EC4	0.23	4	0.92	4	0.92	2	0.46
Total	1		3.48		3.20		3.32

From Table 5-11 controlling commercial losses is first on ranking. This is attributed to the strategy being low cost to implement for the local authority. The software and equipment for meter reading and billing is available. According to Fallis *et al*. (2011) the recovery of apparent losses is possible at relatively low costs and directly improves the water utility's financial position. The same is also supported by Farley *et al*. (2008) who support that reducing commercial losses increases revenues since a small volume of commercial loss have a large financial impact.

Integrated management is ranked second on strategies. This is because of the low cost involved in implementing the strategy. For any other strategies to work there is need for coordination between the various departments. Reducing physical water losses is least on ranking to reduce NRW. This is because of the investment cost required to implement the strategy. The strategy requires capital for pipe replacement programmes, leak detection, ready spares and fittings for repairs and maintenance etc. The results for reducing physical water losses are contrary to Farley *et al*. (2008) who suggest that water saving is a priority to water utilities who face water shortages such as Norton Town Council. However the ranking results are comparable to other water utilities because replacement of pipe networks and zoning has been ranked least on the basis of the huge capital requirements for implementation (Fallis *et al*., 2011 and Mutikanga *et al*., 2011)

It can be concluded that for Norton Town Council the most preferred strategy is one that improves revenues and minimise costs so that higher returns are rapidly realised. Strategies that require capital injections such as reducing physical water losses are least preferred because the objective is to minimise costs. The results of the ranking also fit to the weighting of the criterion which favoured lower costs in implementing a strategy and maximising returns from a strategy respectively.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

From the study the following conclusions can be made.

Non-revenue water for the town was within ranges reported in the region of 20 % to 65%. However it was above the recommended limits for the region which are 20 % to 25 %. The high NRW was attributed to passive leakage management, lag in updating of new water connections for billing and partial meter reading and billing.

The average non-revenue water for the two specific study areas was 56 % for Galloway and 61 % for Katanga-Ngoni. Apparent losses were 65 % and 76 % for Galloway and Katanga-Ngoni respectively. The apparent losses are above acceptable limits of 30 to 40 % of the total losses. The high apparent losses were attributed to poor billing.

The water management system of the local authority has practices which increase NRW. Such practices include non-rotation of meter readers, selective meter reading and water billing, ineffective use of water management equipment and limited appreciation of NRW components.

The most preferred strategy is control of commercial losses. Integrated management and reduction of physical water losses are second and third respectively.

6.2. Recommendations

The following recommendations can be made;

In order to control apparent losses there is need to update the customer data base and improvement of metering and billing. A systematic meter replacement programme should be in place investing in high quality meters and a robust billing system.

Effective use of equipment provided for improving water management should be fully utilised such as the zonal meters and data loggers so that both apparent and real losses are controlled through analysis of zonal flow data and reduced data handling errors.

There is a need to adopt good practices in managing the water system. Such practices are rotation of meter readers, and integrated management of the water system because addressing NRW is a responsibility of all managers across the water utility.

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APPENDICIES

APPENDIX I: Questionnaire for meter readers

I am Bester Maramba a student with University of Zimbabwe, doing an MSc in Integrated Water Resources Management. I am doing a research on: **An assessment of non-revenue water for Norton Town in Zimbabwe.**

You are kindly being requested to contribute to the research by answering questions on this questionnaire. Your responses will be treated confidentially as grouped data. Further note that your identity will not be indicated on this form and all responses shall contribute meaningfully to the study

1. Gender. Male ……… female ……….
2. Age

Age group	15-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	Over 60

3. Highest level of academic qualification

Below ordinary level	Ordinary level	Advanced level	Degree	Masters	Doctorate

4. Period of employment in council

Less than 1 year	1-5 years	6-10 years	11-15 years	More than 15 years

5. Do you have a fixed area of meter reading or the areas change?

   Fixed ……….   Changes………………..

6. How do you conduct meter reading in an area

   ………………………………………………………………………………………
   ………………………………………………………………………………………
   ………………………………………………………………………………………
   ………………………………………………………………………………………
   ………………………………………………………………..

7. What do you record for Non-functional meters
…………………………………………………………………………………………
……………………………………………………

8. Do you read zonal meters? Yes…………………   No……………………….

9. On either answer. Why

…………………………………………………………………………………………
…………………………………………………………………………………………
………………………………………………………………………………………

Thank you very much for your time and cooperation

APPENDIX II: Checklist for NTC management key informant Interviews

I am Bester Maramba a student with University of Zimbabwe, doing an MSc in Integrated Water Resources Management. I am doing a research on: **An assessment of non-revenue water for Norton town in Zimbabwe.**

You are kindly being requested to contribute to the research by answering questions on this questionnaire. Your responses will be treated confidentially as grouped data. Further note that your identity will not be indicated on this form and all responses shall contribute meaningfully to the study

1. Gender. Male ……… female ……….
2. Age

Age group	15-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	Over 60

3. Highest level of academic qualification

Below ordinary level	Ordinary level	Advanced level	Degree	Masters	Doctorate

4. Period of employment in council

Less than 1 year	1-5 years	6-10 years	11-15 years	More than 15 years

5. What is Council's meter reading schedule
6. Do meter readers have fixed routes
7. Who checks their work
8. What is the council's policy on non-working meters
9. What is your role in meter reading
10. What is the function of zonal meters in Norton
11. Are water audits being carried out
12. What improvements have been put in the water management system since the inception of the zonal metering programme
13. Do you have any suggestions on improving water management in Norton

APPENDIX III: Bulk water received 2004 to 2014 from City Of Harare

	Year										
Month	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
January	11,698	10,256	13,584	13,254	12,531	10,239	10,258	12,044	13,159	12,893	11,345
February	13,548	10,478	12,870	11,781	9,090	11,478	9,813	12,893	12,964	12,005	11,204
March	12,546	9,658	12,489	9,531	10,851	12,789	9,102	12,002	11,397	12,410	10,963
April	12,784	11,365	12,563	10,254	10,269	11,596	9,638	13,986	11,541	11,740	10,980
May	11,003	12,004	10,689	9,415	11,788	12,487	10,789	11,789	11,321	12,984	11,009
June	12,658	10,259	11,699	10,256	10,145	10,236	11,401	13,597	12,893	12,047	10,289
July	11,897	11,869	12,589	10,255	11,478	11,259	10,300	12,593	12,534	11,834	12,930
August	12,536	13,890	13,258	10,857	12,478	9,369	9,810	14,005	11,390	11,793	11,402
September	11,451	11,734	12,985	11,458	10,259	10,258	10,279	12,347	12,432	10,399	10,572
October	12,745	10,003	11,329	9,548	9,630	9,525	9,839	12,939	11,892	13,001	10,430
November	12,589	12,741	13,789	10,256	10,239	9,842	10,259	13,894	13,820	12,970	11,748
December	12,897	12,983	12,789	10,987	11,247	10,021	8,830	12,398	12,012	11,245	12,869
Total	148,352	137,240	150,633	127,852	130,005	129,099	120,318	154,487	147,355	145,321	135,741

APPENDIX IV: Billed water from 2004 to 2014

	Years										
Month	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
January	7,205	8,453	7,863	7,815	7,990	6,299	6,554	6,912	6,591	7,145	6,304
February	7,102	7,425	9,102	7,148	8,473	6,215	7,109	9,300	7,265	6,201	6,985
March	8,205	7,142	7,982	9,963	8,412	7,410	7,219	7,006	7,103	7,005	6,312
April	8,141	7,100	8,839	8,147	8,803	7,439	7,101	7,902	7,935	6,305	6,328
May	9,326	7,963	8,841	8,001	8,362	7,940	6,305	6,987	9,303	7,410	6,610
June	8,003	8,930	7,415	8,110	7,284	7,149	7,239	7,802	7,108	6,903	6,792
July	8,701	8,803	9,165	7,998	8,912	7,001	7,510	9,208	7,932	6,257	7,100
August	7,105	7,400	7,103	8,125	8,502	8,104	6,498	7,509	7,413	6,178	6,003
September	7,129	7,125	8,199	9,141	8,295	7,845	6,790	7,703	6,639	7,412	7,131
October	8,812	7,120	8,654	9,210	7,429	6,891	7,983	8,921	6,200	7,001	7,102
November	9,414	8,236	9,874	9,365	7,489	7,009	6,265	9,720	6,003	7,913	6,104
December	8,102	7,450	9,178	7,412	7,903	7,100	6,402	9,355	7,960	8,415	6,432
Total	97,245	93,147	102,215	100,435	97,854	86,402	82,975	98,325	87,452	84,145	79,203

APPENDIX V: Yearly NRW for Norton Town water supply system

Year	Water received (m^3/year)	Water billed (m^3/year)	NRW	
			Vol (m^3/year)	Vol (% of received water)
2004	148,325	97,245	51,080	34
2005	137,240	93,147	44,093	32
2006	150,633	102,215	48,418	32
2007	127,852	100,435	27,417	21
2008	130,005	97,854	32,151	25
2009	129,099	86,408	42,691	33
2010	120,318	82,975	37,343	31
2011	155,487	98,325	57,162	37
2012	147,355	87,452	59,903	41
2013	145,321	84,145	61,176	42
2014	135,741	79,203	56,538	42
2015	141,245	82,025	59,220	42

APPENDIX VI: Zonal readings

Galloway	Meter1	Meter 2
Nov	245186	8506
Dec	257646	11324
Jan	273604	14261
Feb	285596	17923
Mar	299096	20748
Apr	310572	23659
May	320424	26784

Katanga-Ngoni	Reading	
Nov	13925	
Dec	62775	
Jan	106125	
Feb	147477	
Mar	187742	
Apr	228767	

APPENDIX VII: Galloway flow measurements

Day	Time	Meter 1	Meter 2
1-May		32496	27528
	0:00	32533	27541
	1:00	32550	27554
	2:00	32558	27566
	3:00	32572	27582
	4:00	32593	27591
	5:00	32621	27603
	6:00	32682	27622
	7:00	32810	27644
	8:00	33175	27779
	9:00	33502	27902
	10:00	33803	28011
	11:00	34117	28107
	12:00	34507	28177
	13:00	34716	28358
	14:00	35018	28516
	15:00	35419	28655
	16:00	35752	28802
	17:00	36061	29043
	18:00	36416	29108
	19:00	36813	29171
	20:00	37167	29297
	21:00	37452	29362
	22:00	37594	29420
	23:00	37692	29462

Day	Time	Meter 1	Meter 2
2-May		37692	29462
	0:00	37725	29471
	1:00	37750	29479
	2:00	37777	29484
	3:00	37804	29490
	4:00	37825	29495
	5:00	37847	29500
	6:00	37904	29514
	7:00	38029	29542
	8:00	38320	29609
	9:00	38624	29680
	10:00	38973	29753
	11:00	39279	29820
	12:00	39634	29890
	13:00	39941	29950
	14:00	40226	30005
	15:00	40438	30052
	16:00	40685	30108
	17:00	41069	30180
	18:00	41374	30249
	19:00	41583	30315
	20:00	41804	30358
	21:00	41945	30395
	22:00	42043	30416
	23:00	42105	30429

Galloway cont…..

Day	Time	Meter 1	Meter 2
3-May		42105	30429
	0:00	42153	30454
	1:00	42193	30465
	2:00	42225	30478
	3:00	42249	30490
	4:00	42273	30501
	5:00	42301	30506
	6:00	42373	30530
	7:00	42509	30575
	8:00	42765	30626
	9:00	43093	30697
	10:00	43461	30845
	11:00	43709	30954
	12:00	44061	31061
	13:00	44365	31157
	14:00	44605	31255
	15:00	44829	31321
	16:00	45005	31352
	17:00	45293	31411
	18:00	45645	31522
	19:00	45897	31593
	20:00	46073	31650
	21:00	46217	31681
	22:00	46305	31722
	23:00	46369	31747

Day	Time	Meter 1	Meter 2
4 May		46369	31747
	0:00	46417	31754
	1:00	46438	31773
	2:00	46466	31790
	3:00	46480	31806
	4:00	46503	31813
	5:00	46523	31833
	6:00	46587	31879
	7:00	46703	31943
	8:00	46945	32061
	9:00	47199	32127
	10:00	47397	32239
	11:00	47598	32348
	12:00	47839	32487
	13:00	48112	32614
	14:00	48396	32740
	15:00	48661	32865
	16:00	48809	32932
	17:00	49019	33047
	18:00	49308	33148
	19:00	49633	33243
	20:00	49754	33312
	21:00	49852	33374
	22:00	49941	33390
	23:00	50015	33406

Galloway cont..

Day	Time	Meter 1	Meter 2
		50015	33406
5-May	0:00	50056	33435
	1:00	50104	33447
	2:00	50135	33466
	3:00	50153	33478
	4:00	50173	33488
	5:00	50205	33506
	6:00	50314	33522
	7:00	50499	33547
	8:00	50697	33609
	9:00	51022	33654
	10:00	51355	33701
	11:00	51587	33729
	12:00	51832	33804
	13:00	52171	33915
	14:00	52483	33993
	15:00	52743	34028
	16:00	52934	34057
	17:00	53173	34108
	18:00	53414	34177
	19:00	53712	34254
	20:00	53953	34313
	21:00	54118	34358
	22:00	54189	34392
	23:00	54250	34421

Day	Time	Meter 1	Meter 2
		54250	34421
6-May	0:00	54292	34449
	1:00	54333	34458
	2:00	54366	34465
	3:00	54380	34481
	4:00	54397	34494
	5:00	54438	34533
	6:00	54506	34565
	7:00	54646	34665
	8:00	54849	34842
	9:00	55100	35011
	10:00	55368	35148
	11:00	55576	35240
	12:00	55797	35289
	13:00	55977	35414
	14:00	56199	35532
	15:00	56397	35554
	16:00	56531	35660
	17:00	56732	35804
	18:00	56988	35938
	19:00	57205	36076
	20:00	57390	36161
	21:00	57564	36237
	22:00	57703	36288
	23:00	57760	36301

APPENDIX VII: Katanga flow readings

Day	Time	Meter reading
		52767
16-May	0:00	52851
	1:00	52928
	2:00	52999
	3:00	53091
	4:00	53194
	5:00	53392
	6:00	53734
	7:00	54149
	8:00	54996
	9:00	55959
	10:00	56873
	11:00	57591
	12:00	58124
	13:00	58542
	14:00	59006
	15:00	59405
	16:00	59823
	17:00	60245
	18:00	60761
	19:00	61188
	20:00	61506
	21:00	61628
	22:00	61719
	23:00	61796

Day	Time	Meter reading
		61796
17-May	0:00	61889
	1:00	61973
	2:00	62050
	3:00	62132
	4:00	62223
	5:00	62357
	6:00	62644
	7:00	62988
	8:00	63709
	9:00	64571
	10:00	65484
	11:00	66321
	12:00	66939
	13:00	67341
	14:00	67774
	15:00	68225
	16:00	68637
	17:00	69026
	18:00	69448
	19:00	69910
	20:00	70188
	21:00	70289
	22:00	70373
	23:00	70454

Katanga cont…

Day	Time	
		70454
18-May	0:00	70556
	1:00	70649
	2:00	70737
	3:00	70801
	4:00	70884
	5:00	70986
	6:00	71213
	7:00	71517
	8:00	72085
	9:00	72912
	10:00	73910
	11:00	74704
	12:00	75416
	13:00	75920
	14:00	76317
	15:00	76786
	16:00	77170
	17:00	77638
	18:00	77999
	19:00	78411
	20:00	78746
	21:00	78900
	22:00	78998
	23:00	79075

Day	Time	Meter Reading
		79075
19-May	0:00	79156
	1:00	79244
	2:00	79315
	3:00	79398
	4:00	79542
	5:00	79751
	6:00	80039
	7:00	80538
	8:00	81342
	9:00	82248
	10:00	83229
	11:00	84102
	12:00	84735
	13:00	85346
	14:00	85848
	15:00	86160
	16:00	86379
	17:00	86720
	18:00	87019
	19:00	87456
	20:00	87752
	21:00	87854
	22:00	87938
	23:00	88026

Katanga cont….

Day	Time	Meter Reading
		88026
20-May	0:00	88100
	1:00	88183
	2:00	88255
	3:00	88351
	4:00	88453
	5:00	88704
	6:00	89066
	7:00	89467
	8:00	90100
	9:00	91032
	10:00	91980
	11:00	92788
	12:00	93582
	13:00	94276
	14:00	94902
	15:00	95489
	16:00	96003
	17:00	96480
	18:00	96876
	19:00	97250
	20:00	97489
	21:00	97686
	22:00	97797
	23:00	97894

Day	Time	Meter Reading
		97894
21-May	0:00	97988
	1:00	98078
	2:00	98154
	3:00	98236
	4:00	98329
	5:00	98508
	6:00	98750
	7:00	99101
	8:00	99722
	9:00	100606
	10:00	101427
	11:00	102260
	12:00	102901
	13:00	103603
	14:00	104115
	15:00	104633
	16:00	105122
	17:00	105419
	18:00	105832
	19:00	106253
	20:00	106459
	21:00	106613
	22:00	106705
	23:00	106789

APPENDIX IX: Meter testing details

meter ID	year	standard	1st test	2nd test	3rd test	average	% under/over
662543	1974	500	0	0	0	0.00	-100.00
SL92P004132	1974	500	0	0	0	0.00	-100.00
3145241	1976	500	0	0	0	0.00	-100.00
28413000	1980	500	0	0	0	0.00	-100.00
55044	1983	500	478	1003			-100.00
B-YCZ349	1983	500					-100.00
662125444	1983	500	0	0	0	0.00	-100.00
SL657387	1984	500	0	0	0	0.00	-100.00
185362	1984	500	0	0	0	0.00	-100.00
SL007541	1984	500	10	0	10	6.67	-98.67
954752632	1985	500	0	0	0	0.00	-100.00
SLR848A	1985	500	490	630	280	466.67	-6.67
140297940	1986	500					-100.00
1278526	1986	500	108	100	111	106.33	-78.73
SL110402164	1988	500	498	54	0	184.00	-63.20
1134587	1988	500	340	370	360	356.67	-28.67
851362	1989	500	152	165	150	155.67	-68.87
66952132	1990	500	0	0	0	0.00	-100.00
/007133	1994	500					-100.00
7547823	1994	500	0	0	0	0.00	-100.00
2568413	1994	500	312	345	325	327.33	-34.53
216325	1994	500	340	350	340	343.33	-31.33
745963128	1995	500	0	0	0	0.00	-100.00
5267416	1995	500	154	180	630	321.33	-35.73
SL657382	1995	500	470	0	0	156.67	-68.67
785416	1997	500	0	0	0	0.00	-100.00
76239846	1997	500	0	0	0	0.00	-100.00
5103692	1997	500	0	0	0	0.00	-100.00
392547	1997	500	457	452	450	453.00	-9.40
Sl00125478	1998	500	0	0	0	0.00	-100.00
12547823	1998	500	368	360	360	362.67	-27.47
7841269	1998	500	715	645	700	686.67	37.33
R18082	1999	500	0	0	0	0.00	-100.00
/006432	1999	500					-100.00
25418930	1999	500	0	0	0	0.00	-100.00
12456301	1999	500	125	145	130	133.33	-73.33
32548912	1999	500	180	185	180	181.67	-63.67
4218621	1999	500	290	310	185	261.67	-47.67
325698	1999	500	315	301	290	302.00	-39.60
WAR6650341	2000	500					-100.00
526846	2000	500	0	0	0	0.00	-100.00

/0021365	2000	500	145	165	138	149.33	-70.13
R3369	2000	500	310	140	240	230.00	-54.00
4568232	2000	500	205	610	79	298.00	-40.40
8562431	2001	500	0	0	0	0.00	-100.00
,000215478	2001	500	259	310	305	291.33	-41.73
4751230	2001	500	295	290	290	291.67	-41.67
SL55493	2001	500	456	455	59	323.33	-35.33
325687	2001	500	450	470	440	453.33	-9.33
,0025961248	2002	500	0	0	0	0.00	-100.00
36981263	2002	500	295	260	230	261.67	-47.67
,000214578	2003	500	0	0	0	0.00	-100.00
9521487	2003	500	270	270	265	268.33	-46.33
933002700	2003	500	447	479	322	416.00	-16.80
31457120	2003	500	475	486	473	478.00	-4.40
458612	2004	500	0	0	0	0.00	-100.00
2186347	2005	500	205	167	148	173.33	-65.33
2011-856941	2006	500	356	360	360	358.67	-28.27
253872	2006	500	454	456	454	454.67	-9.07
5623589	2006	500	487	485	480	484.00	-3.20
1745124	2007	500	0	0	0	0.00	-100.00
53214689	2007	500	0	0	0	0.00	-100.00
45121211	2007	500	385	415	401	400.33	-19.93
6299473	2007	500	460	470	460	463.33	-7.33
21036812	2007	500	630	605	615	616.67	23.33
SL12574962	2008	500	0	0	0	0.00	-100.00
,.02145874	2008	500	358	365	365	362.67	-27.47
875263	2008	500	440	450	470	453.33	-9.33
5124963	2008	500	470	485	475	476.67	-4.67
7841256912	2008	500	490	490	492	490.67	-1.87
SL4521389	2008	500	504	500	500	501.33	0.27
214785632	2008	500	495	509	504	502.67	0.53
584269	2009	500	0	0	0	0.00	-100.00
SL7452189	2009	500	178	180	180	179.33	-64.13
2011-214823	2009	500	435	480	440	451.67	-9.67
2011-002791	2009	500	495	493	493	493.67	-1.27
2011-001449	2009	500	489	548	503	513.33	2.67
91548723	2010	500	0	0	0	0.00	-100.00
11152436	2010	500	125	485	627	412.33	-17.53
723103	2010	500	481	524	476	493.67	-1.27
7514263	2010	500	501	500	501	500.67	0.13
4785152	2010	500	502	500	500	500.67	0.13
24554152	2010	500	503	502	500	501.67	0.33
G7454Y45	2011	500	495	495	495	495.00	-1.00
1101928	2011	500	503	502	500	501.67	0.33

SL3001917	2011	500	514	559	512	528.33	5.67
0005487912	2012	500	495	495	495	495.00	-1.00
4851236	2012	500	445	440	440	441.67	-11.67
26849215	2012	500	485	490	490	488.33	-2.33
12155	2012	500	490	491	490	490.33	-1.93
14078975	2012	500	508	552	506	522.00	4.40
852100361	2012	500	550	565	560	558.33	11.67
RV4782213	2013	500	0	0	0	0.00	-100.00
70001425	2013	500	145	520	630	431.67	-13.67
1145832	2013	500	495	495	497	495.67	-0.87
1475891	2013	500	495	500	502	499.00	-0.20
4002659	2013	500	512	515	502	509.67	1.93
365189	2014	500	498	498	504	500.00	0.00
7565245812	2014	500	500	500	502	500.67	0.13
200001211	2014	500	498	505	502	501.67	0.33
74125831	2015	500	501	500	500	500.33	0.07
						average	-47.50

APPENDIX X: Gallery of study pictures

Katanga Zonal Meter Reading

Galloway Zonal meter 1

Meter testing Bench- before testing

Meter testing in progresss