

MANAGEMENT OF NON-REVENUE WATER - A
CASE STUDY OF THE WATER SUPPLY IN
LUSAKA, ZAMBIA

By

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A dissertation submitted to the University of Zambia in partial
fulfilment of the requirements for the degree of Master of Engineering

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DECLARATION

I, **Patrick Chabe**, do hereby declare that this dissertation is entirely the product of my own work and that to the best of my knowledge, it has not been presented for the award of a degree at this or any other university, hence all the figures and tables, except those whose sources have been acknowledged, are authentic.

SIGNATURE:

DATE:

APPROVAL

This dissertation of Patrick Chabe has been approved as fulfilling the partial requirements for the award of the Degree of Master of Engineering in Environmental Engineering by the University of Zambia.

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ABSTRACT

Management of Non-Revenue Water (NRW) has been undergoing several and continuous transformations over the past two decades. The International Water Association (IWA) as well as other key stakeholders have been trying to find the ‘Best Practices’ in managing non-revenue water so as to help water utility companies reduce water losses and subsequent loss of revenue. In Zambia, the passing of the water supply and sanitation act no 28 in 1997 led to the establishment of water utility companies. The Non-Revenue Water National Technical Task Force was formed by the Government in 2014 as a national strategy for management of NRW. The main objective of this study was to, “investigate the non-revenue water levels in the water service delivery in Lusaka and to assess the adopted management practices to manage non-revenue water and thereafter come up with some recommendations that would help improve the current strategies”. Both questionnaires and semi-structured interviews as well as document review and participant observation were used in data gathering. The findings revealed that the NRW is at 44%, with the main contributors being physical losses, commercial losses and unbilled authorised consumption, each contributing 45%, 38% and 17%, respectively. The physical losses are mainly due to the poor state of the infrastructure which has led to high levels of leakages and pipe bursts. Metering errors and water theft are the main sources of commercial losses, while fire hydrants for firefighting as well as new connections and reconnections which had not been assigned service, due to lack of meters or negligence on the part of the company personnel, are the main sources of unbilled authorised consumption. The recommended management practices by the International Water Association to augment the overall ‘non-revenue water strategy’ are not wholly being implemented because of the poor state of infrastructure which seems to impede the efforts aimed at reducing NRW. To this effect, there’s an urgent need to undertake a complete overhaul of the existing network in stages starting with the most problematic ones. The current level of NRW may not be a true reflection of the actual situation because about half of the connections are not metered.

Key words: NRW, Real loss, Apparent loss, Unbilled authorized consumption, Leakages, Management, Strategy

DEDICATION

This research work is dedicated to the following:

- My parents, Adam Ngaluka Chabe (late) and Viness Sambwa Mushili Chabe who played a key role in my education through their guidance. Dad would always say that “whoever doesn’t go to school will have to go in the bush to look after cattle”.
- My brother, Webster Chabe, for playing a key role as a guardian, to the point of almost being my second Dad and always leading by example in the pursuit of academic excellence.
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TABLE OF CONTENTS

DECLARATION.....	i
APPROVAL	ii
ABSTRACT.....	iii
DEDICATION.....	iv
ACKNOWLEDGEMENTS	v
LIST OF FIGURES	xi
LIST OF TABLES	xiii
LIST OF APPENDICES.....	xiv
ABBREVIATIONS AND ACRONYMS.....	xv
CHAPTER ONE: INTRODUCTION AND BACKGROUND.....	1
1.1 Introduction.....	1
1.2 The Water Supply Situation in Lusaka	1
1.2.1 The Case Study Area	1
1.2.2 Major Challenges Being Faced.....	3
1.2.3 Meeting the Challenges.....	3
1.2.4 The Non-Revenue Water Strategy	4
1.2.5 The Organisation Structure for LWSC	5
1.3 Background to the Research Study	6
1.4 Problem Statement.....	11
1.5 Aim	12
1.6 Objectives	12
1.7 Research Questions.....	13
1.8 Scope of the Research.....	13
1.9 Dissertation Structure.....	14
1.10 Chapter Summary	14
CHAPTER TWO: LITERATURE REVIEW.....	15
2.1 Introduction.....	15
2.2 The Dublin Principle.....	15
2.3 Definition of Non-Revenue Water.....	16
2.4 Components of Non-Revenue Water	17

2.4.1	Water Balance	17
2.4.2	Physical (Real) Losses	20
2.4.3	Commercial (Apparent) Losses	23
2.4.4	Management of Commercial Losses	24
a)	Measures to Control Apparent (Commercial) Losses.....	24
b)	Customer Meter Inaccuracy	25
c)	Unauthorised Consumption (Water Theft)	26
d)	Meter Reading Errors.....	27
e)	Data Handling and Accounting Errors.....	28
2.4.5	Unbilled Authorised Consumption (UAC)	28
2.5	Developing a Strategy for Water Loss Management	29
2.5.1	Activities Involved in Developing a Water Loss Management Strategy.....	32
2.5.2	Implementing the Strategy	33
2.6	District Metered Areas (DMAs)	34
2.6.1	DMA Establishment Criteria	35
2.6.2	Using a District Metered Area to reduce Non-Revenue Water	37
2.7	Assessment of Non-Revenue Water	38
2.7.1	Top-Down Approach	39
2.7.2	Bottom-Up Approach.....	41
2.7.3	Burst and Background Estimates (BABE).....	42
2.7.4	Synergetic Approach.....	44
2.7.5	International Non-Revenue Water Assessment Matrix	44
2.8	Economics of Water Loss Management	46
2.8.1	Performance Indicators	46
2.8.2	Percentage as a Performance Indicator	46
2.8.3	Economic Level of Losses (Leakages) (ELL)	48
2.8.4	Infrastructure Leakage Index (ILI)	50
2.8.5	Apparent Loss Index (ALI).....	53
2.9	Yard Taps.....	55
2.10	Key Performance Standards.....	55
2.10.1	Metering Ratio	55
2.10.2	Collection Efficiency	56
2.10.3	Connection Efficiency	56
2.10.4	Staff Efficiency	57

2.11	Leakage Management	57
2.11.1	Active Leakage Control (ALC)	57
2.11.2	Pressure Management	59
2.11.2.1	Methods of Pressure Management	60
2.11.3	Infrastructure Management	61
2.11.4	Speed and Quality of Repairs	62
2.11.5	Leak Detection Equipment	62
a)	Noise Loggers	63
b)	Leak Noise Correlators	63
c)	Ground Microphones	64
d)	Sounding (Listening) Sticks	64
2.12	Key Emergent Issues from Literature Review	65
2.13	Chapter Summary	66
CHAPTER THREE: RESEARCH METHODOLOGY		67
3.1	Introduction	67
3.2	Approaches in Conducting Research	67
3.2.1	Qualitative Technique	67
3.2.2	Quantitative Technique	69
3.2.3	Case Study	69
3.2.4	Key Informant Interviews	71
3.2.4.1	Approaches to Analysing Data	72
a)	Quasi-Statistical Method	72
b)	Template Method	72
c)	Editing Method	72
d)	Immersion/Crystallisation Method	73
3.2.5	Questionnaire	73
a)	Advantages of Questionnaires	74
b)	Disadvantages of Questionnaires	74
3.2.6	Participant Observation	74
3.2.7	Methods for Evaluating a Strategy	74
a)	‘With’ and ‘Without’	75
b)	SWOT Analysis	75
c)	‘Before-and-After’ Analysis	76

d) PEST Analysis	77
e) Gap Analysis.....	77
3.3 Adopted Methods for Data Collection and Analysis	78
3.3.1 Adopted Method for Strategy Evaluation	78
3.3.2 Adopted Data Collection Methods.....	78
3.4 Preparation for Field Work and Data Collection	79
3.4.1 Research Permission and Ethical Issues	79
3.4.2 Data Review or Document Review.....	79
3.4.3 Key Informant Interviews	80
3.4.3.1 Mode of conducting interviews	80
3.4.4 Field Participant Observation	81
3.5 Chapter Summary	82
CHAPTER FOUR: RESEARCH FINDINGS.....	83
4.1 Introduction.....	83
4.2 Findings from the Interviews	83
4.2.1 Causes of Non-Revenue Water	83
4.2.1.1 Capacity Building (CB)	84
4.2.1.2 Technical (T).....	84
4.2.1.3 Organisation Structure (OS)	85
4.2.1.4 Logistical (L)	86
4.2.1.5 Socio-Cultural (SC)	86
4.2.1.6 Statutory Obligation (SO).....	86
4.3 Questionnaire	87
4.3.1 Contribution to non-revenue water	87
4.3.2 Sources of Physical Losses	88
4.3.3 Sources of Commercial (apparent) Losses	88
4.3.4 Level of Implementation of the NRW Management Practices	89
4.4 Document Review.....	91
4.5 Participant Observation.....	91
CHAPTER FIVE: DATA ANALYSIS AND DISCUSSION	93
5.1 Introduction.....	93
5.2 Management of Non-Revenue Water	93

5.3 Annual Volumes of Water Sold (Branches & Peri-Urbans).....	101
5.4 Annual NRW for the Duration 2011 - 2016	107
5.5 Annual Collection Efficiency and Cash Inflow	111
CHAPTER SIX: SUMMARY, CONCLUSION AND RECOMMENDATIONS.....	114
7.1 Summary.....	114
7.2 Conclusion	115
7.3 Recommendations.....	116
7.3.1 Future Research Work	117
REFERENCES.....	118
APPENDICES.....	124

LIST OF FIGURES

Figure 1.1:	LWSC Branches found in Lusaka Town.....	1
Figure 1.2:	Organisational structure for LWSC.....	5
Figure 2.1:	The impact of leak run time on physical losses.....	21
Figure 2.2:	The “Four Arrows Chart” for managing physical losses.....	21
Figure 2.3:	Different components of Apparent Losses.....	24
Figure 2.4:	Implementation of the apparent water loss control strategy.....	25
Figure 2.5:	Typical meter reading cycle synchronization.....	28
Figure 2.6:	Typical water distribution network showing a district metered area.....	35
Figure 2.7:	A typical layout of a district metered area.....	37
Figure 2.8:	Adjusted water balance for Developing Countries like Zambia.....	39
Figure 2.9:	Background and Bursts Estimates (BABE) concept.....	43
Figure 2.10:	The reason why percentage non-revenue water is misleading.....	47
Figure 2.11:	Economic Level of Real losses.....	48
Figure 2.12:	Graphical representation of Economic Level of Real Losses.....	49
Figure 2.13:	Basic methods of managing real losses.....	52
Figure 2.14:	The different components of Apparent Losses.....	53
Figure 2.15:	Corroded underground galvanised iron pipe.....	61
Figure 2.16:	An example of a Noise Logger.....	63
Figure 2.17:	Example of a Leak Noise Correlator.....	64
Figure 2.18:	An example of a Ground Microphone.....	64
Figure 2.19:	Example of a Sounding (listening) Stick.....	65
Figure 3.1:	Favourable results after introducing an intervention.....	76
Figure 3.2:	Adverse results obtained as a result of the applied intervention.....	76
Figure 3.3:	Results are not being affected by the applied intervention.....	77
Figure 4.1:	Burst PVC pipe.....	91
Figure 4.2:	High system pressures.....	91
Figure 4.3:	Sign of underground pipe leakage.....	92
Figure 4.4:	Damaged AC and GI pipes respectively.....	92
Figure 5.1:	Respondents’ views about the Causes of NRW.....	94
Figure 5.2:	Billed Vs. Unbilled Connections.....	95
Figure 5.3:	Components of Non-Revenue Water.....	96

Figure 5.4:	Sources of Physical Losses.....	97
Figure 5.5:	Sources of Apparent Losses.....	98
Figure 5.6:	Level of implementation of management practices – Physical Losses.....	99
Figure 5.7:	Level of implementation of management practices – Apparent Losses.....	100
Figure 5.8:	Average water sold for Central Branch.....	101
Figure 5.9:	Average water sold for Chelstone and Kabulonga Branch.....	102
Figure 5.10:	Average water sold for Kabwata and Lumumba Branch.....	103
Figure 5.11:	Average water sold for Matero Zone and Peri-Urban East.....	104
Figure 5.12:	Average water sold for Peri-Urban South and West.....	105
Figure 5.13:	Overall Water sold for LWSC.....	107
Figure 5.14:	NRW for 2011 and 2012.....	108
Figure 5.15:	NRW for 2013 and 2014.....	109
Figure 5.16:	NRW for 2015 and 2016.....	110
Figure 5.17:	Collection Efficiency.....	112
Figure 5.18:	Cash Inflow.....	113

LIST OF TABLES

Table 1.1:	LWSC performance status in 1995.....	2
Table 1.2:	LWSC performance status in 2016.....	3
Table 1.3:	List of projects being undertaken by LWSC.....	4
Table 1.4:	The identified causes of non-revenue water at LWSC.....	4
Table 1.5:	Operating conditions for all the commercial water utilities in Zambia.....	10
Table 1.6:	National urban water supply coverage in Zambia.....	10
Table 1.7:	NWASCO benchmarks for Non-Revenue Water in Zambia.....	11
Table 2.1:	The IWA Standard Water Balance.....	18
Table 2.2:	Tasks and tools for developing strategies for the management of non-revenue water	30
Table 2.3:	Classification of data used in leakage management.....	33
Table 2.4:	Example of how to calculate real losses in a fully metered system.....	41
Table 2.5:	The international non-revenue water assessment matrix.....	45
Table 2.6:	The physical loss target matrix.....	52
Table 2.7:	Similarities between Apparent and Real Losses.....	54
Table 2.8:	Benchmarks for the Collection Efficiency in Zambia.....	56
Table 2.9:	Benchmark for staff per 1000 connections for small and large companies.....	57
Table 3.1:	Illustration of how SWOT analysis is used in decision making.....	75
Table 3.2:	LWSC staff members interviewed.....	81
Table 4.1:	Respondents' perceived causes of NRW in Lusaka.....	83
Table 4.2:	Respondents' views about the constituents of NRW.....	87
Table 4.3:	Sources of physical losses.....	88
Table 4.4:	Sources of commercial losses.....	89
Table 4.5:	Level of implementation of management practices for physical losses.....	89
Table 4.6:	Level of implementation of management practices for commercial losses.....	90
Table 4.7:	Management practices for unbilled authorised consumption	90
Table 4.8:	Metering statistics.....	91
Table 5.1:	Changes in annual water sold between 2010 and 2016.....	106
Table 5.2:	Summary of the cash inflows.....	113

LIST OF APPENDICES

Appendix A: Questionnaire..... 124
Appendix B: Semi-Structured Interview Questions..... 126

ABBREVIATIONS AND ACRONYMS

AfDB	African Development Bank
ALC	Active Leakage Control
ALI	Apparent Leakage Index
AWWA	American Water Works Association
BABE	Bursts and Background Estimates
CAAL	Current Annual Apparent Loss
CARL	Current Annual Real Losses
CSO	Central Statistical Office
ChWSC	Chambeshi Water and Sewerage Company
CU	Commercial Utility
DANIDA	Danish International Development Agency
DMA	District Metered Area
DTF	Devolution Trust Fund
ELL	Economic Level of Leakage (Losses)
EPA	Environmental Protection Agency
ESAWAS	Eastern and Southern Africa Water and Sanitation
GRZ	Government of the Republic of Zambia
HZM	Hour Zone Measurement
ILI	Infrastructure Leakage Index
IWA	International Water Association
KWSC	Kafubu Water and Sewerage Company
LGWSC	Lukanga Water and Sewerage Company
LNF	Legitimate Night Flow
LPWSC	Luapula Water and Sewerage Company
LWSC	Lusaka Water and Sewerage Company
MCAZ	Millennium Challenge Account Zambia
MCC	Millennium Challenge Corporation
MDGs	Millennium Development Goals
MLGH	Ministry of Local Government and Housing
MNF	Minimum Night Flow
MWSC	Mulonga Water and Sewerage Company

NNF	Net Night Flow
NRW	Non-Revenue Water
NUWSSP	National Urban Water Supply and Sanitation Programme
NWASCO	National Water Supply and Sanitation Council
NWSC	Nkana Water and Sewerage Company
NWWSC	North-Western Water and Sewerage Company
RAAL	Reference Annual Apparent Loss
SDGs	Sustainable Development Goals
UAAL	Unavoidable Annual Apparent Loss
UARL	Unavoidable Annual Real Loss
UFW	Unaccounted for Water
UN-WWAP	United Nations World Water Assessment Programme
USAID	United States Aid for International Development
WARMA	Water Resources Management Authority
WMO	World Meteorological Organization
WSS	Water supply and Sanitation
WSPS	Water Supply and Sanitation Programme Support
ZEMA	Zambia Environmental Management Agency

CHAPTER ONE: INTRODUCTION AND BACKGROUND

1.1 Introduction

In this chapter, the research topic is introduced and an overview of the whole research process to be undertaken is laid out. The chapter begins by providing a background of the research study and then a detailed explanation of the research problem is given. The main aim and specific objectives in carrying out this research are outlined together with a list of research questions which helped guide the researcher in answering the specific objectives as well as the main objective of the research study. It ends with a brief description of the scope, the research structure and a brief chapter summary.

1.2 The Water Supply Situation in Lusaka

1.2.1 The Case Study Area

Lusaka City is divided into five (5) districts, namely; Central, Kabulonga, Chelstone, Lumumba and Kabwata Districts, with the sixth being an amalgamation of all the peri-urban areas in the city. The company responsible for the provision of water and sanitation services is Lusaka Water and Sewerage Company Limited (LWSC) which was established in 1988 but became operational in 1990 (LWSC, 2017). Figure 1.1 shows the different branches found in Lusaka town:

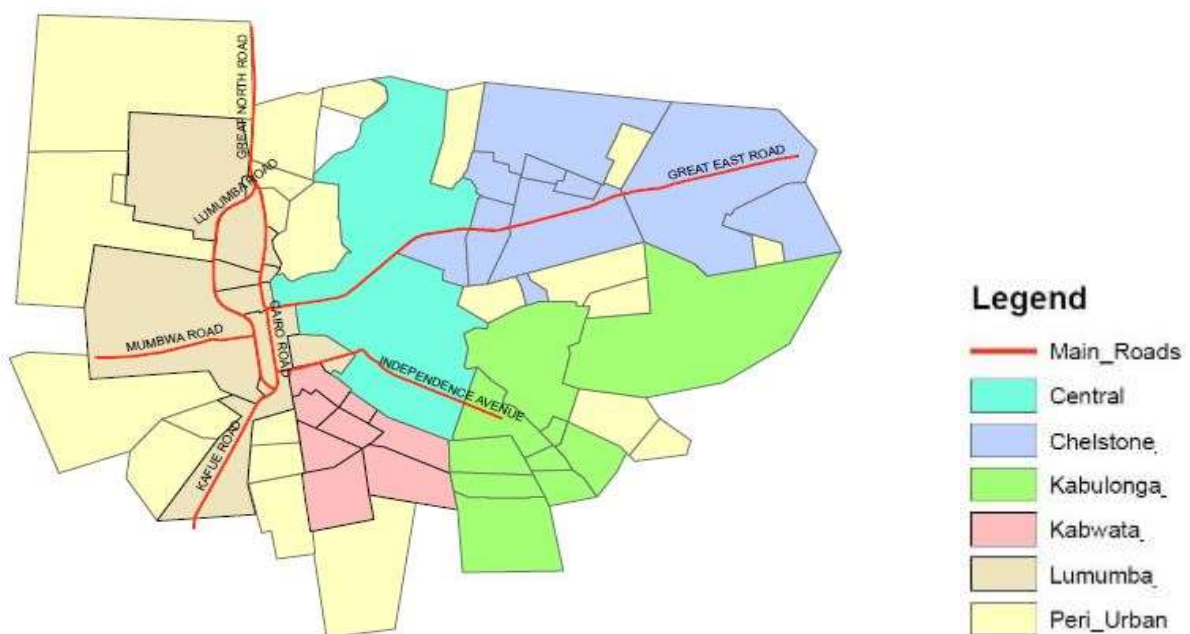


Figure 1.1: LWSC Branches found in Lusaka Town (map not to scale)

There are two types of water sources which are currently being used in Lusaka, i.e. groundwater sources (about 147,000 m³/day) – 57% and from the Kafue River (about 111,000 m³/day) – 43% through the Iolanda Water Treatment plant. Both types of sources are considerably good for human consumption after treatment, but in some areas the groundwater is polluted by sewage and other contaminants (MCC, 2011, p. 2..1).

LWSC operates a total of 116 boreholes around Lusaka, of which only about 55 boreholes are metered. This has led to production volumes being reported based on borehole capacity and not actual readings. At times pump capacities are used to estimate the production, which tends to be overstated-production resulting in overstated NRW (LWSC, 2014, p. 7).

At formation and soon after, the company faced a lot of challenges including old infrastructure, inadequate coverage, low customer metering, low staff production, etc. which required urgent attention in order to preserve the company. The performance status of Lusaka Water and Sewerage Company (LWSC) for 1995 are as shown in Table 1.1 (LWSC, 2013, p. 2):

Table 1.1: LWSC performance status in 1995

NO.	ITEM	STATUS AS IN 1995
1	Water Production	165,000m ³ per day
2	Non-Revenue Water (NRW)	65%
3	Collection Efficiency	35%
4	Net Profit Margin	3%
5	Average Hours of Supply	8 Hours per day

Source: LWSC (2013)

When compared with the current statistics, it can be observed that there has been some major improvements in water and sanitation service delivery in Lusaka. Table 1.2 highlights some of the current performance statistics for the company:

Table 1.2: LWSC performance status in 2016

NO.	ITEM	STATUS AS IN 2016
1	Water Production	258,000m ³ per day
2	Non-Revenue Water (NRW)	44%
3	Collection Efficiency	78%
4	Approximate Net Profit Margin	15%
5	Average Hours of Supply	8 Hours per day

Source: Compiled by author from different sources

1.2.2 Major Challenges Being Faced

Currently the company faces a number of challenges in its operations, with the most prominent ones being (LWSC, 2013, p. 7):

- Demand higher than Production Capacity
- Over loaded sewage treatment plants
- Water loss at 45% (Non-Revenue Water)
- Infrastructure over 50 years old
- 60% of infrastructure beyond reasonable useful life time
- Limited investment capacity
- Increasing operating costs
- Non-payment of bills by some customers e.g. government institutions

1.2.3 Meeting the Challenges

In order to meet some of the challenges mentioned above, Lusaka water and Sewerage Company in association with government and its cooperating partners has embarked on a number of projects to increase water production to meet current and future demand and to expand the sewerage treatment systems. Reduction of NRW through metering, leakage control and repair and replace aged water networks has been targeted as well. Table 1.3 gives a detailed list of water and sanitation projects which are currently underway in Lusaka:

Table 1.3: List of projects being undertaken by LWSC

NO.	PROJECT NAME	DETAILS	FUNDING
1	Lusaka Sanitation Program	Improve access to sanitation services in selected areas of Lusaka	International Financial Institutions (EIB, KfW, AfDB & WB)
2	Lusaka Water Supply Sanitation and Drainage Project	Improve drainage, water supply and sanitation services in Lusaka	MCC
3	Kafue Bulk Water Supply Project	Increase incoming water from the source in Kafue to Lusaka	Chinese Loan
4	Kalingalinga Sanmark Project	Improve access to sanitation services in Kalingalinga	International Financial Institutions (EIB, KfW, AfDB & WB)
5	Misisi Water Project	Construction of a new water network (11.57km)	DFID & Wasser-for-Wasser
6	Kabanana Water Supply Project	Water supply improvement for kabanana	DTF
7	Construction of Water Distribution Network in New Woodlands Extension	Construction of a new water network (12.43km)	LWSC

Source: www.lwsc.com.zm/projects

1.2.4 The Non-Revenue Water Strategy

Lusaka Water and Sewerage Company has identified the causes of high non-revenue water levels with their subsequent remedial measures. Table 1.4 gives the causes of high levels of non-revenue water with the suggested remedial measures:

Table 1.4: The identified causes of non-revenue water at LWSC

NO.	MAIN CAUSES	SPECIFIC CAUSES	SUGGESTED SOLUTIONS
1	Management Issues	organogram, Staff skills, staff attitude, inadequate resourcing	Improve organogram, technology issues, staff knowledge
2	Errors in Measurements	Less metering, Estimated production, unsynchronized meter reading cycles, inconsistent pressure measurements	Metered production, meter branch supply, branch boundaries, DMA designs, synchronized meter reading cycle

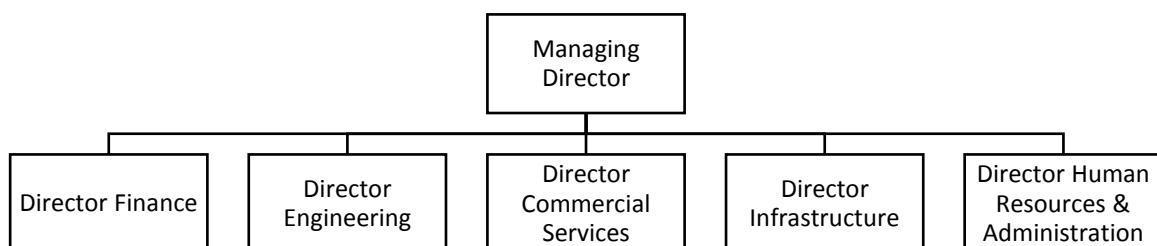
NO.	MAIN CAUSES	SPECIFIC CAUSES	SUGGESTED SOLUTIONS
3	Excessive Physical Losses	Aged Infrastructure, Vandalism, Excessive network pressure, invisible leakages, overflows, delayed response to leakages, no proper asset management, operational inefficiencies	ALC-visible leaks, replace aged pipes, quick response time, pressure management, ALC-invisible leaks
4	Excessive Commercial losses	understated-billing for unmetered properties, meter errors, meter reading errors, data errors, illegal connections, fraud	Database clean-up, reduce meter reading errors, meter technology, process grey areas, stop water theft
5	Excessive Unbilled Authorised Consumption	Regulatory obligations, misuse of fire engines, wastage at LWSC own premises, staff accounts, suspended billing	Reduce LWSC own use, fire engines, suspended billing, Corporate Social Responsibility - political, staff usage
6	Other Causes	Negative attitude of customers towards LWSC and payment of bills	Specifics

Source: LWSC – NRW Strategy (2014) (elaborated by author)

1.2.5 The Organisation Structure for LWSC

Figure 1.2 shows the organization structure for Lusaka Water and Sewerage Company (LWSC). The organogram is divided into three structures, namely; Executive Management, Information Technology and Commercial Services. The Executive Management is headed by the Managing Director, while the Information Technology (IT) and Commercial Services are headed by the IT Manager and the Director – Commercial Services respectively.

Executive Management



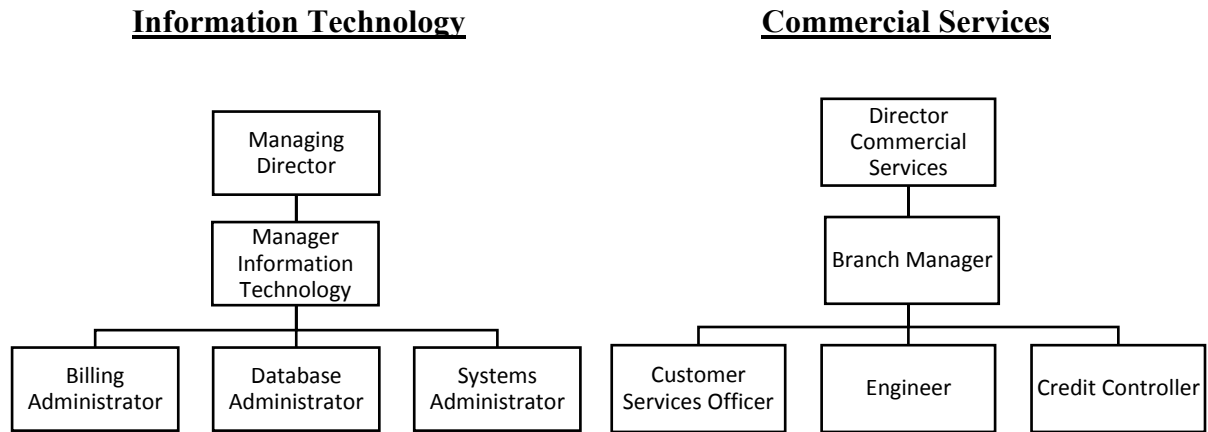


Figure 1.2: Organisational structure for LWSC

1.3 Background to the Research Study

The importance of water in our lives is a universally understood phenomena; clean water supply has been a matter of human concern for so many years and it is a known fact that all major early civilisations regarded an organised water supply as an essential component of any urban settlement (Trifunovic, 2006, p. 1).

It is already known that about one-fifth of the world's population lack access to potable drinking water and that about eighty countries, which constitute about forty per cent of the world's population are already in serious water crisis situation (Aswathanarayana, 2001, p. 47). Statistics further show that there are approximately one billion people in the world who are still living without access to clean and safe drinking water (Trifunovic, 2006, p. 1).

It is further stated that only about 20% of the world population has access to running water. This inadequate water supply affects the health of over 1.2 billion people worldwide with an estimated annual child mortality rate of 15 million children. More than half of the population in developing countries suffers from water-related diseases (Population Institute, 2010, p. 2).

About two-thirds of the earth's surface is occupied by water, but its availability to man as freshwater is significantly limited. Much emphasis is placed on freshwater resources because it is these freshwater resources that are used for consumption, agricultural and industrial purposes. Freshwater constitutes only about 2.76 percent of the total water available on earth. Even with this marginally small percentage, only less than one per cent of freshwater is accessible and used by man (Hu, 2006, p. 12).

Water is essential for life and its importance can only be observed by the diversity of the animals, organisms and plant life which exists in areas of its abundance. It is necessary for drinking, producing food and personal hygiene. It is also required for power generation, as a means of transport and production of many industrial products, all of which are essential for the functioning of any society. Water is also vital in ensuring the integrity and sustainability of the Earth's ecosystems (UN-WWAP, 2003, p. 5).

Zambia's urban population (39.5%) is among the highest urban populations in Sub-Saharan Africa. As a consequence, the rate of urbanization (51%) has exceeded the rate of infrastructure development leading to a lag in the provision of water supply services. Most of these water supply infrastructures were constructed in the 1960's and 1970's and have since been highly dilapidated due to inadequate maintenance (GRZ-NUWSSP, 2010, p. 17). Despite some measure of success which has been achieved in transforming the water sector in Zambia, a number of challenges still remain; access to adequate and safe drinking water in urban, Peri-urban and rural areas remain unsatisfactory (GRZ-WSPS, 2011, p. 5).

As populations continue to grow, there is a decline in the availability of quality water resources because the world's water resources are finite. The fundamental factor in the evolution of civilizations throughout history has been the development of water resources to man's benefit. The supply/demand imbalances are exacerbated by pollution, climate change and construction of cities in dry regions. Therefore, in recent times, innovative technologies have been developed to assist the efficient delivery and utilization of drinking water (Ganorkar, et al., 2013, p. 252)

In 1997, the Water Supply and Sanitation Act was passed in Zambia which led to the establishment of the commercial water utility companies (CUs) by the local authorities throughout Zambia. Due to the need to regulate and monitor the operations of these commercial utility companies (CUs), three regulatory agencies were set up in the water sector. These are: Water Resources Management Authority (WARMA – replaced the Water Board in 2011) which controls all water resources in Zambia and is responsible for the issuance of surface water permits except for international shared water bodies; the Zambia Environmental Management Agency (ZEMA – replaced the Environmental Council of Zambia in 2011) mandated to oversee water quality and pollution controls, standards and enforcement of environmental impact assessment procedures, and the National Water Supply and Sanitation

Council (NWASCO – established in 1997) responsible for regulating the provision of urban water supply and sanitation services throughout the country (GRZ-WSPS, 2011, p. 8).

Besides the public sector, some private sector organisations e.g. large scale farmers, mining and manufacturing companies, provide water supply and sanitation services to their employees and for their own operations (GRZ-WSPS, 2011, p. 8). There are approximately 6.12 million people living in the CUs' service areas with only 1% of it being serviced by private schemes. This implies that commercial utilities (CUs) are the main providers of water and sanitation services in urban areas in Zambia (NWASCO, 2015, p. 2).

In any water supply system, the billed water quantity will always be smaller than the supplied amount. Whether it is billed or not, the volume of water consumed is smaller than the supplied amount. The difference between the charged quantity and the supplied quantity is referred to as Unaccounted-for water (UFW). It can also be defined as the difference between the water delivered to the distribution system and the water sold, and has two basic components: physical losses i.e. water lost from pipes and overflows from tanks, and commercial losses i.e. water used but not paid for (UN-WWAP, 2003, p. 168).

In order to make the most out of water scarcity, the water sector needs to improve the way it uses its water resources so that it can deal with the challenges that lie ahead. In most municipalities, water production is not optimal due to the fact that the difference between the water put into the distribution system and the water billed to consumers (i.e., “non-revenue water”) is quite large. The high levels of Non-Revenue Water (NRW) (35% - globally) is as a result of water being lost through leaks and also a high volume of water not being invoiced to customers (Berg, 2014, p. 2)

An estimated 32 billion m³ of treated water is lost each year through leakage from distribution networks worldwide, with an additional 16 billion m³ of water delivered to customers but not invoiced because of theft, poor metering, or corruption. It is therefore estimated that the total annual cost of water loss to utility companies worldwide is \$14 billion dollars. This represents 50 – 60% of the water supplied in some low income countries with the global average estimated at 35%. An additional 100 million people worldwide would be supplied with water without further investment if just half of this amount was saved (Kingdom, et al., 2006).

The high levels of NRW levels in developing countries are widely acknowledged by many scholars though very little data is available in the literature regarding the actual figure. This is because most water utilities in the developing countries do not have adequate monitoring

systems for assessing water losses. The result is that NRW data is not reliable, because it is common for the management of poorly performing utilities to practice “window dressing” in an attempt to conceal the extent of their own inefficiency (Kingdom, et al., 2006, p. 1).

Leakage is the major component of unaccounted for water besides faulty water meters, illegal connections and poor education of consumers. Since the volume of water used for these purposes is marginally small compared to the total water supplied, the difference between unaccounted for water and non-revenue water is very small in many systems (Trifunovic, 2006, pp. 235 - 236).

Huge water losses are incurred in most urban water utilities in developing countries. Therefore, too many formats and definitions were followed by different utilities with regard to assessment of water losses. This led to the International Water Association (IWA) Task Force recommending for the discontinuity in using the term ‘Unaccounted for Water’ and be replaced with the term ‘Non-Revenue Water’ because of varied interpretations of the term (Jayaramu & Kumar, 2014; Alegre, et al., 2000). An international best practice concept known as the ‘water balance’ was then introduced as a first step in water losses management. IWA defines Non-Revenue Water (NRW) as the difference between system input volume and billed authorized consumption (Lambert & Hirner, 2000).

For a well-functioning CU, a corporate approach to water supply - but not necessarily private ownership - is essential for reliable, efficient, and equitable operations. Such an approach helps to ensure the financial sustainability of water systems and protect the long-term value of water resources. It also opens up doors to external expertise and finance from the private sector (Chiplunkar, et al., 2012, p. 3).

Due to the lack of consistent periodic maintenance of the water systems in Zambia, most of the networks are dilapidated due to old age, vandalism or the use of substandard materials. This in effect has resulted in the loss of treated water through leakages. Illegal connections, estimation of production and consumption where meters are not available and data handling errors are just some of the other factors that contribute to NRW. Nonetheless, losses through physical means make up the larger portion of NRW (NWASCO, 2015, p. 12). Table 1.5 indicates the operating conditions for all the commercial water utilities in Zambia:

Table 1.5: Operating conditions for all the commercial water utilities in Zambia

Commercial Utility	Abbreviation	Start of operations	No. of Connections	No. of towns Serviced	No. of Staff	External Support
Lusaka WSC	LWSC	1989	85832	7	758	MCC
Nkana WSC	NWSC	2000	51868	3	375	AfDB
Kafubu WSC	KWSC	2000	54906	3	638	JICA
Mulonga WSC	MWSC	2000	48641	3	396	–
Lukanga WSC	LGWSC	2006	20326	6	236	–
Southern WSC	SWSC	2000	38273	16	332	–
Chambeshi WSC	CHWSC	2003	15830	12	187	–
North Western WSC	NWWSC	2000	10509	8	117	–
Eastern WSC	EWSC	2009	14324	8	144	Germany
Western WSC	WWSC	2000	11260	7	124	DANIDA
Luapula WSC	LPWSC	2009	4762	7	58	DANIDA

Source: NWASCO Sector Report (2014)

In 2001, NWASCO established the Devolution Trust Fund (DTF) to operate as a basket fund for the improvement of Water Supply and Sanitation services in peri-urban areas. It became fully operational in 2003 and has up to date been providing both financial and technical support to the commercial utilities (NWASCO, 2014, p. 16).

Table 1.6 depicts the Zambia national urban water supply coverage which is a combination of coverage for the commercial utilities and the Private Schemes.

Table 1.6: National urban water supply coverage in Zambia

YEAR	2012	2013	2014
Total Urban Population	5,760,541	5,965,575	6,122,284
Total Urban Population served with water	4,812,279	5,006,510	5,131,657
National Urban Water Coverage	83.50%	83.90%	83.80%

Source: NWASCO Sector Report (2014)

NWASCO, being the regulatory body in the provision of water supply and sanitation services in urban areas in Zambia (NWASCO, 2016, p. 1), has set out some benchmarks to be followed

by the commercial utilities in the management of NRW. Hence Table 1.7 shows the benchmarks alluded to.

Table 1.7: NWASCO benchmarks for non-revenue water in Zambia

Benchmark for NRW	Good	< 20%
	Acceptable	20 – 25%
	Unacceptable	> 25%

Source: NWASCO Sector Report (2014)

1.4 Problem Statement

As Zambia strives to meet the Sustainable Development Goals - SDG on halving the number of people without access to clean water, the service providers are faced with so many challenges, the major one being the high water losses. When water is lost it does not contribute to the revenue generated and is therefore termed Non-revenue Water (NRW). Despite the efforts to address NRW, the sector average in Zambia has still remained high at 51%, thereby needing a lot of effort to reduce it to the sector benchmark of 25% (NWASCO, 2015, p. 12).

Despite the efforts that CUs have been making, the NRW sector average has remained high. This is partly because most of the CUs do not have the technical and in some cases, financial capacity to address this problem. This led to the formation of the Non-Revenue Water National Technical Task Force by the Government of the Republic of Zambia in 2014, to develop and steer a national strategy for management and reduction of NRW to acceptable economic levels. The management of NRW calls for the involvement of all stakeholders i.e. Government, CUs and the general public. For instance consumers can help combat NRW by reporting leakages, illegal connections and other unauthorised water uses (NWASCO, 2015, p. 14).

A common factor among all high-performing water utilities is a low Non-Revenue Water. Once water is wasted through losses in the system, it signifies lost revenue and a lost opportunity to serve the users better and at lower cost. Water saved from reducing NRW could be redistributed to areas not receiving sufficient water supplies, thereby improving water access and revenue. The solutions to achieve NRW reduction require a combination of technical interventions and involvement of the community (Chiplunkar, et al., 2012, p. 201).

The estimated treated water loss of 32 billion m³ globally with an additional 16 billion m³ of water delivered to customers not paid for represents about 50 – 60% of water being lost

worldwide. In Zambia's water sector, non-revenue water ranges from 30 – 58%, with an average of 45%, which is way above the sector benchmark of 25%. This clearly reveals the urgent requirement for interventions to reduce non-revenue water. But due to the huge capital investments required to completely replace the dilapidated water supply systems in Zambia, it is imperative to look at how well the existing water infrastructure is being managed and the interventions being implemented to reduce non-revenue water. But due to insufficient funds to do a complete over-haul of the entire water sector in Zambia, Lusaka town was chosen so as to understand the issues pertaining to the management of non-revenue in more detail. This is because prudent measures to ensure efficient management of non-revenue, in order to supplement the current levels of water supply, are in critical need.

1.5 Aim

The aim of this research work is to assess the adopted management practices in managing non-revenue water and to investigate the non-revenue water levels and subsequent revenue lost in the water service delivery in Lusaka and thereafter come up with some recommendations which would help improve the current strategy.

1.6 Objectives

The objectives of this research were as follows:

- a) To review the existing strategy which has been developed by the water utility company in managing non-revenue water
- b) To investigate the measures being undertaken to achieve the set targets in managing non-revenue water
- c) To investigate the amount of revenue being lost as a result of the current levels of non-revenue water
- d) Recommend solutions which would help improve the non-revenue water levels in Lusaka, for ultimate improvement in water service delivery in the city.

1.7 Research Questions

- a) What management strategy is the water utility company using to deal with non-revenue water in Lusaka, and how can it be improved?
- b) To what extent has the water utility been affected by the current non-revenue water levels?
- c) How much revenue is being lost as a result of the current non-revenue water management policies?
- d) How can the non-revenue water levels be improved on the basis of efficiency and improved water service delivery?

1.8 Scope of the Research

The scope of this research work focuses on the water service delivery in Lusaka in the line of management strategies and methods adopted for efficient water service delivery with emphasis on management of non-revenue water. But it should be noted that most of the statistical information about non-revenue water are not specific to the city of Lusaka because the commercial utility responsible for water supply is also mandated to supply water to other small towns in the entire Lusaka Province. Hence the findings are representative of the entire province.

In this regard therefore, the research assesses the current levels of non-revenue water, the adopted strategies and methods in the management of non-revenue water and the effectiveness or otherwise of these strategies and methods. Hence the focus would be mainly on assessing whether the management of the water system is fully encompassing the management of non-revenue water based on internationally accepted guidelines and the results thereof.

Due to the limited time and resources available for the current research work, the study was limited to the area of non-revenue water and the adopted strategies and methods which are being used to improve the situation. It is also in the view of the researcher that the numerous problems faced by the commercial water utility company in water supply can better be sorted if tackled separately thereby ensuring a comprehensive understanding of the different aspects involved.

1.9 Dissertation Structure

This dissertation report consists of six chapters as listed below:

Chapter One - Introduction and Background: It introduces the research problem, main aim, objectives and the scope of the research.

Chapter Two – Literature Review: A detailed review of literature focusing on the various aspects that impact the management of Non-Revenue Water in general and Lusaka in particular. It concludes by identifying key issues that require further exploration and verification in the study to address the research questions.

Chapter Three – Research Methodology: This chapter reviews some of the commonly used research methodologies and methods for data collection. This culminates into the adoption of the most appropriate research methodologies and methods after a detailed consideration of the methodological approaches.

Chapter Four – Data Collection: This chapter outlines the data collected using the chosen methodologies and data collection methods as explained in Chapter Three. This chapter further creates the platform for the analysis of the data in chapter five.

Chapter Five – Data Analysis and Discussion: This Chapter analyses all the data collected in Chapter Four by presenting it in form of graphs, charts and figures. A detailed discussion and comparison of the key findings is undertaken where interrelationships amongst the key findings are noted and explained in detail.

Chapter Six – Summary, Conclusion and Recommendations: In this chapter, conclusions and recommendations are drawn from the key findings of this research. The chapter ends with an identification of the proposed issues to consider in this research topic for future research.

1.10 Chapter Summary

This chapter outlined the area of study, defined the research problem requiring investigation and the aims and objectives to guide the research. In addition, it provided a scope so as to streamline the research to the research topic. The subsequent chapter provides further theoretical and conceptual framework for the research under study through the review of the available literature.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The previous chapter introduced the research topic, water situation in Lusaka, background, aim and objectives. Problems in providing satisfactory water supply to the ever expanding urban population in developing countries is a major concern from time to time. Water supply systems in urban areas are often unable to meet existing demands and are not available to everyone. Both financial and technical problems are said to be reasons for the situation, hence the Commercial Utilities' (CU's) failure to develop and expand their water supply systems. The bottleneck to delivery, among other issues, is the failure to manage and reduce water losses. Therefore, in order to get a better understanding of the issue of Non-Revenue Water (NRW) in Lusaka, it is necessary to review available literature on the topic.

2.2 The Dublin Principle

Following a meeting of experts on water related problems in Dublin in 1992, four water management principles were developed which have been the basis for much of the subsequent water sector reforms (Simbeye, 2010, p. 19; WMO, 1992). The four principles referred to by the World Meteorological Organization (1992) are as stated below;

- Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment. Since water sustains life, effective management of water resources demands a holistic approach, linking social and economic development with the protection of natural ecosystems. Effective management links land and water uses across all the catchment areas or groundwater aquifers.
- Water development and management should be based on a participatory approach involving users, planners and policymakers at all levels. The participatory approach involves raising awareness of the importance of water among policy-makers and the general public. It means that decisions are taken at the lowest appropriate level, with full public consultation and involvement of users in the planning and implementation of water projects.
- Women play a central part in the provision, management and safeguarding of water. This pivotal role of women as providers and users of water and guardians of the living

environment has seldom been reflected in institutional arrangements for the development and management of water resources. Acceptance and implementation of this principle requires positive policies to address women's specific needs and to equip and empower women to participate at all levels in water resources programmes, including decision-making and implementation, in ways defined by them.

- Water has an economic value in all its competing uses and should be recognised as an economic good. Within this principle, it is vital to recognise first the basic right of all human beings to have access to clean water and sanitation at an affordable price. Past failure to recognise the economic value of water has led to wasteful and environmentally damaging uses of the resource. Managing water as an economic good is an important way of achieving efficient and equitable use, and of encouraging conservation and protection of water resources.

2.3 Definition of Non-Revenue Water

In recent terminology, Non-revenue water (NRW) is the difference between the supplied and the billed quantity. The part of NRW that remains after deducting unbilled but authorised consumption is Unaccounted-for Water (UFW) (Trifunovic, 2006, p. 235).

In the past, the terms Unaccounted for Water and Non-Revenue Water have widely been used interchangeably. However, their use in this manner has been very confusing. Therefore, the International Water Association (IWA) recommends the use of Non-Revenue Water in all instances (McIntosh, 2003, p. 59).

Lambert & Hirner (2000) define Non-Revenue Water as “the difference between the System Input Volume and Billed Authorised Consumption”. On the other hand, both Berg (2014) and Kingdom, et al. (2006) indicate that “Non-revenue water is the difference between the volume of water put into a water distribution system and the volume that is billed to customers”. Furthermore, it is stated that Non-Revenue Water are those components of System Input volume which are not billed and do not produce any revenue (Thanh, 2006).

The United States Agency for International Development (USAID) state that NRW is equal to the total amount of water flowing into the water supply network from a water treatment plant, a borehole or imported bulk water minus the total amount of water that consumers are authorised to use and are billed for (USAID, 2010, p. 10).

Farley (2008) also defines NRW as being the “total amount of water flowing into the water supply network from a water treatment plant (the ‘System Input Volume’) minus the total amount of water that industrial and domestic consumers are authorised to use (the ‘Authorised Consumption’)”.

Therefore, the most appropriate definition of NRW adopted in this research was that “**NRW is the difference between the System Input Volume and Billed Authorised Consumption**” (Lambert & Hirner, 2000).

2.4 Components of Non-Revenue Water

2.4.1 Water Balance

In most cases, the Water Balance is based on measurements or estimations of water produced, imported, exported, used and lost in the water network. The most effective way of managing water losses involves both continuous water balance calculations as well as night flow measurements on a continuous or ‘as required’ basis (Thanh, 2006, p. 2).

Most water utilities are able to provide estimates of water produced, imported, exported and consumed, but they have a lot of difficulties in quantifying the different components of the water lost. Regardless of these difficulties, each and every water utility company has a way in which they determine the quantities of the water balance components. Therefore, in order to sort out the problem of different water balance formats and methods, the IWA developed a standard international water balance structure and terminology, generated based on the best practice of water utilities from many countries as shown in Table 2.1 (Thanh, 2006, p. 2).

Table 2.1: The IWA Standard Water Balance

System Input Volume	Authorised Consumption	Billed Authorised Consumption	Billed Metered Consumption	Revenue Water
			Billed Unmetered Consumption	
		Unbilled Authorised Consumption	Unbilled Metered Consumption	Non- Revenue Water
			Unbilled Unmetered Consumption	
	Water Losses	Commercial or Apparent Losses	Unauthorised Consumption	
			Metering Inaccuracies	
		Real or Physical Losses	Leakage on Transmission and/or Distribution Mains	
			Leakage and Overflows at Utility's Storage Tanks	
			Leakage on Service Connections up to point of Customer Metering	

Source: McIntosh (2003)

The following are the proposed definitions of the principal components of the Water Balance as defined by the International Water Association (McIntosh, 2003):

- **System Input Volume** is the annual volume put into the part of a water supply system that relates to water balance calculation.
- **Authorized Consumption** is the annual volume of metered and/or unmetered water taken by registered customers, water suppliers, and others who are implicitly or explicitly authorized to do so for residential, commercial, and industrial purposes. It includes water that is exported.
- **Water Losses** can be identified by calculating the difference between system input volume and authorized consumption. They consist of apparent losses and real losses.
- **Apparent Losses** result from unauthorized consumption and all types of inaccuracies associated with metering.

- **Real Losses** result from losses at mains, service reservoirs, and service connections (up to the point of customer metering). The annual volume lost through all types of leaks, bursts, and overflows depends on their individual frequencies, flow rates, and duration.
- **Non-Revenue Water** is the difference between system input volume and billed authorized consumption, and it consists of the following:
 - ✓ Unbilled Authorized Consumption (usually a minor component of water balance),
 - ✓ Apparent Losses, and
 - ✓ Real Losses.

Thanh (2006) further defines the rest of the components of the Standard Water balance as follows:

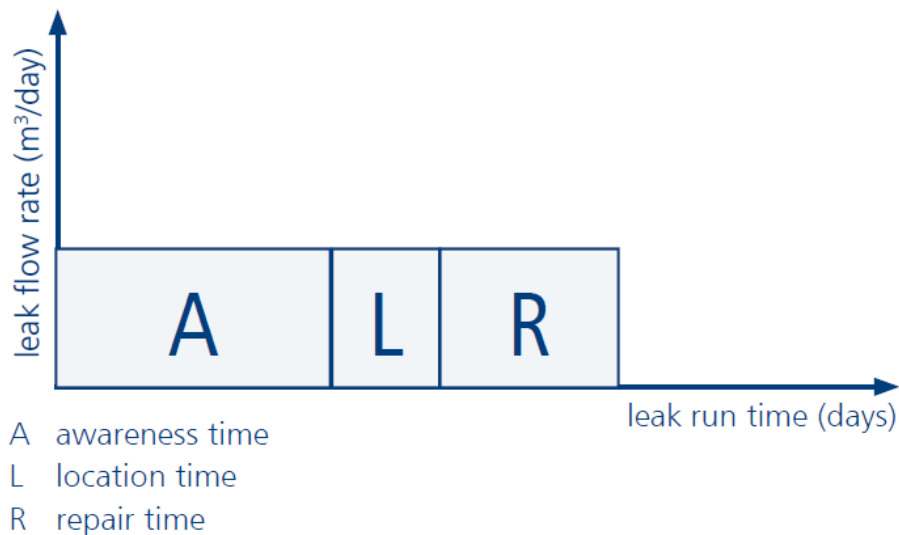
- **Billed Authorized Consumption:** Those components of Authorized Consumption which are billed and produce revenue (Billed Metered Consumption plus Billed Unmetered Consumption).
- **Unbilled Authorized Consumption:** Those components of Authorized Consumption which are legitimate but not billed (Equal to Unbilled Metered Consumption plus Unbilled Unmetered Consumption).
- **Billed Metered Consumption:** All metered consumption which is also billed. This includes domestic, commercial, industrial or institutional and also water exported as long as it is metered and billed.
- **Billed Unmetered Consumption:** All billed consumption which is calculated based on estimates or norms but is not metered.
- **Unbilled Metered Consumption:** Metered Consumption which for any reason or the other is unbilled e.g. metered consumption by the utility itself or water provided to institutions free of charge.
- **Unbilled Unmetered Consumption:** Any kind of Authorized Consumption which is neither billed nor metered e.g. firefighting.
- **Unauthorized Consumption:** Any unauthorized use of water e.g. illegal water withdrawal from hydrants, illegal connections etc.

- **Customer Metering Inaccuracies and Data Handling Errors:** Apparent water losses caused by customer meter inaccuracies and data handling errors in the meter reading and billing system.
- **Leakage on Transmission and/or Distribution Mains:** Water lost from leaks and bursts on transmission and distribution pipelines.
- **Leakage and Overflows at Utility’s Storage Tanks:** Water lost from leaking storage tank structures or overflows of such tanks.
- **Leakage on Service Connections up to point of Customer Metering:** Water lost from leaks on service connections from (and including) the tapping point until the point of customer use.
- **Revenue Water:** Those components of Authorized Consumption which are billed and produce revenue (Equal to Billed Metered Consumption plus Billed Unmetered Consumption).

2.4.2 Physical (Real) Losses

Physical Losses, sometimes referred to as “real losses”, are the annual volumes lost from transmission and distribution systems through all types of leaks, bursts and overflows on mains, service reservoirs and service connections, up to the point of customer metering (USAID, 2010, p. 11) . The annual volume lost through all types of leaks, bursts, and overflows depends on their individual frequencies, flow rates, and duration (McIntosh, 2003), and the largest volume of real losses occurs on service connections rather than mains, though networks characterised by a low density connections are an exception (Hamilton, et al., 2006; Alkaseh , et al., 2013).

Though people think of leaks to be large and visible pipe bursts which show on the surface, the volume of water lost through these leakages are insignificant compared to all the other leaks that do not show on the surface. About 90% of the water that is physically lost from leaks cannot be seen on the surface. These leaks may only be visible after so many years after large volumes of water have been lost annually. For instance, the underground undetected leaks which run directly into a sewer line may stay undetected for so many years leading to large volumes of water being lost (Frauendorfer & Liemberger, 2010, p. 17). The magnitude of the impact of the leak run time on physical losses is illustrated in figure 2.1.



$$(A + L + R) [d] \times \text{flow rate} [m^3/d] = \text{water lost} [m^3]$$

Figure 2.1: The impact of leak run time on physical losses (Source: Frauendorfer & Liemberger, 2010)

For any water utility company aiming to reduce water losses, it should as a first step carry out a water audit to establish the current levels of water losses which is a prerequisite for designing any NRW reduction strategy (Frauendorfer & Liemberger, 2010, p. 15).

The entire physical loss management phenomena is best visualized with the help of the ‘Four Arrows Chart’ as shown in figure 2.2 (Frauendorfer & Liemberger, 2010).

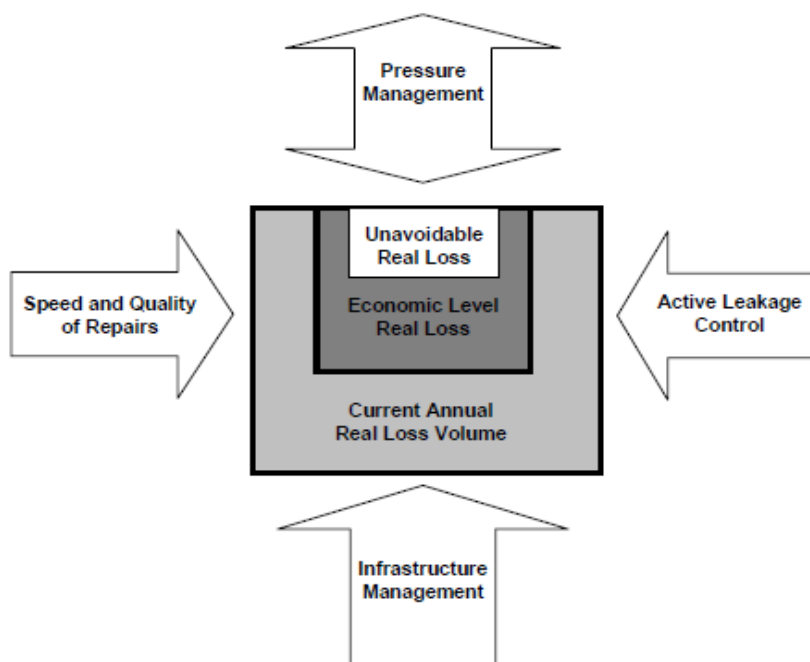


Figure 2.2: The “Four Arrows Chart” for managing physical losses (Source: Charalambous et al, 2014)

It shows the relationship between the Current Annual Real losses (CARL), represented by the larger rectangle, and the Unavoidable Annual Real Losses (UARL) or the minimum achievable volume of physical losses, represented by the smaller rectangle (Farley & Trow, 2003, p. 42).

Each single component of the 'Four Arrows Chart' (figure 2.2) for controlling physical losses influences leakage in a specific way. Pressure management influences the frequency of new leaks and the flow rates of bursts and leaks while Active leakage control determines how long it will take for unreported leaks to run before being detected. The average duration of leaks is influenced by the speed and quality of repairs. On the other hand, asset management influences the number of new leaks that will develop each year (Farley & Trow, 2003, p. 42).

The current annual volume of physical losses is represented by the big box while the smallest box in figure 2.2 represents the minimum achievable annual volume (Frauendorfer & Liemberger, 2010, p. 18). Frauendorfer & Liemberger (2010) further state that the current level of physical losses can only be successfully reduced if all four elements shown in figure 2.2 are implemented as follows:

- Active leakage control must be introduced in order to detect all present and future leaks;
- Known leaks must be repaired as soon as possible to keep leak run times low, and good quality of the repairs will make the efforts sustainable (in poorly run water utilities, even visible leaks are often not repaired);
- In the long run, pipes must be rehabilitated or replaced using good quality materials and installation (asset management); and
- Pressure management must be exercised.

Despite many countries recognizing pressure control as the main component in leakage management, there is need to adhere to the local limits of the lowest acceptable average pressures that can be achieved. Operating pressures are the main determinants of the average frequency with which new leaks occur as well as the rates of flow of individual leaks (Winarni, 2009).

Frauendorfer & Liemberger (2010) assert that leakages are directly related to pressure and that Pressure management is the only component of the 'Four Arrows Chart' which can shrink or expand the small box representing the minimum achievable volume of physical losses. They further state that pressure management requires zoning by elevation, because the higher the pressure the higher the volume of water lost from any leak.

Due to the complexity of the relationship between pressure and leakage, a roughly linear relationship is assumed between the two. This implies, for instance, that when the pressure increases by 5%, the volume of the leakage will also increase by 5% (Frauendorfer & Liemberger, 2010, p. 19)

2.4.3 Commercial (Apparent) Losses

Commercial losses represent the amount of water which pass through the meters and used by the consumers but is not paid for or not accurately recorded. It is sometimes referred to as ‘Apparent Losses’ because the lost water is invisible. Its invisibility leads many water utilities to overlook it and rather concentrate on physical losses though in essence commercial losses can amount to a higher volume of water than physical losses (Farley, et al., 2008, p. 43).

Reducing commercial losses usually has a greater value than for physical losses, since reducing commercial losses increases revenue, whereas physical losses reduce production costs. This implies that even a small volume of commercial loss may have larger financial impact compared to the equivalent amount of physical loss (USAID, 2010, p. 35).

In addition, reducing commercial losses has proved to be cost-effective and offers fast payback. Most of the activities involved are technically easy to carry out, but politically difficult, owing to the fact that a strong stance against fraudulent practices of utility staff, and the other portion of the population, benefiting from the status quo is required (Kingdom, et al., 2006, p. 40).

It is advisable not to express commercial losses as a percentage of the total system input volume because this could be very misleading in systems with high leakage and it is very difficult to convert the percentage into the actual volume of water lost (Kingdom, et al., 2006, p. 35).

Farley et al (2008) state that commercial losses can be broken down into four fundamental components as shown in figure 2.3, which are as follows:

- Customer meter inaccuracy (meter under-registration);
- Unauthorised consumption (water theft);
- Meter reading errors; and
- Data handling and accounting errors.

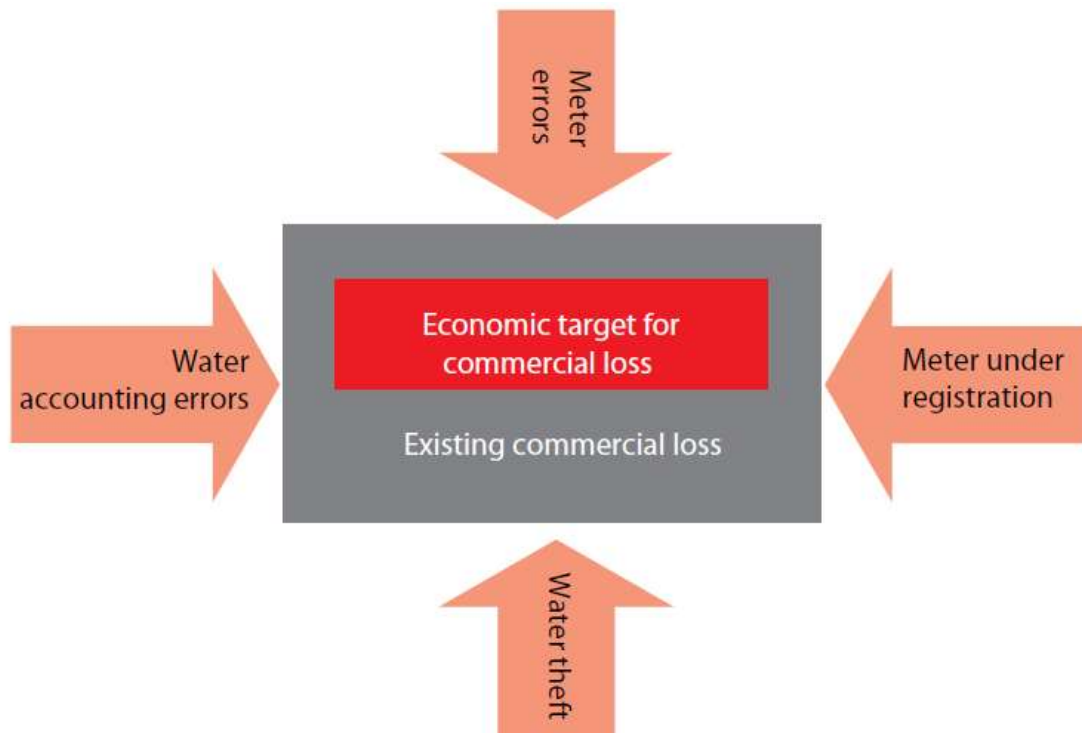


Figure 2.3: Different components of Apparent Losses (Source: Farley et al, 2008)

2.4.4 Management of Commercial Losses

a) Measures to Control Apparent (Commercial) Losses

Apparent losses are both dynamic and multidimensional in nature. This can for instance be shown by the ability of a single apparent loss strategy to have a double or even triple effect on the results obtained, for example “improving upon meter readings by adding discipline to a meter reader may reduce meter reading errors but may also reduce water theft”. Therefore, to resolve all these dynamics and complexities involved, there’s need to implement an integrated loss strategy by the utility. Figure 2.4 shows one such example of the strategy and the different aspects it may involve in its implementation (Rizzo, et al., 2007, p. 3).

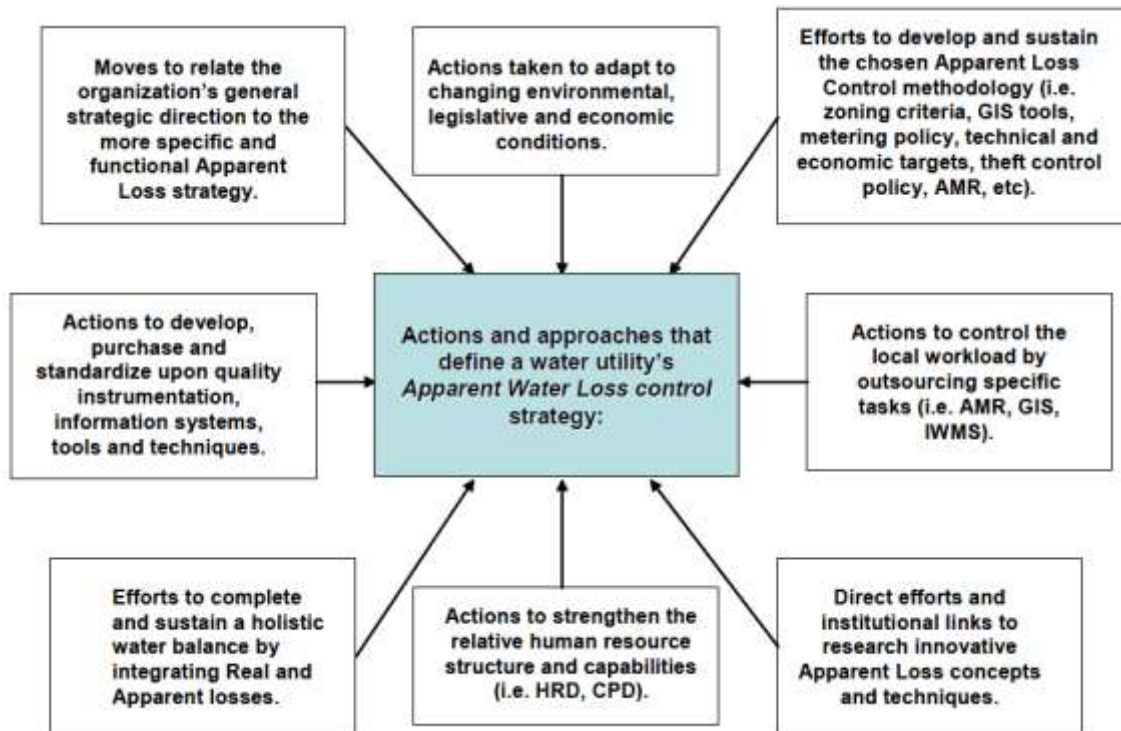


Figure 2.4: Implementation of the apparent water loss control strategy (Source: Rizzo, 2006)

b) Customer Meter Inaccuracy

Customer meter inaccuracies, i.e. under- or over registration, are usually determined based on tests of a representative sample of meters whose composition reflect the various brands and age groups of domestic meters. The tests are either done by the utility's own trained personnel or by specialised contractors. These tests result in the determination of average meter inaccuracy values (as % of metered consumption) for different user groups (Thanh, 2006, p. 10).

In most cases, inaccurate meters tend to under-register water consumption which leads to reduced sales and eventually reduced revenue. It is in very rare occasions that meters over-register consumption (Farley, et al., 2008, p. 34).

Below are some common problems with customer meter inaccuracies for utilities, as outlined by Farley et al (2008) in 'The Manager's Non-Revenue Water Handbook' pages 34 – 38:

- **Installing meters properly:** Installation of meters should be according to the manufacturer's specifications, and meters should be installed in a place where it can

easily be accessed by meter readers. The management and staff responsible for meter installations should be adequately trained on proper handling of meters;

- **Monitoring water quality:** Poor water quality due to poor raw water, inadequate treatment processes, or dirt infiltration may cause sediments to form in the pipes which after their build up on the internal parts of meters, especially mechanical meters, may affect the meter's accuracy by increasing friction losses, which causes the meter to under-register consumption;
- **Monitoring intermittent water supply:** Where there is no continuous supply of water to the customers, customer meters will register a certain volume of air when the water supply is restored. In addition, the sudden large increase in pressure can damage the internal components of the meter. Therefore, intermittent water supply should be avoided in order to reduce its negative impacts on customer meter accuracy;
- **Sizing meters properly:** Customer meters work within a defined flow range, when the flow rate is lower than the specified minimum, large meters will not register it. For instance, installing a storage tank controlled by a float valve has the effect of reducing the flow through the meter because the ball or float valve will never fully open making the flow through the meter to be continually low;
- **Using the appropriate class and type of meter:** The accuracy of customer consumption data is made possible by choosing the appropriate class and type of meter;
- **Maintaining and replacing meters properly:** Meters should be installed above ground where they can easily be audited and accessed by meter readers. Old meters should be replaced and others serviced especially in areas of poor water quality; and
- **Addressing meter tampering:** Customer surveys on properties with older meters that are not as tamper-resistant as the new ones should be conducted regularly to assess the expected water usage according to the number of household occupants or nature of businesses. This is because customers may insert pins or other objects into the meter to disturb its moving parts.

c) **Unauthorised Consumption (Water Theft)**

This component of commercial losses is mainly comprised of illegal connections, meter bypassing, illegal use of hydrants, and poor billing and revenue collection systems (Farley, et al., 2008, p. 38). Outlined below are some of the common types of unauthorised consumption:

- **Illegal connections:** It involves the physical installation of a connection to the water distribution network without the knowledge and approval of the water utility (USAID, 2010, p. 41). Therefore, contrary to common belief, a large portion of water stolen from public utilities come from large industrial customers and those with much political influence and not from poor urban or peri-urban areas (Kingdom, et al., 2006, p. 40). Illegal connections usually occur during the installation of a new supply connection or during reconnection (Farley, et al., 2008, p. 38);
- **Meter bypassing:** Customers may use an additional pipe installed illegally around a meter to try and reduce their water bills. Due to the complexity of this type of unauthorised consumption, it is usually committed by industrial and commercial premises (Farley, et al., 2008, p. 39);
- **Fire hydrants:** The legal use of fire hydrants is for firefighting, but some of them have been spotted illegally filling tankers (normally at night) and sometimes providing water for construction at construction sites (Farley, et al., 2008, p. 39);
- **Corrupt meter readers:** This component of unauthorised consumption is often times over-looked but the reality is that it can significantly impact a utility's monthly billed consumption. For instance, the same meter reader working in an area for a long time may collude with those customers to record lower meter readings in exchange for a monetary incentive (Farley, et al., 2008, p. 40).

d) Meter Reading Errors

Negligence, aging meters as well as corruption during the process of reading the meters and billing customers may be the major sources of errors. Seemingly small things like placing a decimal in the wrong place may have a major impact on the meter readings. Meter readers are the utility's main contact with the customers, hence their activities have an immediate impact on cash flow. Therefore, managers should establish systems and procedures to prevent meter reading errors through greater supervision of meter readers, implementation of rotating reading routes, and frequent spot checks (USAID, 2010, pp. 42-43).

On the other hand, in order to calculate NRW correctly, all types of meters in the system should be read within the same period so that the resulting calculations compare 'like for like', hence meter reading cycle synchronization is highly recommended (LWSC, 2014, p. 7). The recommended meter reading cycle synchronization is shown in figure 2.5.

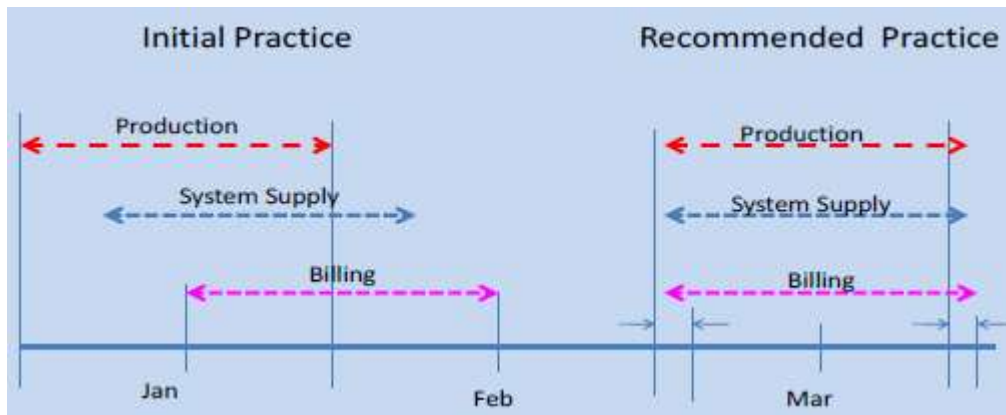


Figure 2.5: Typical meter reading cycle synchronization (Source: LWSC – NRW strategy, 2014)

e) **Data Handling and Accounting Errors**

Data handling errors may at times be a very substantial component of apparent losses. Many utility companies lack a reliable billing system, and the inadequacy of these billing systems lead to problems which often remain unrecognized for so many years. Hence the easiest way of detecting data handling errors is by exporting the billing data and analysing it using standard database software (Thanh, 2006, p. 11)

The typical method of data handling and billing involves the meter reader visiting each property to read the meter with the data recorded on a form which is then taken back to the office and typed into the billing system. After which a bill is printed and mailed or delivered to the customer. In this method numerous errors may occur at different stages: the meter reader writes down incorrect data; the billing department transfers incorrect data into the billing system; or the bill is sent to the wrong address. Therefore, improved capacity building of the meter readers and other billing department staff members may decrease meter reading errors (Farley, et al., 2008, p. 41).

2.4.5 Unbilled Authorised Consumption (UAC)

Unbilled Authorised Consumption is a component of Non-Revenue Water representing the amount of water that is supplied to the intended customers but in one way or the other not billed. UAC may be classified into two categories, i.e. servicing water and free water supply. Servicing water includes tank cleaning, pipe cleaning (or flushing), water discharge to preserve water quality, hydrant flow and pressure tests, specific water treatment, and others. While free

water supply include diverse cases depending on the utility's legal obligation and other local constraints, for instance, water Utilities are not allowed to bill water for some type of use by law (e.g. firefighting) (Vermersch, et al., 2016).

Therefore in order to establish the water balance and calculate the levels of water losses in a given locality, UAC should be correctly measured. Underestimating it would lead to overestimated values of real or apparent losses, thereby leading to a wrong plan of action. UAC can easily be determined with the help of water meters to identify Unbilled Metered Consumption. If this is not possible, Unbilled Unmetered Consumption should be determined (Vermersch, et al., 2016).

2.5 Developing a Strategy for Water Loss Management

In most cases, real losses and apparent losses contribute more to NRW than does the unbilled authorised consumption. Therefore, appropriate strategies should be developed to control water losses especially through real and apparent losses, with the starting point being the understanding of the network system of the utility (Butler & Memon, 2006, p. 143). Hence, “Decision makers at all levels in water utilities must understand that for any water loss control strategy to be effective must be a continuous activity based on a long term strategy and should form an integral part of the utility's vision” (Charalambous, et al., 2014).

In order to progress with the strategy, there's a need to get a better and detailed understanding of the reasons for the persistent water loss and the factors that influence its components (Kingdom, et al., 2006; Farley & Liemberger, 2004). Generally, besides the adoption of appropriate strategies and techniques, the success of any strategy is dependent on the commitment and dedication of the utility management team at all levels. Therefore, the benefits of a water loss control strategy could be summarised as follows (Charalambous, et al., 2014):

- Saving a precious and valuable resource;
- Increasing the efficiency of existing systems;
- Delaying huge infrastructure investments;
- Increasing the life expectancy of the systems;
- Increasing the revenues for the water utility;
- Reducing energy requirements; and
- Improving the Carbon Footprint of the utility.

It is suggested that certain questions be posed about the water utility with regard to the characteristics, the production process, and the existing operating practices. In answering these questions using the current situation in the utility will usually form the first step in the right direction to deal with the prevailing water losses (Butler & Memon, 2006, p. 143).

Butler and Memon (2006, p.143) as well as Farley and Trow (2007) state that in the process of trying to answer the suggested questions, a better understanding of the water network system would be obtained, which will in turn form the basis for formulating the water loss strategies. Hence, suggestions on the following questions as a diagnostic approach for developing a water loss reduction strategy were made:

- How much water is being lost?
- Where is it being lost from?
- Why is it being lost?
- What strategies can be introduced to reduce losses and improve performance?
- How can the strategy be maintained and the achievements sustained?

Table 2.2 shows a summary of the tasks required to address the above questions.

Table 2.2: Tasks and tools for developing strategies for the management of non-revenue water

QUESTION/SOLUTION	TASK
<p><i>How much water is being lost?</i></p> <ul style="list-style-type: none"> - Measure components 	<p>Water Balance</p> <ul style="list-style-type: none"> - Improve estimation/measurement techniques - Meter calibration policy - Meter checks - Identify improvements to recording procedures.
<p><i>Where is it being lost from?</i></p> <ul style="list-style-type: none"> - Quantify leakage - Quantify apparent losses 	<p>Network Audit</p> <ul style="list-style-type: none"> - Leakage studies (reservoirs, transmission mains, distribution network) - Operational/customer investigations

Table 2.2 (Cont'd)

QUESTION/SOLUTION	TASK
<p><i>Why is it being lost?</i></p> <ul style="list-style-type: none"> - conduct network and operational audit 	<p>Review Network Practices</p> <p>Investigate:</p> <ul style="list-style-type: none"> - historical reasons - poor practice - quality measurement - procedure - poor materials/infrastructure - local/political influences - cultural/social/financial
<p><i>How to improve performance?</i></p> <ul style="list-style-type: none"> - Upgrade the network - Design a strategy and action plans 	<p>Strategy Development</p> <ul style="list-style-type: none"> - Update record systems - Introduce zoning - Introduce leakage monitoring - Address causes of apparent losses - Initiate leak detection/repair policy - Design short/medium/long term action plans
<p><i>How to sustain performance?</i></p> <ul style="list-style-type: none"> - Ensure sustainability with appropriate staffing and operational structures. 	<p>Training And O&M</p> <ul style="list-style-type: none"> - improve awareness - increase motivation - transfer skills - introduce best practice/technology - community involvement - water conservation/demand management programmes - monitor action plan recommendations - introduce O&M procedures

Source: Butler & Memon (2003)

By conducting a water balance i.e. the difference between system input volume and authorised consumption, the questions, “how much is lost” and “where it’s lost from”, can be answered. The third question, “why it’s being lost” can be answered by reviewing the management practices of the water system. After addressing the “how”, “where” and “why” of the losses in the system, it then becomes easier to address the last two questions which deal with issues of

strategies, policies and methodologies to be formulated and adopted in order to address the system's losses and improve its performance (Butler & Memon, 2006, p. 146).

Not only do the strategies, methodologies and policies referred to above involve the introduction of equipment for measuring and monitoring flows and leakage control as well as leak repair policies, but also education programmes with a fully operational O&M policy (Butler & Memon, 2006, p. 146).

The water balance and network audit enable priority areas to be identified and tackled easily. This would enable the utility to identify the priority which would be tackled accordingly, depending on the urgency attached to it (Thornton, 2002, p. 172).

2.5.1 Activities Involved in Developing a Water Loss Management Strategy

The effectiveness of any water loss management strategy is rooted in the understanding of the characteristics and significance of the water loss components. It is worth noting that water loss varies from country to country and place to place even within a single water network. The water loss management policies in place and the available technology for dealing with leakages will greatly affect the volume of water loss. Therefore it is imperative that the actual causes of leakages in the system are identified (Butler & Memon, 2006, p. 147).

Therefore, Farley and Trow (2003) state that the strategies that would give a better estimate of the actual losses to be assessed include the following:

- Distribution Input (DI) verification – leakage in District Metering Areas (DMAs) and losses in the supply zone;
- Per capita consumption (PCC) studies;
- Property counts;
- Non-household water use; and
- Operational use.

Before spending any funds towards leakage management, some procedures have been established to ensure that all relevant data for leakage management is collected and analysed (Butler & Memon, 2006, p. 157). The data should be accurate, well organised and accountable (Thornton, 2002, p. 59).

But according to Thornton (2002), even in a situation where the available data is not good and accurate enough, the water utility must take a decision to do something by either using the same questionable data or make estimations and work towards improving the data for future use.

Hence Farley and Trow (2003), state that the data collected would fall under; operational, tactical or strategic data as shown in Table 2.3:

Table 2.3: Classification of data used in leakage management

OPERATIONAL DATA	<ul style="list-style-type: none"> • Current leakage levels • Current pressure data • Outlet settings of pressure relief valves (PRVs) • Records of the number and type of leaks found • Records of hours spent on the ALC • Industrial water use
TACTICAL DATA	<ul style="list-style-type: none"> • Zone boundaries • Types of PRVs • Maintenance Records • PRV performance records • Asset data
STRATEGIC DATA	<ul style="list-style-type: none"> • Distribution input average • Water balance calculations • Results of studies and pilot exercises • Lessons learnt database • Numbers of ALC staff employed

Source: Farley & Trow (2003, p. 66)

2.5.2 Implementing the Strategy

Implementing or introducing the leakage reduction programme is just as important as the formulation and strategizing of the techniques for the programme. There should be an integrated approach in implementing the strategy if it is to yield the expected results. This is achieved where all the departments of the water utility are brought on board and made to participate in one way or the other (Farley & Trow, 2003, p. 79).

Farley and Trow (2003) further state that as an integral part of the leakage management strategy, the implementation or introduction of the strategy should be done with the consideration of the following:

- A launch event such as a major seminar, to serve as a platform to announce and explain to the staff who would be engaged in the programme, what is involved, what is expected of them and how the whole programme is going to impact on their jobs;
- Education and training of all staff. This should involve the entire staff of the organisation;
- A “reward and punishment” approach to staff management. The staff responsible for the management of the leakage reduction infrastructure should be rewarded and disciplinary action taken against those found to wilfully not keeping the infrastructures as expected; and
- Public relations. In as much as it is good for the organisation to maintain an image in the eyes of the public, it is also important to involve the public in the leakage management programme.

2.6 District Metered Areas (DMAs)

District Metered Area is simply the creation of areas in the water network whose quantity of water supplied and consumed can be measured easily. A good number of commercial water utility companies where this technique has been implemented successfully demonstrates the sustainability of the district metered area technique in managing non-revenue water (Morrison, et al., 2007).

It is a very common practice in water supply services to operate the pipe networks as an open system where water is fed into the system from several isolated water treatment plants or at times from underground water supply. In this arrangement, calculation of non-revenue water can only be done for the entire network, which poses a big challenge in determining the exact locations of leakages and locations where non-revenue water reduction activities should take place especially for large networks. Therefore, non-revenue water reduction activities are carried out only after the loss becomes visible or is reported (Farley, et al., 2008, p. 55).

The district metered area is a very useful technique when implemented in conjunction with other measures in reducing or monitoring leakage levels in the distribution network. “The use of DMAs has proved suitable for leakage control with many differing network configurations, irrespective of whether the customers are unmetered or metered and on both continuous and intermittent supply systems” (Morrison, et al., 2007).

In order to achieve ‘active non-revenue water management’, it is imperative to use zones, “where the system as a whole is divided into a series of smaller sub-systems for which non-revenue can be calculated individually”. These zones are referred to as District Metered Areas (DMAs), and should ideally be hydraulically. Dividing the water system into smaller, more manageable areas, makes it easier to plan for non-revenue water reduction activities as well as management of the system pressure. In general, district metered areas enables utility managers to manage the system more effectively in terms of pressure control, water quality, and non-revenue water (Farley, et al., 2008, p. 55). Figure 2.6 shows a typical water distribution network which clearly indicates the district metered area.

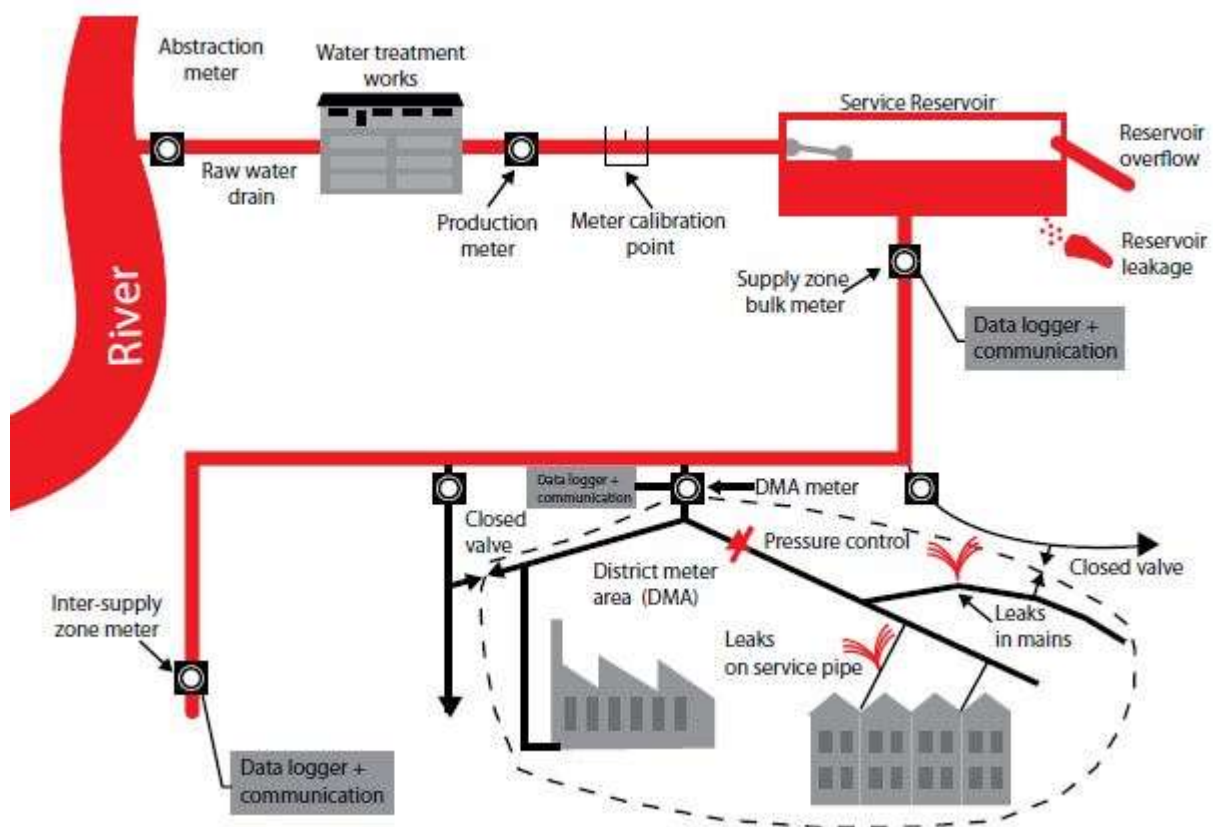


Figure 2.6: Typical water distribution network showing a district metered area (Source: Farley et al, 2008)

2.6.1 DMA Establishment Criteria

The most important aspect to consider in the design of DMAs is the DMA size (Hunaidi & Brothers, 2007). Other aspects to consider when designing a DMA include; pressure, topography, and a good understanding of how the network is operated, with practical

considerations (Morrison, et al., 2007). Hence, in order to ensure that all the designs conform to specific standards, there's a set of criteria used to create a preliminary DMA design that should be tested in the field or at times made into a network model (Farley, et al., 2008, p. 56).

Usually, the size of DMA ranges from 500 to 3000 service connections. But in most cases, the actual DMA size is dependent on the ease of isolation of the area. The size of the DMA should also be governed by economics but this has not been considered in the past (Hunaidi & Brothers, 2007, p. 57).

The design criteria as stated by Farley et al (2008), is as follows:

- Size of DMA (generally between 1,000 and 2,500 connections);
- Number of valves that must be closed to isolate the DMA;
- Number of flow meters to measure inflows and outflows (the fewer meters required, the lower the establishment costs);
- Ground-level variations and thus pressures within the DMA (the flatter the area the more stable the pressures and the easier to establish pressure controls); and
- Easily visible topographic features that can serve as boundaries for the DMA, such as rivers, drainage channels, railroads, highways, etc.

Isolation valves are mainly used to divide a large open system into a series of DMAs where flow meters are installed to measure the inflows and outflows into and out of the DMA. In undertaking these activities, the system pressures are affected, therefore it's the duty of the water utility company to ensure that customers are not receiving water at compromised system pressures. Isolation tests are conducted to check if the DMA is both pressure-tight and water-tight. The isolation test is performed as follows (Farley, et al., 2008, p. 56):

- Close all metered inlets into the DMA; and
- Check if the water pressure in the DMA drops to zero, since no water should now be able to enter the area.

Hence the conclusion by Farley et al (2008) that, "If the pressure does not drop to zero, then it is likely that another pipe is allowing water into the area and therefore needs to be addressed".

A typical layout of a district metered area is as shown in figure 2.7:

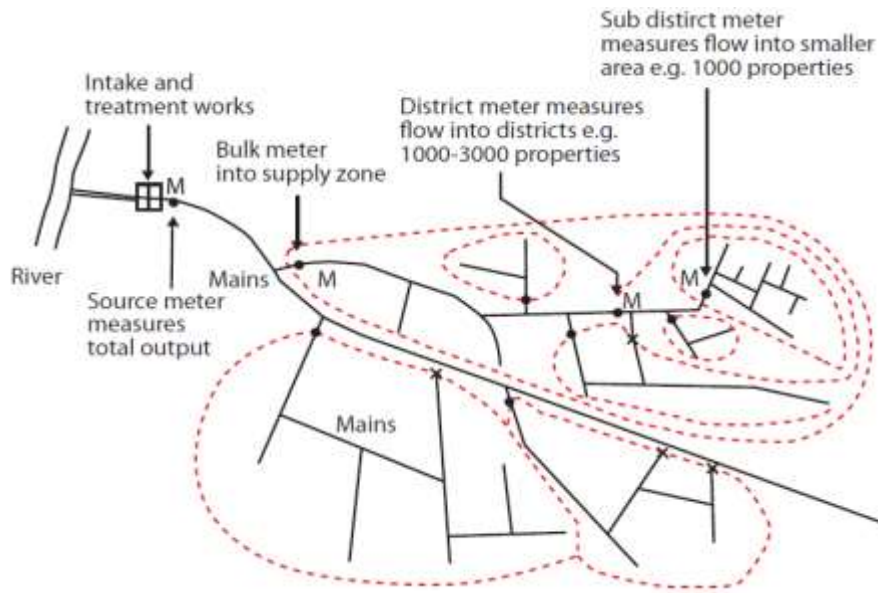


Figure 2.7: A typical layout of a District Metered Area (Source: Farley et al, 2008)

2.6.2 Using a District Metered Area to reduce Non-Revenue Water

With the help of the inlet flow meters, the overall inflow can be measured which will in turn give the total volume of water received for the given period of time. But the total DMA consumption will mainly depend on the customer metering ratio. If the DMA is fully metered, the total DMA consumption is simply the summation of all customer meter measurements for the period under consideration. If not fully metered, the consumption is estimated using per capita consumption figures (Farley, et al., 2008, pp. 58-59). The calculation of NRW within a DMA is given by Equation 1:

$\text{DMA NRW} = \text{Total DMA Inflow} - \text{Total DMA Consumption}$Equation 1
---	-----------------

The level of leakage in a DMA is estimated by calculating the system’s Net Night Flow (NNF) i.e. subtracting the Legitimate Night Flow (LNF) from the Minimum Night Flow (MNF) as shown in equation 2. Since “Leakage is proportional to the pressure in the system”, the pressure will be highest when the DMA has its lowest inflows. “This is because frictional headloss is proportional to velocity, so when flows are low, the velocities in the pipes are also low and less headloss occurs”. On the other hand, commercial losses are calculated subtracting leakage from the NRW, as shown in equation 3 (Farley, et al., 2008, p. 60).

$$\boxed{\text{NNF} = \text{MNF} - \text{LNF}} \dots\dots\dots \text{Equation 2}$$

$$\boxed{\text{Commercial Loss} = \text{NRW} - \text{NNF}} \dots\dots\dots \text{Equation 3}$$

2.7 Assessment of Non-Revenue Water

“Preparing a baseline to establish current levels of water losses (by carrying out a water audit that leads to a water balance) is the first critical step for any commercial utility wanting to reduce water losses”. But strangely, this step is often overlooked in the development of urban water supply projects (Liemberger, 2010, p. 1).

The Water Balance and Non-Revenue Water assessment is a prerequisite stage required when preparing a baseline for a NRW strategy formulation (Liemberger & Farley, 2004; Kingdom, et al., 2006). Therefore, the main aim of undertaking a NRW assessment is to determine the quantity of NRW in the system under study, without necessarily considering the actual location of the losses in the system (Puust, et al., 2010).

In assessing the amount of NRW, System input volume is synonymously used, by many authors, with “water production” or “water put into the distribution system”. But it should be stated that considerable adjustments to the IWA Water Balance are needed for most of the situations in developing countries. This is because, not all the water that is billed is actually paid for. Therefore, counting the water that is paid for (actual revenue collected) is of the essence as opposed to counting the water that is billed (as used in the IWA Water balance) (Wyatt, 2010, p. 4). Hence the adjusted water balance as suggested by Wyatt (2010) may appear as shown in figure 2.8:

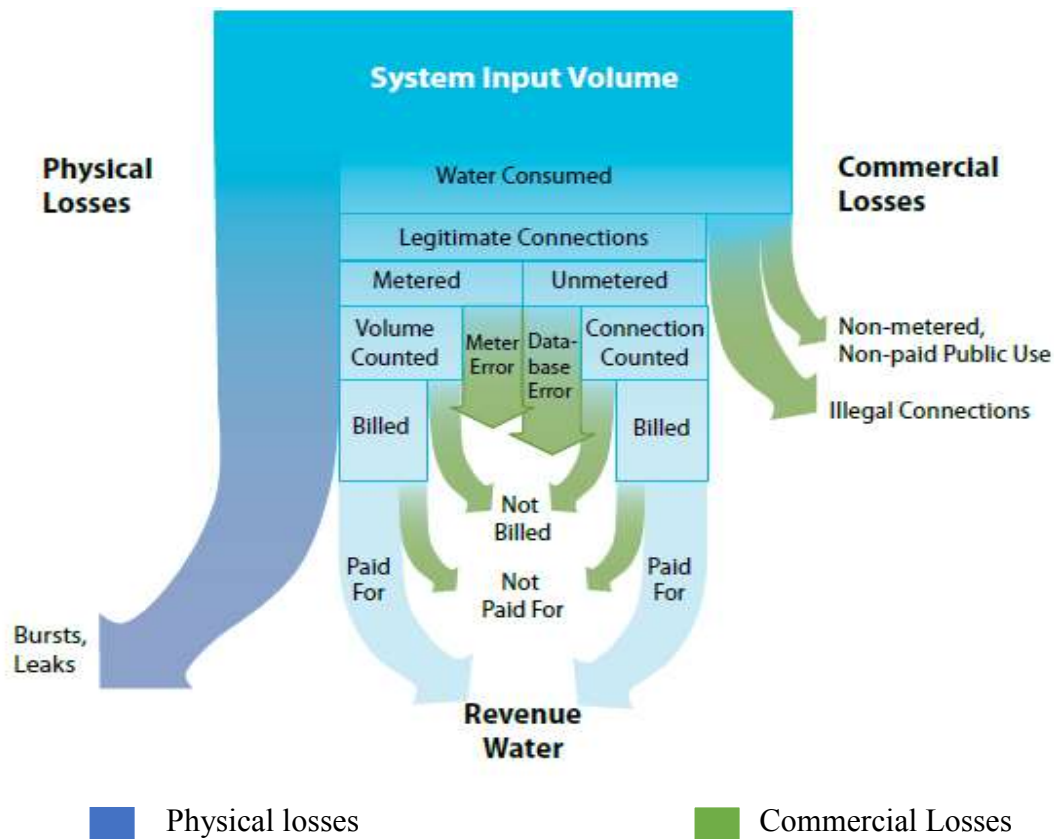


Figure 2.8: Adjusted water balance for developing countries like Zambia (Source: Wyatt, 2010).

Physical (real) losses can be assessed using any of the following methods, in singularity or a combination of them all: component analysis (the top-down approach) and physical loss assessment (the bottom-up approach) (IWA, 2004; Farley, et al., 2008, p. 43). The current leakage or water loss assessment methods are classified into two main groups as stated above, namely; Top-Down assessment method (using the water balance) and Bottom-Up assessment method (using 24 Hour Zone Measurement (HZM), or Minimum Night Flow (MNF) analysis) (Puust, et al., 2010).

2.7.1 Top-Down Approach

The IWA Water Loss Task Force was the first to suggest the Top-Down approach method through the use of the water balance (Farley & Trow, 2007). According to Farley et al (2008), the four basic steps to conduct a water balance assessment using the IWA water balance are as summarised below:

- Step 1: Determine system input volume;
- Step 2: Determine authorised consumption (Billed and Unbilled);

- Step 3: Estimate commercial losses (theft, meter inaccuracy and data handling errors); and
- Step 4: Calculate physical losses.
 - ✓ Leakage on transmission mains
 - ✓ Leakage on distribution mains
 - ✓ Leakage from reservoirs and overflows
 - ✓ Leakage on customer service connections

From the steps above, it is easier to deduce that the system input volume, billed consumption and unbilled metered consumption are in most cases metered. While on the other hand unbilled unmetered consumption and commercial losses are estimated.

Most commonly, the unbilled authorised consumption (metered and unmetered) is estimated by the utility as it is mainly specific to the given site conditions and it ranges between 0.5% and 1.25% of the system input volume. Unauthorised consumption is assumed to be between 0.1% and 0.25% of the system input volume. The ‘customer meter under registration’ component of apparent losses is usually assumed to be 2% of the billed consumption by registered metered customers (AWWA, 2009; Lambert & Taylor, 2010, p. 15). Therefore, Lambert & Taylor (2010), state that the real losses are calculated using equation 4.

$$\text{Real loss} = \text{NRW} - (\text{Unbilled Authorised Consumption} + \text{Apparent Losses}) \dots \text{Equation 4}$$

Equation 4 is illustrated using a hypothetical example as shown in table 2.4.

Table 2.4: Example of how to calculate real losses in a fully metered system

Components of Water Balance		Volume (kL/day)	Comment
Water Supplied		20000	Data entry
Billed Consumption	Metered	1000	
	Unmetered	0	
Non-Revenue Water		10000	Calculated values
Unbilled authorised consumption	0.5% of water supplied	100	
Apparent Losses	Unauthorised consumption; 0.1% of water supplied	20	
	Customer metering errors; 2% of metered connections	200	
Real Losses		9680	

Source: Lambert & Taylor (2010) – Modified by author

Sample Calculation:

$$\text{Real losses} = 10,000 - (100+200+20) = 9,680 \text{ kL/day}$$

All water balance data should have confidence limits of 95% applied to them so as to define the boundaries within which the true value for that particular component lies. This is also very important as it gives utility managers 95% confidence in the data being used. Pinpointing the nature and location of physical losses as well as quantifying commercial losses is made difficult due to the lack of data in most utilities (Farley, et al., 2008, p. 14).

2.7.2 Bottom-Up Approach

This method uses the real loss volumes determined in the top-down water balance approach and it involves the use of discrete zones or sectors of a distribution network known as the District Metered Areas (DMA). In bottom-up approach, the physical losses are estimated using the 24 Hour Zone Measurement (HZM) or Minimum Night Flow (MNF) analysis. Minimum Night Flow analysis is the most commonly used because even though the HZM is used, it will eventually require the application of MNF analysis approach (Puust, et al., 2010).

Although the exact timing of the minimum night flow will vary from zone to zone depending on the characteristics of the zone, it normally occurs during the early morning period, between

02:00 and 04:00 hours. It is the most meaningful piece of data as far as physical loss levels are concerned because consumption is at its minimum during this period and therefore physical losses are at their maximum percentage of the total flow. At Minimum Night Flow, estimation of the physical loss component is carried out by subtracting an assessed amount of Minimum Night Consumption for each of the customers connected in the zone under study (Farley, et al., 2008, p. 89).

Farley and Trow (2007) state that the MNF is the lowest flow into a DMA over a 24 hour period, which usually occurs at night when most consumers are inactive. Therefore, Minimum Night Flow analysis requires a DMA and the field tests to be performed at night between 02:00 and 04:00 hours when most consumers are not using the water (Cheung, et al., 2010; Farley & Trow, 2007).

2.7.3 Burst and Background Estimates (BABE)

The National Leakage Initiative of the United Kingdom developed the Bursts and Background Estimates (BABE) concepts between 1991 and 1993. The BABE concepts were the first to model physical losses objectively, rather than empirically, which enabled rational management planning and development of strategies for its operational control and reduction (AWWA, 2009; Farley, et al., 2008, p. 88; EPA, 2009).

Most of the losses from fittings in mains and service connections fall under the background category including air valves, hydrants, stop taps, dripping taps, cisterns, etc. For tanks and reservoirs, background losses represent leakage from the structure, and overflows are equivalent of bursts (AL-Washali, et al., 2016).

This concept is a computer modelling tool which is used to “assess the individual components of a leakage in a supply zone and then to compare that estimate with the level of leakage derived from either the water balance or from nightline data or preferably both” (Farley & Trow, 2003, p. 70).

In the Bursts and Background Estimates’ concept, water loss is assessed by estimating the volume of real losses which is then used to determine the apparent losses by subtracting from the total volume of water lost. The main principle is that there are numerous leakage events in real losses and that the lost volume of water in each event is a function of the average flow rates and average run-times for the different types of leakages (Thornton, et al., 2008)

Bursts and Background Estimates (BABE) concept categorizes real losses into three components, namely; background leakage, reported leaks and bursts, and unreported leaks and bursts as shown in figure 2.9 (Lambert, 2002; Tabesh, et al., 2009; Thornton, 2002, p. 136). These loss components of real losses commonly occur in the distribution mains and joints, service line connections and service line piping (Wyatt, 2010). Lately, to conduct real loss component analysis, real losses are categorized into four categories (EPA, 2009):

- Background leakage at joints and fittings (small flow rate running continuously);
- Reported leaks and bursts (high flow rates with short durations);
- Unreported leaks and bursts (moderate flow rates with duration dependant on active leakage control method); and
- Hidden loss or excess losses (flow rates too low to be detected by sonic detection devices) (EPA, 2009).

Figure 2.9 further illustrates the BABE concept.

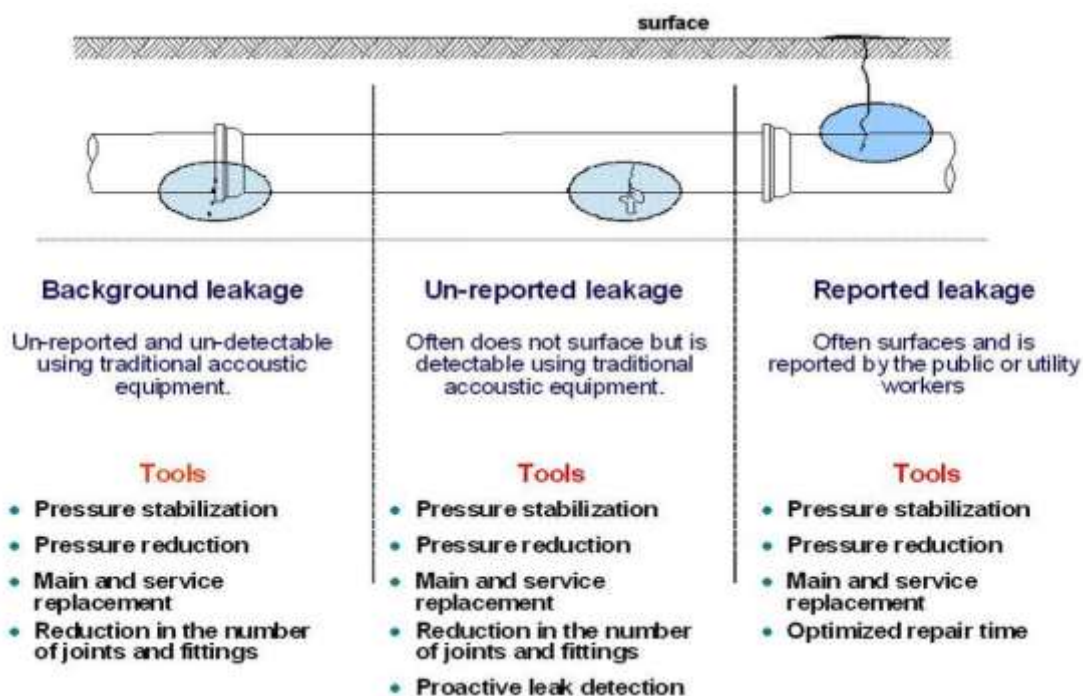


Figure 2.9: Components of the Background and Bursts Estimates concept (Source: Lambert, 2008)

The BABE model is sometimes considered to be a statistical model in that similar events are grouped together and then simple calculations are performed on them. The accuracy of the results is greatly affected by the number of events gathered. The larger the number of the events

gathered, the more accurate would be the results. Hence the BABE models work well with systems which have more than five hundred service connections (Thornton, 2002, p. 137).

In BABE concept, “the volume of an individual leak or burst is calculated as the average flow rate times the duration for which the leak or burst runs”. On the other hand, “Assessing real losses with the factors generated by the BABE model should not be conducted unless there is no other option due to its excessive assumptions”. But this method is usually used as a supplementary tool to break down real losses into its sub-components (AL-Washali, et al., 2016; Thornton, et al., 2008).

2.7.4 Synergetic Approach

In practice it is highly recommended that combining the top down approach with the bottom up approach enhances a high level of accuracy in assessing Non-Revenue Water thereby ensuring satisfactory results (EPA, 2009; Puust, et al., 2010; Thornton, et al., 2008; Lambert & Taylor, 2010).

Thornton et al (2008), furthermore state that after conducting top down approach, it is recommended that the BABE concept should be used as a supplementary analysis for the top down water balance. This would in the process aid the quantifying of hidden losses, thus help in redesigning an effective leakage prioritization and reduction policy.

2.7.5 International Non-Revenue Water Assessment Matrix

This matrix is used to categorise non-revenue water into internationally recognised categories of non-revenue water. It involves the calculation of non-revenue water in litres per connection per day by simply dividing the number of service connections into the 24/7 volume (continuous 24/7 supply situation) of non-revenue water. With the help of the calculated average pressures, the non-revenue water performance category is then determined using this matrix (Liemberger, 2010). Table 2.5 shows the different components of the International NRW Assessment Matrix:

Table 2.5: The International Non-Revenue Water Assessment Matrix

NRW Management Performance category		Non-Revenue Water in Litres/connection/day when the system is pressurised at an average pressure of:				
		10m	20m	30m	40m	50m
High Income countries	A1	-	<50	< 65	< 75	< 85
	A2	-	50-100	65-125	75-150	85-175
	B	-	100-200	125-250	150-300	175-350
	C	-	200-350	250-450	300-550	350-650
	D	-	> 350	>450	>550	>650
Low & Middle Income countries	A1	<55	<80	<105	<130	<155
	A2	55-110	80-160	105-210	130-260	155-310
	B	110-220	160-320	210-420	260-520	310-620
	C	220-400	320-600	420-800	520-1000	620-1200
	D	>400	> 600	>800	>1000	>1200

Source: Liemberger (2010)

Liemberger (2010) describes the categories in the international non-revenue water assessment matrix (table 2.5) as follows;

- **Category A1:** World class NRW management performance; the potential for further NRW reductions is small unless there is still potential for pressure reduction or accuracy improvement of large customer meters;
- **Category A2:** Further NRW reduction may be uneconomic unless there are water shortages or very high water tariffs; a detailed water audit is required to identify cost-effective improvements;
- **Category B:** Potential for marked improvements; establish a water balance to quantify the components of NRW; consider pressure management, better active leakage control practices, and better network maintenance; improve customer meter management, review meter reading, data handling and billing processes and identify improvement potentials;
- **Category C:** Poor NRW record; tolerable only if water is plentiful and cheap; even then, analyse level and causes of NRW and intensify NRW reduction efforts; and
- **Category D:** Highly inefficient; a comprehensive NRW reduction program is imperative and high-priority (Liemberger, 2010).

2.8 Economics of Water Loss Management

2.8.1 Performance Indicators

NRW performance indicators (PIs) are used by managers, policymakers, regulatory agencies, and financing institutions to rank the utility's performance against the sector standards (Farley, et al., 2008, p. 67). Performance indicators help a utility to (Farley, et al., 2008, p. 67; Simbeye, 2010, p. 67):

- Better understand water losses;
- Define and set targets for improvement;
- Measure and compare performance;
- Develop standards;
- Monitor compliance; and
- Prioritise investments.

Farley et al (2008) as well as Simbeye (2010) further state that “a good NRW performance indicator should be clear and easy to understand and have a rational basis. It should also be easy to calculate using data that the utility gathers regularly”. And that, “utilities should include standard performance indicators to measure performance to facilitate comparisons with other utilities”.

2.8.2 Percentage as a Performance Indicator

In general, the method of expressing NRW as a percentage of system input volume is often misleading and imprecise. The misleading effects of this method are highly observed in systems with intermittent supply and very low operating pressures i.e. utilities in low and medium income countries (Liemberger, 2010, p. 10).

But on the contrary, the percentage of non-revenue water by volume is still recommended for use as a basic financial Performance Indicator for non-revenue water, but not for real losses from a water resources point of view. In general, it should not be used for assessing any aspect of operational performance management of water losses (Liemberger & Farley, 2004). It is calculated as stated in equation 5.

$$NRW (\%) = \frac{(Q_{in} - Q_{revenue})}{Q_{in}} \times 100\% \dots\dots\dots \text{Equation 5}$$

Where; Q_{in} = annual system input volume

$Q_{revenue}$ = annual billed volume

On the other, percentage representation of non-revenue water is only accurate if the consumption is constant over time, which is rarely the case in real time situations. This has led to the International Water Association (IWA) discouraging the use of NRW as a percentage of the system input volume but rather recommends several key indicators with NRW, physical losses, and commercial losses, all measured in L/connection/day, m³/day/connection, m³/day/km of pipe system or m³/day/connection/m pressure (Wyatt, 2010, p. 4).

To illustrate this point, consider a hypothetical situation, as shown in figure 2.10, where the water losses are constant over time. Any decrease in consumption (maybe due to tariff increase) would lead to a proportionate decrease in production by the water utility company, leading to an increase in the ratio of losses to production even though the number of losses are still unchanged. This proves the fact that NRW as a percentage depends on consumption and losses (Wyatt, 2010, p. 4).



Figure 2.10: The reason why percentage non-revenue water is misleading (Source: Wyatt, 2010)

Therefore, if we use and depend on percentage NRW as an indicator of the total amount of water losses in the distribution system would lead to believing that the water losses have increased when in fact not.

2.8.3 Economic Level of Losses (Leakages) (ELL)

In any water distribution system, an economic level of leakage (ELL) exists between the current annual real losses (CARL) and the unavoidable annual real losses (UARL) (Lambert & Lalonde, 2005). In order to reduce water losses to a minimum, four strategies could be adopted i.e. Pressure management, Active leakage control (ALC), Quality and speed of repairs, and Asset management. This implies that the ELL for any given system can only be calculated if the utility commits itself to effectively applying all the four methods of real loss management as shown in figure 2.11 (Lambert & Lalonde, 2005).

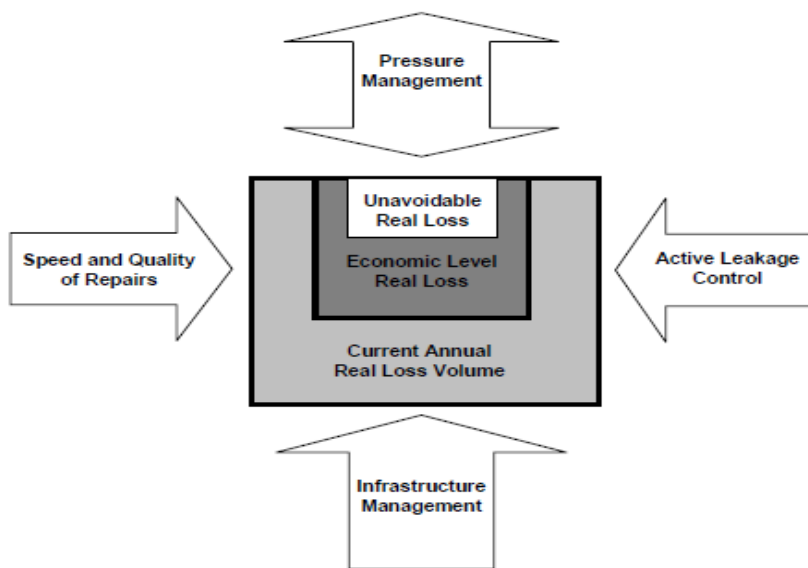


Figure 2.11: Economic Level of Real losses (Source: Charalambous et al, 2014)

The Economic Level of real Losses is thought to be based on the knowledge that all activities aimed at reducing leakage follows the law of diminishing returns, which states that the greater the level of resources employed, the lower the benefit which results (Pearson & Trow, 2005, p. 1). In the context of water loss reduction, Butler and Memon (2006, p. 194) indicate that, “leakage reduction programmes follow the law of diminishing returns - the more effort to reduce leakage, the less will be the return in terms of water saved”. This understanding forms the basis for the methodology where each activity is analysed in such a way that its marginal

cost is compared with the marginal cost of water in that supply zone as well as that of the other interrelated activities (Pearson & Trow, 2005, p. 1).

The level of leakage control which defines ELL is the level at which the cost of leakage reduction meets the cost of water saved through replacement and rehabilitation of the water mains (Pickard, et al., 2008). Butler and Memon (2006, p. 195), defines Economic level of real losses as being “the level of leakage where the marginal cost of active leakage control equals the marginal cost of the leaking water”. While Farley and Trow (2003, p. 54) defines ELL as the level where “the value of water saved is less than the cost of making further reduction”.

On the other hand, ELL can be viewed as the level of leakage beyond which it would cost more to make any further reductions than it would if a different water source was used to produce the water, meaning that the total cost of supplying water to the customer is minimized thereby operating efficiently (Stephens, 2003). The economic level of real losses is determined using a graph as shown in figure 2.12:

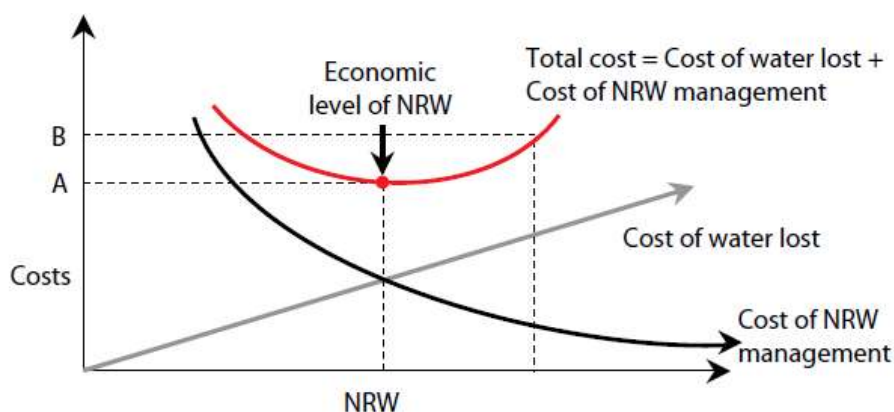


Figure 2.12: Graphical representation of Economic Level of Real Losses (Source: Farley et al, 2008)

The BABE component analysis models can be used to determine or predict the Economic Level of real Losses (Lambert & Fantozzi, 2005). Several components of the volume for the annual real losses should be calculated using all the necessary flow rates and average run-times, i.e. background leakage, reported leaks and bursts, and unreported leaks and bursts (Lambert & Fantozzi, 2005; Lambert & Lalonde, 2005; Pearson & Trow, 2005).

There are some useful points to note about ELL which always influence the choice of methods to be used in assessing the value of ELL. These points, as indicated by Farley and Trow (2003), are as follows:

- There is no single ELL, as it varies over time depending on factors often resulting from weather conditions and mains condition improvements;
- The degree of active leakage control (ALC) will change the ELL;
- The value of water changes over time;
- The ELL will be different depending on the method used for leak detection; and
- The estimation of ELL must use data, information and policy rules specific to the given area and water utility company.

2.8.4 Infrastructure Leakage Index (ILI)

The Infrastructure Leakage Index (ILI) is an excellent indicator of physical losses, and due to its international recognition, it is used to compare the performance of one utility with another. This index takes into account the way in which a network is being managed. The IWA, which developed the index and the Water Loss Control Committee of the American Water Works Association (AWWA) both recommend the use of this indicator (Simbeye, 2010). Hence the conclusion by Farley and others (2008) that “the best performance indicator for physical losses is the Infrastructure Leakage Index”.

Infrastructure Leakage Index is categorized as a level-3 indicator i.e. indicators which provide the greatest amount of specific detail but are still relevant at the top management level (Winarni, 2009), and is particularly useful in networks where NRW is relatively low, e.g. below 20%, as it can help identify areas which can be reduced further (Farley et al, 2008, p. 70). Therefore, “the ILI is a measure of how well a distribution network is managed (i.e. maintained, repaired, and rehabilitated) for the control of physical losses, at the current operating pressure” (Farley et al, 2008, p. 70).

Winarni (2009) state that “Infrastructure Leakage Index is the ratio of Current Annual Real Losses (CARL) to Unavoidable Annual Real Losses (UARL)”. Hence being a ratio, it has no units thereby making it possible for comparisons between countries that use different systems of measurement i.e. metric and imperial systems as shown in equation 6:

$$\boxed{ILI = \frac{CARL}{UARL}} \dots\dots\dots \text{Equation 6}$$

This ratio indicates how well the three infrastructure management techniques, i.e. repairs, pipelines and asset management and active leakage control are being undertaken independent from the aspects of pressure management (Winarni, 2009).

The IWA Water Losses Task Force developed a formula (equation 7) for the assessment and determination of the specific values of Unavoidable Annual Real Loss. This assessment requires the following data; the number of service connections N_c , the length of mains L_m (km), the length of private pipes (L_p in km), and the average operating pressure (P in metres). Equation 7 shows the general equation for UARL (Lambert, 2003):

$$\text{UARL} = (18 \times L_m + 0.8 \times N_c + 25 \times L_p) \times P \dots\dots\dots\text{Equation 7}$$

Units: (litres/day, when system is pressurised)

Equation 7, which is based on component analysis of Real Losses in well-managed systems with good infrastructure, has proved to be good in many diverse international situations (Lambert & McKenzie, 2002), and is the best predictor of the least attainable level of real losses for systems with more than 5000 service connections with a connection density (N_c/L_m) of more than 20 per km, and average pressure of more than 25m (Lambert, 2003).

Real losses will always exist, even in the very best systems. The least level of real losses is known as Unavoidable Annual Real Losses (UARL), and is the lowest achievable annual real loss for a system which is well maintained and managed. The concept of Unavoidable Annual Real Losses is very useful as it helps predict, with reasonable reliability, the lowest technical annual real losses for any given water utility at current operating pressures, assuming that the system is in good condition (Winarni, 2009).

Figure 2.13 shows the Current Annual Real Losses (large rectangle) and Unavoidable Annual Real Losses (small rectangle) whose difference is the potentially recoverable real losses. The four components shown in Figure 2.13 are used in managing real losses (Winarni, 2009).

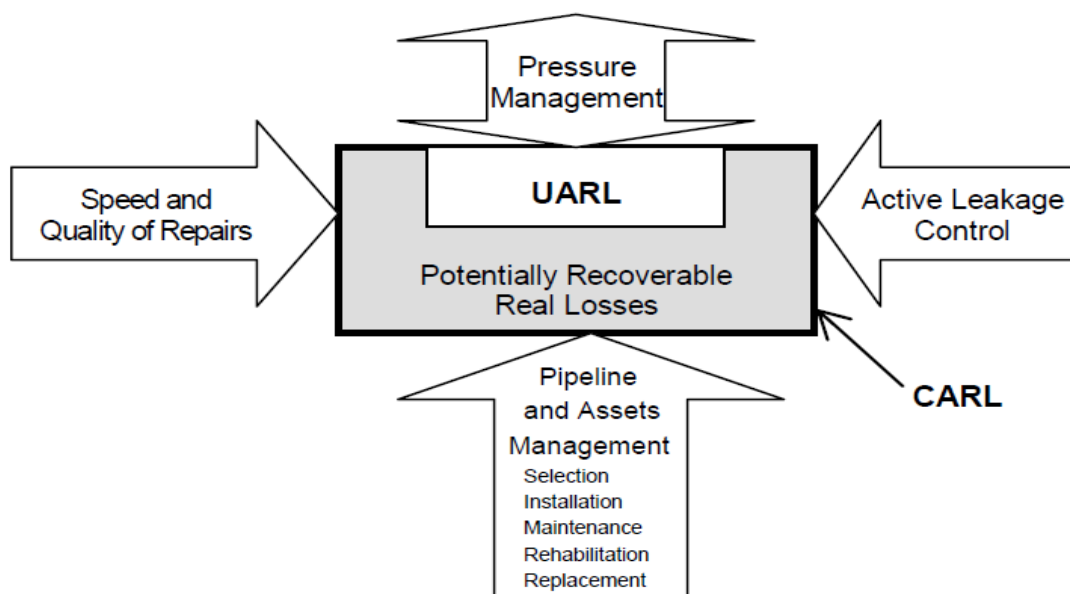


Figure 2.13: Basic methods of managing real losses (Source: Winarni, 2009)

Even when a well-managed system has an ILI of 1.0 (CARL = UJARL), it should not necessarily be the target because ILI is a purely technical performance indicator and does not take into account any economic considerations (Winarni, 2009).

In practice, the obtained ILI is compared with the physical loss target matrix, which shows the expected level of ILI and physical losses in litres/connection/day for utilities in different countries at specific network pressure (Farley et al, 2008, p. 71). The physical loss target matrix is as shown in Table 2.6:

Table 2.6: The physical loss target matrix

Technical Performance category		ILI	Physical Losses in [Litres/connection/day] when the system is pressurised at an average pressure of:				
			10m	20m	30m	40m	50m
Developed countries	A	1 - 2	-	< 50	< 75	< 100	< 125
	B	2 - 4	-	50-100	75-150	100-200	125-250
	C	4 - 8	-	100-200	150-300	200-400	250-500
	D	> 8	-	> 200	> 300	> 400	> 500
Developing countries	A	1 - 4	< 50	< 100	< 150	< 200	< 250
	B	4 - 8	50-100	100-200	150-300	200-400	250-500
	C	8 - 16	100-200	200-400	300-600	400-800	500-1000
	D	> 16	> 200	> 400	> 600	> 800	> 1000

Source: Farley et al (2008)

This matrix is usually used by utility managers as a guide to further develop and improve the water network (Farley et al, 2008, p. 71), where:

- **Category A:** Good - Further loss reduction may be uneconomic and careful analysis is needed to identify cost-effective improvements;
- **Category B:** Potential for marked improvements - Consider pressure management, better active leakage control, and better maintenance;
- **Category C:** Poor - Tolerable only if water is plentiful and cheap, and even then intensify NRW reduction efforts; and
- **Category D:** Bad - The utility is using resources inefficiently and NRW reduction programmes are imperative (Farley et al, 2008, p. 71).

2.8.5 Apparent Loss Index (ALI)

Figure 2.14 shows the principal components of Apparent Losses and is based on the approach that it is possible to define several management concepts for Apparent Losses similar to those already defined for Real Losses (Vermersch, et al., 2016).

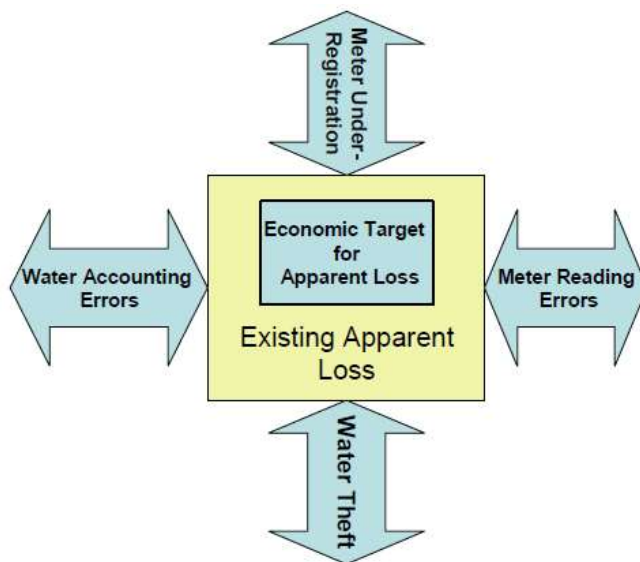


Figure 2.14: The different components of Apparent Losses (Source: Rizzo, 2006)

In Apparent Loss calculation, the concept of Current Annual Real Loss (CARL) has been replaced by the concept of Current Annual Apparent Loss (CAAL), while the Unavoidable Annual Level of Real Losses (UARL) is replaced by the Unavoidable (Reference) Annual

Level of Apparent Losses (UAAL) (Vermersch, et al., 2016). The other corresponding indicators for apparent losses are as shown in table 2.7:

Table 2.7: Similarities between Apparent and Real Losses

APPARENT LOSS	CORRESPONDING REAL LOSS
Current Annual Apparent Loss (CAAL)	Current Annual Real Loss (CARL)
Unavoidable (Reference) Annual Level of Apparent Losses (UAAL) or (RAAL)	Unavoidable Annual Level of Real Losses (UARL)
Economical Apparent Loss Level (EALL)	Economical Level of Leakage (ELL)
Apparent Loss Index (ALI)	Infrastructure leakage index (ILI)

Source: Elaborated by author

It is very important to set a value of RAAL that represents a realistic overall sum of its individual components and then choosing its appropriate units. RAAL and CAAL are calculated respectively using equation 8 and 9 (Vermersch, et al., 2016).

$$\text{RAAL} = 5\% \times \text{Billed Authorised Metered Consumption (water sales)} \quad \dots\dots \text{Equation 8}$$

$$\text{CAAL} = \text{Water Losses} - \text{CARL} \quad \dots\dots\dots \text{Equation 9}$$

A similar performance indicator to the Infrastructure leakage Index has been developed by the IWA Water Loss Task Force which uses a base value of 5% of the water sales as a reference and the actual value of the commercial losses is calculated against this benchmark. This index is referred to as the apparent (commercial) Loss Index (ALI), and is shown as equation 10 (Farley, et al., 2008, p. 72).

$$\text{Apparent Loss Index (ALI)} = \frac{\text{Apparent Loss Value}}{5\% \text{ of Water Sales}} \quad \text{Or} \quad \text{ALI} = \frac{\text{CAAL}}{\text{RAAL}} \quad \dots\dots\dots \text{Equation 10}$$

Due to poor management of the meters coupled with a high number of unregistered consumption, the value of ALI is very high (i.e. over 5) in most countries, but when the

management of the meters and customers is under control, the Apparent Loss Index may be lower than 1 (Vermersch, et al., 2016).

Apparent Loss Index (ALI) is currently the most commonly used performance indicator for commercial losses. Commercial losses are usually measured as a percentage of the authorised consumption (Farley, et al., 2008, p. 73). On the other hand, Farley and others (2008, p. 72) comment that the commonly used indicator which expresses commercial losses as a percentage of water supplied is misleading because it does not reflect the true value of the lost revenue.

2.9 Yard Taps

Yard taps are usually stand-pipes installed within an individual's plot whereby the plot owner is liable for all the water used. The connected consumer can sell water to those residing within close proximity to him/her. The main incentive here is that the seller may actually benefit from cheaper water supply as he/she will recoup the consumption costs from the sales (Banda, 2004).

According to Banda (2004), the following are some of the experiences encountered in working with yard taps:

- Accessibility is increased as water is taken directly to the users since they spend less time acquiring their daily water needs
- Bills are not allowed to accumulate for too long
- Water is cheaper since the total number of users per tap is lower (i.e. no excessive rates charged since several other consumers are connected as well)
- The property of the defaulter can be used as collateral in lieu of outstanding debt settlement, hence easier to recover monies owed from plot owners.

2.10 Key Performance Standards

2.10.1 Metering Ratio

The metering ratio is very important as it indicates the proportion of the total number of connections which are metered. It refers to the ratio between the unmetered and metered connections (Banda, 2004) as shown in equation 11.

NWASCO Benchmark: 100%

$$\text{Metering Efficiency (ME)} = \text{N/L \%} \dots\dots\dots \text{Equation 11}$$

Where; N - is the number of metered connections
 L - is the total number of connections

2.10.2 Collection Efficiency

This indicator measures the revenue collection efficiency of the utility calculated using equation 12. It shows how much revenue has to be collected compared to how much has been actually collected over a specific period (Banda, 2004). For instance, there was a decline in the sector’s average collection efficiency in Zambia from 86% in 2015 to 77% in 2016, where only five CUs managed to meet the acceptable benchmark of 85%. One of the major reasons noted for this drop in the collection efficiency was the non-payment of bills by government. Collection efficiency is given by equation (12) (NWASCO, 2016, p. 22):

NWASCO Benchmark: 85%

$$\text{Collection Efficiency (CE)} = \text{TC/TB X 100\%} \dots\dots\dots \text{Equation 12}$$

Where; TC - is the total monthly (0r annual) collection
 TB - is the total monthly (or annual) billing

This indicator may have to be adjusted in cases where government has a poor record of paying for the services provided. The government collections are normally measured separately to avert distortions (Banda, 2004). Table 2.8 shows the benchmarks for collection efficiency.

Table 2.8: Benchmarks for the Collection Efficiency in Zambia

Benchmark for Collection Efficiency	Very Good	> 95%
	Good	90 – 95%
	Acceptable	85 – 90%
	Unacceptable	< 85%

Source: NWASCO sector report (2014)

2.10.3 Connection Efficiency

The connection efficiency basically indicates the level of inactive connections in the network. The connection efficiency is the ratio of the number of active connections to the total connections as shown in equation 13 (Banda, 2004).

$$\text{Connection Efficiency (C)} = J/L \quad \dots\dots\dots \text{Equation 13}$$

Where; J - is the number of active water supply connections
L - is the total number of Connections

2.10.4 Staff Efficiency

This indicator refers to the number of staff per 1000 connections. It is expressed as the ratio between the number of staff to the number of connections multiplied by 1000 as shown in equation 14 (Banda, 2004).

$$\text{Number of staff per 1000 connections} = NS \times 1000/NC \quad \dots\dots\dots \text{Equation 14}$$

Where; NC - is the total number of connections
NS - is the total number of staff

Table 2.9 shows the benchmark for staff efficiency.

Table 2.9: Benchmark for staff per 1000 connections for small and large companies

Description	Small Companies	Large Companies
Good	< 8	< 5
Acceptable	8 – 12	5 – 8
Unacceptable	< 12	> 10

Source: NWASCO sector report (2001)

2.11 Leakage Management

2.11.1 Active Leakage Control (ALC)

Active Leakage Control is a continuous process which involves identifying and quantifying all the existing leakage losses, which is usually achieved through conducting acoustic leak detection as well as information and data obtained by continuously monitoring the flows and pressures at DMA or Zonal level. The design of the water distribution network as well as the level of degradation of the pipes in the network impacts greatly on the effectiveness of ALC (Charalambous, et al., 2014).

There's a considerable difference between active leakage control and passive leakage control. Passive leakage control is where the company responds only to reported bursts/leaks or pressure drops which are either reported by the customers or noticed by the company personnel. Passive leakage control is a common practice in less developed systems where detection of underground leakage is not well established. It is also common in areas with abundant or plentiful water and a marginally low cost of supplying the water to the customers (Butler & Memon, 2006, p. 160).

On the other hand, Butler and Mamon (2006) indicate that passive leakage control is an integral part of the leakage management plan and is the first step to any active leakage control programme i.e. to ensure that all visible leaks are repaired.

Active leakage control (ALC) is a program which involves management policies and processes to locate and repair unreported leaks from both the supply system and the customer supply pipes (Pearson & Trow, 2005). Success in any active leakage control programme is only attained if the correct methodology and appropriate staff as well as the correct equipment are made available for the programme. ALC together with speedy repairs limit the amount of water lost from the system because they are the most cost-effective and efficient leakage management techniques (Charalambous, et al., 2014). Hence, many utilities have developed policies and strategies to reduce water losses to an economic or acceptable level using these techniques (Alkassseh, et al., 2015, p. 45).

These policies involve techniques such as pressure management, active leakage control, sectorisation and economic intervention (Puust et al. 2010). Therefore, the most effective tool for leakage control in District Metered Areas (DMAs) is the implementation of pressure management, especially in large networks and systems which have both deteriorated infrastructures and high operating pressure (Gomes, et al., 2012).

Due to the high expense of leakage control, water utility companies always perform a cost-benefit analysis, between the costs of leakage control and the accrued benefits. The balance between costs and benefits is very common in many fields because the economic level of operation is of the essence (Pearson & Trow, 2005, p. 1). Active leakage control will help convert the capital costs (reducing bursts) to operational costs (maintaining a level of bursts) (Crowder, et al., 2012).

Significant improvement in water loss detection and pressure management as well as water safety in water distribution systems can be achieved through partitioning the network into

hydraulically independent subsystems or districts, called District Metered Areas (DMAs). This is achieved by installing flow meters and gate valves in the network with at least one supply point (Gomes, et al., 2013; Di Nardo, et al., 2013). Monitoring the flows into and out of DMAs or zones is now the internationally most accepted technique to locate leakages. Therefore, “the quicker the water utility can analyse DMA flow data, the faster bursts or leaks can be located” (Charalambous, et al., 2014).

The DMAs usually have between 3,000 and 5,000 service connections, but an ideal DMA size should have less than 1,000 service connections to allow quick identification and repair of new service leaks (Karadirek, et al., 2012). Thornton and others (2008) state that “If a DMA is larger than 1000 service connections it becomes difficult to differentiate small leaks (e.g., service line leaks) from customer consumption volumes”.

2.11.2 Pressure Management

Pressure management is one of the most cost-effective and system optimisation measures for a well-organized leakage management strategy (Winarni, 2009). “Pressure Management aims at minimising excess (unnecessary) pressures in the water distribution system as well as removing transients” (Charalambous, et al., 2014).

Butler and Memon (2006, p. 166), state that, “the rate of leakage in a water distribution system, is a function of the pressure applied by pump or gravity head”. In many circumstances, Pressure management give the fastest pay back on most of the water utility investments (Thornton, 2002, p. 261). Hence according to Winarni (2009), the benefits of pressure management include the following:

- i. Extension of the life of the distribution infrastructure;
- ii. Reduction of new burst frequencies on distribution mains and service connections;
- iii. Reduction of flow rates of all leaks and bursts present in the system at any time;
- iv. Reduction of new leaks on private pipes and overflows at private storage tanks; and
- v. Reduction of some components of consumption subject to direct mains pressure.

In most cases, the system pressures and topography of the service area will affect the cost effectiveness of managing real losses through pressure management (Munoz-Trochez, et al., 2010). In practice, the seemingly little and simple efforts in pressure management activities often lead to considerable reductions in Real Losses (Charalambous, et al., 2014). Moreover,

recent studies have shown that a 10% reduction in peak pressures in the water system will result in a 14% reduction in the systems' tendency to leak. Therefore, system pressure has a direct impact on the average leak flow and the annual number of new leaks and bursts (Fantozzi & Lambert, 2010; Williams, 2013).

Charalambous and others (2014), state that, “there is a physical relationship between leakage flow rate and pressure, and the frequency of new bursts is also a function of pressure”, hence:

- The higher or lower the pressure, the higher or lower the leakage; and
- The lower the pressure the lower the number of new bursts.

The relationship between pressure and leakages is so complex that in order to analyse it, a linear relationship is assumed (i.e. 10% less pressure = 10% less leakage). On the other hand in order to analyse the relationship between pressure and the number of new bursts, it is assumed that for any 10% reduction in pressure there is a 14% reduction in new bursts/breaks until a relationship is established based on actual data relevant to the specific distribution network (Charalambous, et al., 2014).

2.11.2.1 Methods of Pressure Management

The most common methods of pressure management falls in either of the following categories (Thornton, 2003):

- Pressure reduction or sustaining;
- Surge relief or anticipation; and
- Altitude control.

The most common form of pressure management is pressure reduction, but all three are part of a proactive water loss management program. Various methods of pressure reduction are used, but the most common methods used during the economic analysis are as listed below (Thornton, 2003):

- Zonal boundaries;
- Pump and level control;
- Fixed outlet control valves;
- Time modulated control valves;
- Flow modulated control valves; and
- Remote node control.

2.11.3 Infrastructure Management

Infrastructure or asset management deals with network assets which are maintained periodically or replaced at the end of their useful life. It is a good engineering and business practice, which includes all aspects of water utility management and operations. Long-term economic leakage management requires a good asset management with the sole purpose of tackling leaks in the most cost-effective way (Charalambous, et al., 2014).

In order to fully understand real losses, it “requires priority setting and decisions on whether to repair, replace, rehabilitate, or leave the assets as they are, while simultaneously implementing pressure management and improving the operation and maintenance programme”. In most cases, asset management involves the following factors (Charalambous, et al., 2014):

- Understanding the current performance of the assets;
- Collecting data and turning it into useful information for planning; and
- Good information systems.

The ageing of pipe networks (see figure 2.15) is the most important aspect in developing a non-revenue water strategy, which requires an understanding of the assets’ condition. The frequency of the occurrence of pipe bursts will help prioritise pipe rehabilitation, renewal or replacement. Active leakage control will help in identifying pipes in the network with a continuous occurrence of bursts and repairs (Charalambous, et al., 2014). Figure 3.15 depicts a corroded underground pipe.



Figure 2.15: Corroded underground steel pipe (Source: LWSC NRW Strategy, 2014)

2.11.4 Speed and Quality of Repairs

Speed and Quality of Repairs is the backbone of any real loss control program and it ensures timely and lasting repairs. Leak run-time is mainly of the essence as it affects the volume of real losses. Quick response to reported leaks through repairs is very important, so does the quality of the repairs which affects whether the repair would be sustained (Charalambous, et al., 2014).

Charalambous et al (2014) give some key issues to consider when formulating a repair policy, which are as follows:

- Efficient organisation and procedures from the initial alert through to the repair itself;
- Availability of equipment and materials;
- Sufficient funding;
- Appropriate standards for materials and workmanship; and
- Committed management staff.

They further state that the quality of service connections should be top notch because the majority of the leaks are on service connections.

2.11.5 Leak Detection Equipment

Leak detection is one very important component of the active leakage control process. Therefore, it's very paramount that utility managers ensure a detailed process is undertaken to locate leaks in the system (Farley, et al., 2008, p. 49). This process is achieved through the following activities:

- Identify DMAs that contain unreported bursts or an accumulation of leaks using flow meters;
- Narrow down the area of leakage within the DMA; and
- Pinpoint the exact (or nearly exact) position of the leak.

Each step of the above stated process requires a high level of accuracy to avoid high excavation costs as well as 'dry holes' (excavations that reveal no obvious leak). The easiest and most basic method of detecting and locating a leak is to listen to the noise of the pressurised water being released from the pipe. Therefore, system pressure, size and shape of the leak as well as

pipe material will determine the effectiveness of this method of leak detection (Farley, et al., 2008, p. 49).

A number of acoustic equipment help in pinpointing the exact location of leaks and bursts which include noise loggers, leak noise correlators, ground microphones, and sounding sticks. Hence it is important for utility managers to understand their proper applications and maintenance requirements so as to maximise their use. Most, if not all, of the equipments below will not only detect the noise that a leak makes but noises in the system are also detected, e.g. a pump, tap, air valve, etc. Hence experienced leakage detection staff are needed to ensure that leaks are correctly identified (Farley, et al., 2008, p. 49).

a) Noise Loggers

Usually a cluster of 6, 12, or 18 loggers are deployed in the survey area with each logger placed on a hydrant, meter, or any other surface fitting. Noise loggers usually narrows down to areas of a DMA that contain suspected bursts or leaks. The suspected noises as being caused by leaks or bursts are confirmed and the leak is located using other locating equipment (Farley, et al., 2008, p. 49). An example of a noise logger is as shown in Figure 2.16:



Figure 2.16: An example of a Noise Logger (Source: www.sewerin.co.uk)

b) Leak Noise Correlators

Leak noise correlators use the velocity of the sounds made by the water at the leaks or bursts as it travels along the pipe wall towards the two microphones placed on either sides of the suspected leak area. Therefore, the leak noise level and the sound conductivity of the pipe material determines the effectiveness of this process. In situations where the pipe material has very poor sound conductivity qualities, hydrophones are used to listen to the leak noise

travelling through the water which is a far much better conductor of sound compared with most of the pipe materials (Farley, et al., 2008, p. 49). Figure 2.17 shows a leak noise correlator.



Figure 2.17: Example of a Leak Noise Correlator (Source: www.h2oleaktech.co.za)

c) Ground Microphones

Ground microphones operate in such a way that they electronically amplify the sound of a leak. It is usually used in two modes i.e. either contact or survey mode. Contact mode operates in a similar manner as the electronic listening stick and is used for sounding on fittings, while the Survey mode is used for searching for leaks on lengths of pipeline between fittings. The process of using ground microphones involves placing the microphone on the ground at intervals along the line of the pipe and noting changes in sound amplification as the microphone nears the leak position. Once a leak is detected, either mode can be used to locate it (Farley, et al., 2008, pp. 49-50). Figure 2.18 shows a Ground microphone.



Figure 2.18: An example of a Ground Microphone (Source: www.sewerin.co.uk)

d) Sounding (Listening) Sticks

Sounding sticks are sometimes referred to as Stethoscopes. A sounding stick is simply a rod of wood or metal with an ear piece attached to amplify sounds. They are used to directly listen to leak sounds on the surface or on exposed pipes and fittings. It is used as a confirmation tool to confirm the leak site already identified by a correlator (Farley, et al., 2008, p. 50). An example of a sounding (listening) stick is shown in Figure 2.19.



Figure 2.19: Example of a Sounding (listening) Stick (Source: *actualplumbing.ca*)

2.12 Key Emergent Issues from Literature Review

Several issues pertaining to the water sector in general and particularly the management of Non-Revenue Water which have an impact on the service delivery of the water and sanitation services have been reviewed and identified through the review of the available literature. The following issues and their ensuing implications in the management of non-revenue water will need further field investigations in order to fully understand the phenomena under research:

- Effective management of water resources demands a holistic approach, where all the stakeholders i.e. users, service providers, planners and policy makers take part in its management;
- Water has an economic value attached to it, hence the need for the users to pay for it
- Before formulating a non-revenue water strategy, there's need to undertake a water audit to determine the current levels of water losses. And for the loss control strategy to be effective, it should be a continuous activity so as to promote an active non-revenue water management system;
- Reducing commercial (apparent) losses increases revenue while reducing physical (real) losses reduces production costs;
- Top-down and Bottom-up approaches are the two main water loss assessment methods commonly used and hence applicable in developing countries;
- A District Metered Area should be both pressure-tight and water-tight, and should have less than 1000 connections but in practice it is usually between 3000 and 5000 connections;
- The Burst and Background Estimate (BABE) is not highly recommended because of too many assumptions in its use;

- ‘Percentage’ as a performance indicator is not suitable for real losses but can be used as a financial performance indicator for non-revenue water;
- To measure how well a distribution network is being managed in the control of real losses and apparent losses, Infrastructure Leakage Index and Apparent Loss Index are used respectively;
- Active leakage control is highly recommended compared to Passive leakage control; and
- System pressure has a direct impact on the average leak flows. Therefore, pressure management is one of the most cost effective measures for a well-organised leakage management strategy,
 - ✓ 10% less pressure = 10% less leakage; and
 - ✓ 10% less pressure = 14% less new bursts/leaks.

2.13 Chapter Summary

In this chapter, literature has revealed that the best way to fight water losses is to establish the Water Balance accurately which would help explain the nature of the existing losses before embarking on activities to fight NRW. At LWSC, commercial losses are determined using the BABE (Bursts and Background Estimations) by first establishing the commercial losses then subtract them from the total loss to get the level of physical losses using an excel based software known as WB-Easy calc.

In many cases, the major yardsticks in measuring the performance of a water utility is the level of non-revenue water. Low level of non-revenue water is desirable which is only achievable through many inputs including control of leakages and bursts, elimination of accounting errors and water theft, infrastructure maintenance and necessary resources. The availability of all these input factors will bring about a low non-revenue water and higher income for the company.

The review in this chapter clearly highlights the need for further exploration to find possible answers to the research questions in order to achieve the aim and specific objectives of this research. Hence an appropriate methodological framework is required to explore on the many issues that have emerged from the review of the available literature.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Introduction

In any research, a research method is regarded as a technique or route taken in gathering data. On the other hand, a methodology is regarded as a theory and analysis of the philosophical parameters in which the research should proceed (Clough & Nutbrown, 2007, p. 23). A theory is an attempt to develop a generally acceptable explanation for a phenomenon. It explains non-observable phenomena which are inferred from observable facts and events, and are thought to have an effect on the phenomenon under stud (Best & Kahn, 2006, p. 10).

Although a hybrid model approach consisting of both Qualitative and Quantitative techniques in a single study may be considered to be two separate studies within one larger study, the two approaches complement each other in the knowledge gained on the given research problem. A combination of the two approaches is very much desirable despite the dangers of the difficulty in maintaining the integrity of each approach when having a comprehensive qualitative study whilst conducting a quantitative study at the same time (Castellan, 2010). Therefore this chapter looks at the commonly used research techniques in more detail, from which a choice of the most appropriate methods and methodologies to be used in this research will be made.

3.2 Approaches in Conducting Research

3.2.1 Qualitative Technique

Qualitative research is more abreast with quotation, description and narration, as researchers endeavour to capture conversations, experiences, perspectives and meanings, thereby making it a research using words instead of numbers (Willis, 2007, p. 40). Essentially, a qualitative research have to do with non-statistical methods and small samples which are often times purposively selected (De Vos, et al., 2011). Therefore, a qualitative research technique is “an approach towards an insider’s view” (Babbie & Mouton, 2001).

This technique examines human behaviour in social, economic, cultural and political contexts in which they occur instead of numerical analysis (Salkind, 2003). He further states that the collection of data is done through a variety of research tools such as interviews, observations, historical methods and case studies.

Qualitative research uses an interpretative approach which is much needed to understand certain situations and settings which are way too intricate to be understood by mere foraging through random sampling or the calculation of means and modes of results. The qualitative method is typically used on purpose in research and is mainly used to unfold a complex phenomenon, usually one with little or no information concerning its characteristics (Njie & Asimiran, 2014). Therefore, qualitative researchers study things in their natural settings, relying mainly on the interpretations and meanings which people bring to them (Denzin & Lincoln, 2004). The naturality of qualitative research is further affirmed by Leedy & Ormrod (2005) who state that qualitative research is not the best approach to take if one is looking for quick results and easy answers.

The following are some of the characteristics of qualitative research (Jones & Kottler, 2006, p. 83; Bogdan & Biklen, 2007, pp. 3-8, 40-41; Leedy & Ormrod, 2010, pp. 94-97; Kumar, 2011, pp. 13, 20, 104-105):

- In qualitative research, how a phenomena is in reality, is just as important as how the participants think it really is;
- Its emphasis is mainly on the processes and activities involved in the phenomena rather than on the product obtained;
- It is mainly based on inductive reasoning or logic: reasoning from the specific to the general;
- It is conducted in natural settings without disturbing the environment in which the research is being carried out; and
- It extensively uses descriptive data, where researchers turn to describe a phenomenon with words, rather than with numbers.

Therefore, in qualitative research, random sampling is not used as a sampling technique because some aspects are more important in the sampling process hence cannot be randomly selected. Thus, more emphasis is put on the sample that will give the best and more in-depth information. This implies that a purposive sampling is the most appropriate method where a researcher carries out a careful selection of the source of information, which will yield more relevant information to unearth the questions that are asked in the research process (Schreiber & Asner-Self, 2011).

The three most common kinds of data collection methods that are utilized in qualitative research are: interviews, observations, and written documents' review. Most of the data comes

from the field where the researcher spends most of the time. The researcher interacts and makes first-hand observations of activities, and at times getting physically involved in those activities as a “participant observer” (Castellan, 2010).

3.2.2 Quantitative Technique

Castellan (2010) indicate that Quantitative research operates in the positivism paradigm, which is the belief that the physical and social reality are independent of the observer. In Quantitative research, the researcher is independent of that which is being researched and their objective is to discover the reality that is out there to be discovered. Their assumption is that social reality is specific to any given local situation and it is constructed by the participants in it.

The common practice in many quantitative researches is to randomly select a subset of the population being studied. This random selection of the Sample is to ensure that all the distinguishing features of the subjects under study and in the total population appear in the same proportion (Castellan, 2010).

This research method is used to collect information that can be expressed using numerical measures. Therefore, in this study, data on aspects of performance indicators, revenue collection, volumes of water supplied and sold, etc. will be analysed using this technique.

3.2.3 Case Study

A Case study is employed in research if there’s need to study an individual, a group, a situation or an institution in a more detailed manner as possible over a period of time (Salkind, 2003). It is also said that Case studies are a type of qualitative research involving an in-depth look at a single individual, program, or event for the sole purpose of gaining knowledge about an unidentified or insufficiently understood situation (Leedy & Ormrod, 2005). The phenomenon under research will in most cases determine the research method to be used. The main focus of a case study is to find out the distinguishing features of a particular entity, and it involves an in-depth description of a given phenomenon anchored on real time situations and uses multiple data collection methods (Njie & Asimiran, 2014).

Case study research consists of a detailed investigation of a given phenomenon with data collected over a period of time so as to provide an analysis of the processes which clarify the theoretical issues being studied (Hartley, 2004). Njie and Asimiran (2014) indicate that case studies concentrate mainly on experiential knowledge of the case with close attention to the

influence of its social, political and other contexts which can only be brought out through a special skill by the researcher to convince respondents or interviewees to respond appropriately.

McLeod (2008) also states that case study researches may continue for extended periods of time so as to study the processes and developments as they happen. He further says that the data collection tools in a case study may include observations, unstructured and structured interviews and official documents' review all of which will be qualitative. He goes on to suggest the following as the strengths of case studies:

- Provides detailed information;
- Provides insights for further research; and
- Permits investigation of otherwise impractical and unethical situations.

One of the most significant activities in a case study is data collection. This is because the richness and depth of what will eventually be known is dependent on the effectiveness of the data collection method. Therefore, six commonly used data collection methods are: Direct observation, Interviews, Document review, Archival Records, Physical Artifacts and Participant observation (Njie & Asimiran, 2014).

The Observation data collection technique can be used for collecting both qualitative and quantitative data. Since this technique results in very precise measurements which are highly recommended in quantitative data analysis, it is highly recommended for this research. The technique is also suitable in the analysis of human behaviour which then requires subjective investigations of what is being measured (Scheyvens & Storey, 2003, p. 39).

Interviews are conducted by asking a series of questions to an informant with the responses well recorded and stored (Laws, et al., 2003). They further state that interviews are an ideal form of methodology when:

- One is able to rely on information from a small number of respondents;
- The issue under study is sensitive and people may not give full details in a group;
- There's need to know about people's experiences and perceptions in some more depth; and

- There's need to give the respondents a better chance to express themselves fully which may not be possible through a written questionnaire.

3.2.4 Key Informant Interviews

Interviews are a social connection intended to exchange information between the interviewee and the interviewer. The characteristics of the information exchanged, in terms of quantity and quality, would depend on the incisiveness and creativeness of the interviewer in managing the interview (Monette, et al., 2005). The interviewers are intensely and inevitably concerned with annexing information, from within the respondents or interviewees, which cannot easily be extracted using questionnaires and other means (Greeff, 2011, p. 342).

The main purpose (aim) of any given qualitative research interview is mainly to see the research topic from the angle or perspective of the interviewees, thereby understand why they have a particular perception (King, 1994, p. 14). Interviews compel the researcher to extract information from respondents so as to gain a better understanding of the importance and implication of what is happening in the area of the research study (Scott & Usher, 2011, p. 93).

Qualitative research interviews have the following characteristics which will help in achieving its goals (King, 1994, p. 15):

- Low degree of structure imposed by the interviewer;
- Mostly open-ended questions are used; and
- Mainly centred on 'specific situations and action sequences in the world of the interviewee' rather than thoughts and general ideas.

Depending on the nature of the event as determined by the researcher who initiates the interview, standardised open-ended, semi structured or structured interviews can be used (Greeff, 2011, p. 347).

A qualitative research interview is best applicable in the following circumstances (King, 1994, p. 16):

- i. Where the study focuses on the meaning of the given phenomena to the participants;
- ii. Where potential distinct opinions of processes in a phenomenon are to be studied using a series of interviews;
- iii. Where specific historical accounts of how a particular phenomenon progressed are required;

- iv. Where tentative work is required before a quantitative study is carried out; and
- v. Where qualitative data are required to validate particular measures or to clarify and illustrate the meaning of the findings from the quantitative study.

3.2.4.1 Approaches to Analysing Data

There are mainly four approaches in analysing data from the qualitative research interviews i.e. Quasi-statistical, templates, editing and immersion/crystallisation methods (King, 1994, p. 26).

a) Quasi-Statistical Method

This analysis method turns textual data into quantitative data which can be manipulated statistically. The items found are categorised into themes where a suitable unit of measure can be used to analyse the data statistically. Content analysis in this approach is within the quantitative, logical-positivist paradigm or practice, which is mainly concerned with hypothesis-testing, generalisability and the separation of the researcher from the data to maintain objectivity. Therefore, it should not be used to answer research questions which are essentially qualitative (King, 1994, p. 26).

b) Template Method

Analysis is done using an analysis guide or ‘codebook’ which stipulates the themes relevant to the research questions. The codebook is usually revised and updated through exposure to the textual data and built upon existing knowledge or developed from the initial analysis of the interview data. The pattern of the emerging themes is interpreted qualitatively rather than quantitatively (King, 1994, p. 26).

c) Editing Method

This analysis method involves searching for meaningful segments, cutting, pasting and rearranging them until the reduced summary reveals the interpretive truth in the text. The distinctive feature of the editing approach is its cyclic nature, where interpretations are repeatedly compared with the original textual data in order to come up with the best interpretation. This process in grounded theory is called ‘constant comparison’, up until a point of ‘theoretical saturation’ where additional analysis no longer contributes to discovering anything new about a category (King, 1994, p. 26).

d) Immersion/Crystallisation Method

This analysis approach is where researchers engage themselves in the research subject through qualitative interviews in the form of conversations, observation, self-analysis and literature reviews over a prolonged period of time, and produce an account of their findings through analytical reflection and intuitive or perceptive crystallisation of the topic (King, 1994, p. 27).

3.2.5 Questionnaire

In most survey researches, a questionnaire is regarded as a method of data collection using documented questions on the questionnaire form that people respond to honestly and frankly without the help of the researcher (Monette, et al., 2011, p. 164).

Once the target area or group has been identified, a small portion of the population known as a Sample is selected which will be a representative of the whole population in the study area (Monette, et al., 2011, p. 13; Neuman, 2011, p. 241). In this research for instance, a purposive sample was selected within Lusaka consisting of 24 mid- and top management members of staff of Lusaka Water and Sewerage Company, which is the company operating in the study area.

Purposive sampling is the most important type of non-probabilistic sampling. In this type of research, researchers rely on their experience and ingenuity as well as previous research findings to purposely select a sample that will be representative of the population under study. The sufficiency of the sample for quantitative studies mainly depends on the judgment of the researcher, hence sometimes referred to as judgment sampling. Purposive sampling demands the researcher to first think critically about the parameters to consider and then choose the sample case accordingly. Therefore, the criteria for selecting the participants is of a critical importance (Welman, et al., 2009, p. 69).

Questionnaires have both advantages and disadvantages in using them as a data collection tool in research, as can be noted below (Best & Kahn, 2006, p. 313; Wilkinson & Birmingham, 2003, p. 39; Muijs, 2011, pp. 38-39):

a) Advantages of Questionnaires

- Questionnaires are very useful in showing relationships with easily quantifiable data. Therefore, a well- designed questionnaire allows for the identification of relationships between data;
- Questionnaires are reliable data collection tools as they can be used over and over again to measure differences between groups of people;
- Questionnaires ease the collection of huge amounts of data with minimal effort and less expensive if the participants are in one place; and
- It is very convenient as it allows participants to fill out at their own free time, giving them enough time to critically think of the best answers to the questions.

b) Disadvantages of Questionnaires

- Due to its ease of production and distribution, way more than necessary data can be collected which cannot even be effectively used;
- Questionnaires often have a low response rate (return rate) and time-consuming in doing follow-ups and data entry;
- They lead to the collection of superficial data due to lack of time on the part of the participants; and
- Questionnaires are everywhere, hence competing for participant's time.

3.2.6 Participant Observation

Participant observation involves the researcher physically going in the field to get first-hand information on how things are done. The main purpose of participant observation is to provide a brief account of the situation on the source of data so as to ease the understanding of the setting in which the respondents work as well as to provide information about the environment in which the interview took place (Creswell, 2009, p. 177; Scott & Usher, 2011, p. 106).

3.2.7 Methods for Evaluating a Strategy

In order to provide evidence for the need to continue supporting any given strategy or intervention, monitoring and evaluation is very vital to determine whether the strategy or intervention is working. It will not only provide feedback on the effectiveness of a programme

but will also determine appropriateness of the programme and any ongoing concerns that need to be resolved as the programme is implemented (Ristic & Balaban, 2006).

Evaluation can be applied to many points during planning or formulating a strategy, program, project, action plan or intervention. They help in checking the effectiveness and efficiency of the set goals, strategies, programs, projects or interventions in different situations and organizational frameworks (Ristic & Balaban, 2006). The following are some of the methods used in evaluating the performance of a strategy:

a) ‘With’ and ‘Without’

‘With’ refers to the results obtained with the intervention (the factual), which are compared with the results ‘without’ the intervention (the counterfactual) to determine the impact of the intervention (World Bank, 2006).

b) SWOT Analysis

This involves an in-depth look at the Strengths, Weaknesses, Opportunities and Threats affecting the intervention. This analysis method can be used to formulate a strategy for an organisation or changing the outlined objectives in the organisational strategy. It stipulates and identifies the existing relations between internal and external features. “A SWOT analysis measures a business unit, a proposition or idea” (Chapman, 2017). Table 3.1 illustrates how the SWOT analysis is applied in decision making.

Table 3.1: Illustration of how SWOT analysis is used in decision making

	Helpful	Harmful
Internal Origin (attributes of the organisation)	Strengths	Weaknesses
External Origin (attributes of the environment)	Opportunities	Threats

Source: Xhienne (2007)

c) 'Before-and-After' Analysis

This analysis method compares the performance of an entity or company 'before' the introduction of the strategy, program or intervention with the performance 'after' the strategy or intervention has been in use. It is usually used to check whether the change in trends coincide with the inception of the strategy or intervention regardless of whether favorable or not. Figure 3.1 shows the 'favourable results' on a performance indicator, obtained after the introduction of an intervention:

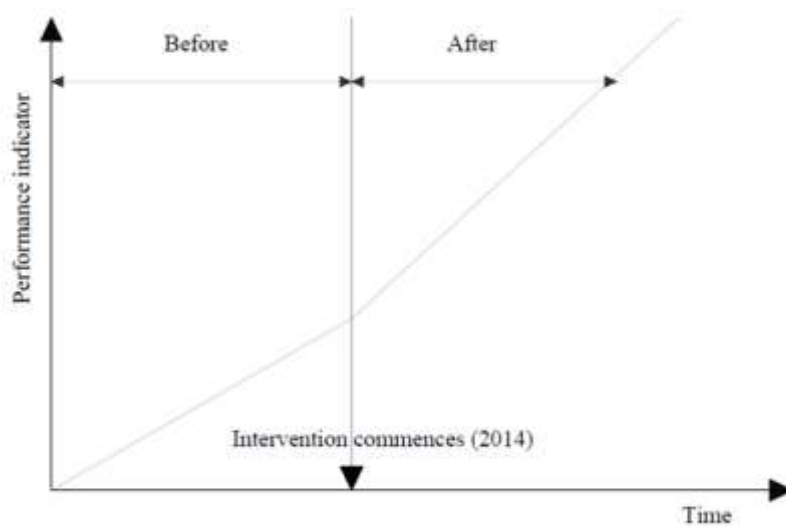


Figure 3.1: Favourable results after introducing an intervention (modified by author)

Figure 3.2 shows the 'adverse results' on a performance indicator, obtained after the introduction of an intervention:

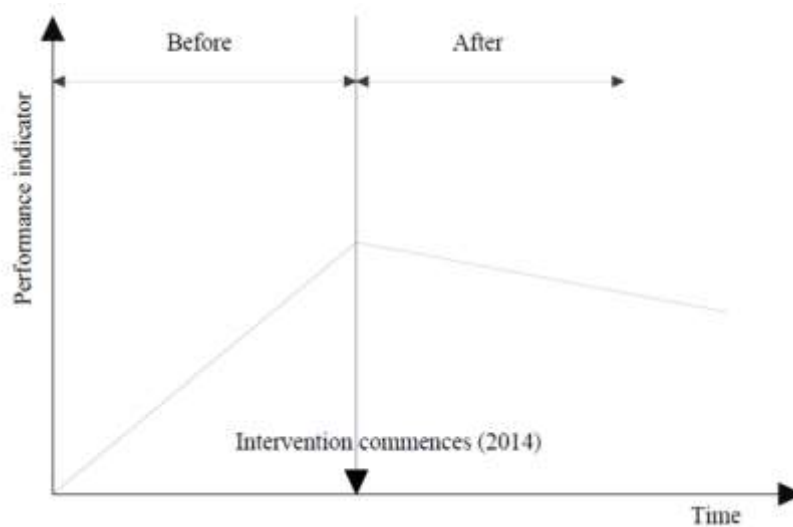


Figure 3.2: Adverse results obtained as a result of the applied intervention (modified by author)

Figure 3.3 shows the situation when the ‘results’ on a performance indicator are not affected by the intervention being applied:

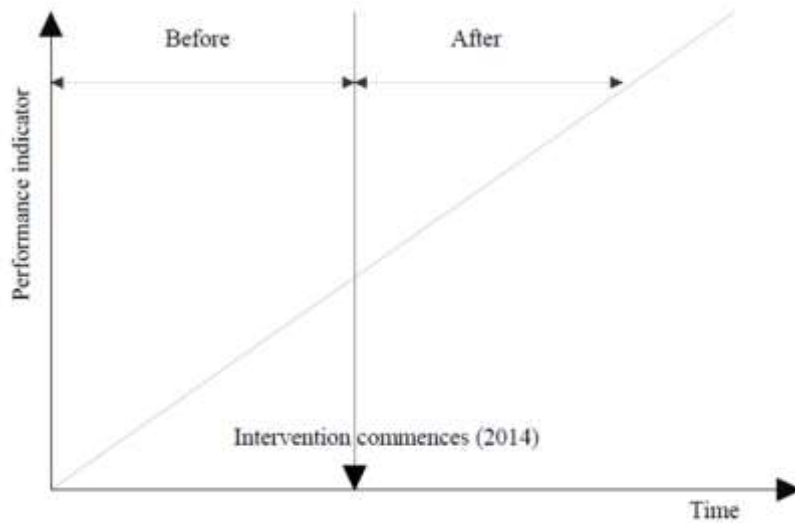


Figure 3.3: Results are not being affected by the applied intervention (modified by author)

d) PEST Analysis

This method of analysis focuses mainly on the influences of the Political, Economic, Social and Technological variances on the introduced strategy or intervention. When used with other internal drivers and external micro-environmental factors, the PEST factors can be classified as either opportunities or threats in a SWOT analysis. “A PEST analysis most commonly measures a market” (Chapman, 2017).

e) Gap Analysis

This analysis compares the actual performance with the potential or desired (projected) performance i.e. the ‘current state’ and the ‘desired future state’. The most important aspect of Gap analysis is its ability to identify the corrective actions to be under-taken. The difference between actual performance and the set benchmarks, are the existing ‘Gaps’. At an organisational level, the Gap analysis is used in developing a strategy to move the organisation from the existing state to the envisioned future state (Emery, 2017).

3.3 Adopted Methods for Data Collection and Analysis

3.3.1 Adopted Method for Strategy Evaluation

The ‘**before-and-after**’ analysis offers very good evidence of the effectiveness or otherwise of the intervention, which is very useful in demonstrating the immediate impacts of any strategy with a defined starting point. It was therefore adopted for application in undertaking the assessment of the performance of the current non-revenue water strategy at Lusaka Water and Sewerage Company.

3.3.2 Adopted Data Collection Methods

This research is a mixed method type of research which will use both qualitative and quantitative approaches in data collection and analysis. Therefore, in this research, the following methods will be used for field data collection;

- Participant Observation;
- Questionnaire;
- Key Informant Interviews; and
- Data review or Document review.

It is in the view of the researcher that the methodologies chosen above are more appropriate for this research as it is focusing on a given locality for a defined period of time, with the focus on the management of non-revenue water a case study of the city of Lusaka where Lusaka Water and Sewerage Company operates. This will help the researcher, for instance, to ask open ended questions to the key informants who will in turn have the freedom to answer them in their own best way possible thereby exhausting all the angles in a given situation. In addition, this methodology will allow the researcher to add additional questions to the ones prepared thereby ensuring flexibility in the way questions will be phrased.

Furthermore, the researcher will use a qualitative participant observation approach where he will be involved with field workers as they carry out their water loss reduction activities, whilst taking note of how things are being done. On the other hand, some aspects like the levels of implementation of the NRW strategy by the different branches, the sources of physical and commercial losses and their contribution to the overall NRW levels will require the use of a questionnaire because the statistics are unique to each branch.

3.4 Preparation for Field Work and Data Collection

3.4.1 Research Permission and Ethical Issues

After presenting the researcher's introductory letter (dated 8th June, 2016) from the University of Zambia School of Engineering (Civil & Environmental Engineering Department) to the Director – Human Resources & Administration at LWSC headquarters, an authorisation letter (dated 25th August, 2016) allowing the researcher to conduct the intended research at LWSC was issued which gave him access to information from different departments which were of importance to the research topic.

On the other hand, all key informant interviews were conducted on the premise of anonymity of the interviewees. This was to ensure that the participants were availed the most conducive environment to express themselves without fear of being identified by their superiors. This in turn gave rise to a free and open interaction between the researcher and the interviewees. Political considerations were also made in conducting this research so as to ensure that the research does not attract any political attention which would hamper the process of conducting the research owing to the fact that the research was conducted on a Parastatal Company which is politically sensitive.

3.4.2 Data Review or Document Review

The following documents were obtained from the different departments at LWSC headquarters:

1. The 'Non-Revenue Water strategy 2014' for the reduction of NRW from 48% to more economic levels of around 25%
2. 'Summary list of the total number of customers', stating those which are metered and the ones not metered
3. 'Inception Report for the assessment of Pre-paid metering model at Lusaka Water and Sewerage Company'
4. 'Assessment report of Pre-paid metering model at Lusaka Water and Sewerage Company'
5. 'Non-Revenue Water master copy Report with Dashboard for the period from 2011 to 2016'
6. 'LWSC Organisation Structure: Executive management, Information technology and Commercial Services'

7. 'Questionnaire Analysis for the Pre-paid Metering model by the Managing Director's task team, 2016'.

3.4.3 Key Informant Interviews

The interviews were conducted in line with the questions prepared to guide the researcher in the field (see Appendix B). The questions were prepared in line with the IWA recommendation on the management of water losses in distribution systems. The respondents were divided into two groups, with the first group comprising of the members of staff from Lusaka Water and Sewerage Company at Branch level in Lusaka City and the second group comprising of members of staff from the Headquarters in Lusaka. The respondents in both groups were a combination of top and mid-management staff members.

3.4.3.1 Mode of conducting interviews

The interviews were conducted in line with the questions which were prepared to guide the researcher in the field (see Appendix B). The questions were developed based on the IWA recommended 'best practices' in managing non-revenue water. The respondents were divided into two groups, with the first group comprising of the Lusaka Water and Sewerage Company members of staff from branches in Lusaka city and the second group comprising of members of staff from the head office in Lusaka. The respondents in both groups mainly fall under the mid- and top management category. Therefore, the respondents were coded from N1 to N24, with 'N1 to N11' being respondents from the branches, and 'N12 to N24' from the head office. A lot of issues were raised in the field as having a major influence on the management of NRW. But for ease of analysis, they were grouped into the following themes:

- i. Capacity Building (CB);
- ii. Technical (T);
- iii. Organisation Structure (OS);
- iv. Logistical (L);
- v. Socio-Cultural (SC); and
- vi. Statutory Obligation (SO).

Table 3.2 shows the members of staff from LWSC who were interviewed.

Table 3.2: LWSC staff members interviewed

NO.	STAFF MEMBERS INTERVIWED	DATE
1	Branch Engineer – Kabulonga	30/03/17
2	Billing Officer – Kabulonga	30/03/17
3	Branch Engineer – Kabwata	30/03/17
4	Senior Engineer – Water Supply	31/03/17
5	Manager – Technical Services	31/03/17
6	Branch Engineer – Lumumba	03/04/17
7	Branch Manager – Kabwata	03/04/17
8	Manager – Maintenance	03/04/17
9	Branch Manager – Chelstone	04/04/17
10	Branch Engineer – Central	04/04/17
11	Branch Engineer – Chelstone	04/04/17
12	Senior Engineer – Infrastructure Management	06/04/17
13	Manager – Peri-urban	06/04/17
14	Manager – Audit & Inspectorate	06/04/17
15	Manager – Finance	06/04/17
16	Senior Engineer – Planning & Design	06/04/17
17	Manager – GIS	06/04/17
18	Engineer – GIS	06/04/17
19	Engineer – Planning & Design	06/04/17
20	IT Specialist - IT	07/04/17
21	Senior Engineer – Network Analysis	07/04/17
22	Director – Commercial Services	07/04/17
23	Branch Manager - Central	07/04/17
24	Manager - NRW	08/04/17

3.4.4 Field Participant Observation

The researcher took two trips to two different branches, namely Chelstone and Lumumba Branches, to acquaint himself with the processes involved in carrying out the NRW reduction activities such as leakage repair and pressure control. These trips helped in validating the responses from the respondents. Challenges faced by the company personnel in conducting these activities were also observed and noted during these trips.

3.5 Chapter Summary

The main focus of this chapter was primarily to identify the theoretical leanings of the different research techniques which have a direct influence on the selection criteria of the most appropriate methodological approach to be used. Hence the choice of the procedures to be followed during data collection, the type of data to be collected and the data analysis techniques was made in this chapter.

The expression of the theoretical or philosophical leanings of the different techniques resulted in the classification of this research as principally being a mixed method type of research which will use both qualitative and quantitative approaches in data collection and analysis. The specific methods used for data collection and analysis in this research were chosen as being; Participant Observation; Questionnaire; Key Informant Interviews and Data review or Document review. The next chapter is concerned with data collection, presentation and a brief interpretation of data.

CHAPTER FOUR: RESEARCH FINDINGS

4.1 Introduction

This chapter presents the field data collected from the questionnaires, participant observation, key informant interviews and data review or document review. The qualitative data collected from interviews was grouped into themes which represented a common basis in the responses.

The insights gathered from the literature review were used to conceptualize the data through fragmentation in order to allow for the emergence of core categories from which the various phenomenon are identified. The knowledge from literature review was further used as a guide to ensure that the questions for both the questionnaire and the interviews were in line with the IWA recommended good practices in the management of non-revenue water.

4.2 Findings from the Interviews

4.2.1 Causes of Non-Revenue Water

Table 4.1 gives a summary of the emerging themes from the interviews about the perceived causes of non-revenue water in Lusaka City.

Table 4.1: Respondents' perceived causes of NRW in Lusaka

RESPONDENTS	THEMES					
	CB	T	OS	L	SC	SO
N1	✓	✓				
N2		✓	✓			✓
N3	✓	✓				
N4				✓	✓	
N5	✓	✓	✓			
N6			✓			✓
N7	✓	✓		✓		
N8	✓				✓	✓
N9		✓		✓		
N10		✓				
N11	✓	✓	✓			
N12		✓	✓			✓
N13			✓		✓	
N14		✓		✓		
N15		✓	✓			
N16		✓	✓			

RESPONDENTS	THEMES					
	CB	T	OS	L	SC	SO
N17					✓	✓
N18	✓	✓				
N19		✓		✓		
N20		✓				✓
N21			✓			✓
N22		✓			✓	
N23	✓	✓		✓		
N24		✓	✓			
Total	8	18	10	6	5	7
% Contribution	15%	33%	19%	11%	9%	13%

[Key: CB = capacity building; T = Technical; OS = organisation structure; L = logistical; SC = socio-cultural; and SO = statutory obligation]

4.2.1.1 Capacity Building (CB)

- i. Special NRW capacity building programs to educate the staff members about the effective ways of managing NRW as well as best practices to prevent water losses at branch level were not adequate.
- ii. When the company holds any form of workshop where each branch is required to send at least one or two representatives for training e.g. a plumber, meter reader, etc., there's always a component of NRW in the topics to be discussed, but such meetings are rare maybe once per year or none.
- iii. More training for LWSC staff members, in some of the recommended IWA water loss management practices, is required.
- iv. Lusaka Water and Sewerage Company embarked on a non-revenue water capacity building program which resulted in the creation of the Non-Revenue Water Department.

4.2.1.2 Technical (T)

- i. Calculating the NRW for physical losses is easier compared to the commercial losses
- ii. The performance indicator used is the expression of NRW as a percentage of the system input volume

- iii. NRW is calculated based only on post-paid and fixed charged customers, while the other component from pre-paid customers is estimated
- iv. Not all customers are metered and not all the necessary water supply points have bulk meters, and some of those which have are not working due to old age or mere malfunctioning
- v. The infrastructure (water network) in general is highly dilapidated
- vi. Pressure management is rarely done at the moment because the system pressures have drastically dropped in recent times due to an increased number of new connections without expanding the capacity of the network. Therefore, pipe bursts and leakages due to high pressure in the system are very rare
- vii. Some existing infrastructure (water network) have materials which are difficult to repair or replace because they are no longer used in the water sector e.g. AC pipes (Asbestos Cement pipes) and iron pipes
- viii. There is no periodic maintenance of the infrastructure because currently the company only responds to reported leakages or those observed on the surface, so some parts of the water network have been built-upon by the public. Thereby needing a thorough network verification and remapping exercise promptly.

4.2.1.3 Organisation Structure (OS)

- i. There is a shortage of personnel to attend to all the reported leakages in branches as was evident in one of the branches where on average they receive 600 complaints (leakage related) per month, i.e. 150 per week and 30 per day, all this against 5 plumbers at the branch (i.e. 6 per plumber per day)
- ii. Most of the staff members from the branches were of the view that the NRW Department needs to be decentralised to branch level, so that there can be a dedicated group to carryout NRW reduction activities
- iii. LWSC staff members connive with the customers in water theft activities such as illegal connections, meter by-passes and illegal reconnections for the disconnected customers
- iv. There is no clear-cut separation of the roles and responsibilities of some departments involved in NRW reduction activities
- v. Meter readers stay in one branch for far too long

- vi. The NRW strategy was not well known mostly among the mid-management staff in branches and some top management personnel from headquarters

4.2.1.4 Logistical (L)

- i. There is no proactivity in active leakage control and repairing of leakages because the necessary materials to carry out these activities are in constant short supply. This leads to a single leak on a connection line to take 3 days to be repaired, while those on supply lines take 7 days. All this against the ‘immediate’ action recommended for best practice, once a leak is detected.
- ii. The short supply of the necessary materials for repairs has led to an increase in ‘Temporal Works’ e.g. using rubber bands and plastics to repair leaks, thereby compromising on the quality of the repairs.
- iii. Transportation of the field workers i.e. meter readers, technicians, plumbers and other personnel was also a major concern

4.2.1.5 Socio-Cultural (SC)

- i. Bad attitude towards leak management by company personnel leads to delays in doing repairs
- ii. Some members of the public feel they shouldn’t pay for water because it is freely given to them by God and wonder why they should pay for something they consider to be a gift to them, thereby involving themselves in illegal connections, meter bypasses, at times even conniving with the company personnel to alter meter readings

4.2.1.6 Statutory Obligation (SO)

- i. Some government agencies and departments draw water from the fire hydrants purported to be for disaster management when in fact not
- ii. Fire engines sometimes draw water from the fire hydrants in the name of firefighting when in fact not
- iii. Some areas are left to be on fixed charge basis due to directives from the regulatory body – NWASCO

- iv. Some areas with poor service delivery by the utility company are put on ‘Suspended Billing’ by the regulatory body – NWASCO, until normal service is attained.

4.3 Questionnaire

4.3.1 Contribution to non-revenue water

Table 4.2 shows the respondent’s views on the individual quantity contribution of physical losses, commercial losses and unbilled authorised consumption on the overall level of non-revenue in Lusaka. The ranking scale used was: high = 3; moderate = 2; and low = 1.

Table 4.2: Respondents’ views about the constituents of NRW

Respondents	NRW Components		
	Real Losses	Apparent Losses	Unbilled Authorised consumption
N1	2	3	1
N2	3	2	1
N3	2	3	1
N4	2	3	1
N5	3	2	1
N6	2	3	1
N7	3	2	1
N8	2	3	1
N9	3	2	1
N10	3	2	1
N11	2	3	1
N12	3	2	1
N13	3	2	1
N14	3	2	1
N15	3	2	1
N16	3	2	1
N17	3	2	1
N18	2	3	1
N19	3	2	1
N20	3	2	1
N21	3	2	1
N22	3	2	1
N23	3	2	1
N24	3	2	1

Respondents	NRW Components		
	Real Losses	Apparent Losses	Unbilled Authorised consumption
Sum Total	65	55	24
Grand Total	144		
% Contribution	45	38	17

4.3.2 Sources of Physical Losses

Table 4.3 shows a summary of the respondent's perceived sources of physical losses in Lusaka. The weighting scale used was: very high = 5; high = 4; moderate = 3; low = 2; and very low = 1.

Table 4.3: Sources of physical losses

Sources of Physical Losses	Weighting				
	1	2	3	4	5
Pressure Management		✓			
Poor State of Infrastructure					✓
Leakages and Pipe Bursts				✓	
Bad attitude and negligence (By Staff)		✓			

4.3.3 Sources of Commercial (apparent) Losses

Table 4.4 shows a summary of the respondent's perceived sources of commercial losses in Lusaka. The weighting scale used was: very high = 5; high = 4; moderate = 3; low = 2; and very low = 1.

Table 4.4: Sources of commercial losses

Sources of Commercial Losses	Weighting				
	1	2	3	4	5
Human Errors	✓				
Water Theft				✓	
Metering Errors					✓
Computing Errors	✓				

4.3.4 Level of Implementation of the NRW Management Practices

In order to check how well the International Water Association (IWA) recommended practices in managing non-revenue were being implemented in Lusaka, a rating scale was used to concisely determine the levels of implementation.

Physical Losses

The rating scale used to measure the level of implementation of management practices for physical losses was: very highly implemented = 5; highly implemented = 4; moderately implemented = 3; lowly implemented = 2; and not implemented = 1. The results obtained are shown in table 4.5:

Table 4.5: Level of implementation of management practices for physical losses

Management Practice	Rating				
	1	2	3	4	5
Active Leakage Control		✓			
Speed and Quality of Repairs			✓		
Pressure Management			✓		
Infrastructural Management				✓	

Commercial Losses

The rating scale used to measure the level of implementation of management practices for commercial losses was: very highly implemented = 5; highly implemented = 4; moderately implemented = 3; lowly implemented = 2; and not implemented = 1. The results obtained are shown in table 4.6.

Table 4.6: Level of implementation of management practices for commercial losses

Management Practice	Rating				
	1	2	3	4	5
Reduction of metering errors		✓			
Reduction of Human errors			✓		
Water Theft Reduction		✓			
Reduction of Computing Errors				✓	

Unbilled Authorised Consumption

In order to measure the level of implementation of management practices for unbilled authorised consumption, the scale used was: very highly implemented = 5; highly implemented = 4; moderately implemented = 3; lowly implemented = 2; and not implemented = 1. The results obtained are shown in Table 4.7:

Table 4.7: Management practices for unbilled authorised consumption

Management Practice	Rating					NOTES
	1	2	3	4	5	
Unbilled Authorised Consumption				✓		There are very few users in this consumption category, except in instances of a disaster where water is drawn by the disaster management and mitigation unit, and at times misuse by the fire engines contribute a huge amount. Otherwise all other customers are billed, including government institutions and departments.

4.4 Document Review

Table 4.8 gives the current status in terms of the number of customer connections, categorizing them into metered and unmetered connections.

Table 4.8: Metering statistics (as at March, 2017)

	REGISTERED	BILLED	UNBILLED
Total Number of Connections	97,477	91,649	5,828
Metered Connections	47,215	44,392	2,823
Unmetered Connections	50,262	47,257	3,005

Source: LWSC – commercial services department

$$\text{Metering Efficiency (ME)} = \frac{N}{L} \times 100,$$

Where; N = Number of metered connections

L = Total number of connections

$$\text{M.E} = (47215/97477) \times 100 = 48.44\% = \mathbf{48\%}$$

Note: All other information obtained from the indicated Literature in section 3.4.2 was analysed and plotted into graphs which are presented in chapter 5 from section 5.2 to 5.5.

4.5 Participant Observation

Figures 4.1 to 4.4 show the different leakage situations observed from the field.



Figure 4.1: Burst PVC pipe



Figure 4.2: High system pressures



Figure 4.3: Sign of underground pipe leakage



Figure 4.4: Damaged AC and GI pipes respectively

CHAPTER FIVE: DATA ANALYSIS AND DISCUSSION

5.1 Introduction

The findings in this research indicate that the NRW is a huge challenge for the water utility company as it was very evident that the value of NRW being quoted is to a greater extent not a true reflection of what is on the ground. This is mainly because there are too many estimations in calculating the value for NRW, which makes it virtually be a mere guess.

The International Water Association (IWA) has set up activities or management practices known as ‘Good Practices’ which should be undertaken in order to manage or reduce real losses and apparent losses. For real losses, Active leakage control, Speed and quality of Repairs, pressure management and Infrastructure Management are the IWA recommended ‘Good Practices’, while reduction of Metering Errors, reduction of Human Errors, Water theft reduction and reduction of Computing Errors are for apparent losses.

As a consequence, LWSC developed a ‘Non-Revenue Water Strategy’ to help curb the high non-revenue water levels which have a negative impact on the company’s revenues. This strategy emphasizes on the accurate determination of all parameters from production, supply to branches/zones up to consumption by all the customers, because this would help understand the accurate size of the problem before identifying corrective course of action to reduce losses. The strategy has also emphasized the need to adhere to the guidelines provided for by IWA for improving the operational efficiency of a water network in order to sustain a good performance.

5.2 Management of Non-Revenue Water

The causes of NRW are diverse, but for ease of analysis they were grouped into themes (section 4.2), which indicated that the major causes of NRW at Lusaka Water and Sewerage Company are technical issues (33%) (Figure 5.1), with the least causes being Socio-Cultural (9%) issues. Technical issues include; mode of calculating NRW, performance indicator used, customer metering, state of the infrastructure and inconsistent periodic maintenance. While Socio-Cultural issues include; bad attitude of company personnel and the notion by members of the public who don’t want to pay for the water because they feel it’s a free resource given to them by God hence no need to pay for it.

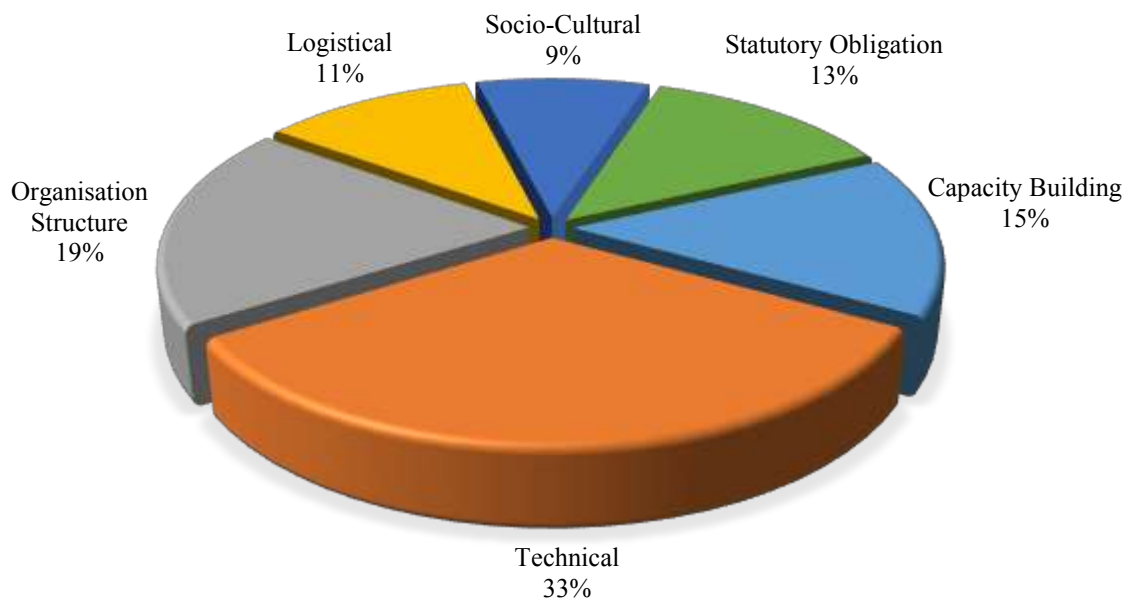


Figure 5.1: Respondents' views about the Causes of NRW

Other notable causes of NRW in Lusaka included the Organisation Structure (19%), logistics (11%), Capacity Building (15%) and Statutory Obligation (13%). Notable issues from these include; the NRW department as well as the Inspectorate and branches are understaffed (for instance in one branch considered, 150 leakage related complaints were received per week against 5 plumbers i.e. 6 cases per plumber per day), the NRW department needed to be decentralised to branch level, no clear-cut separation of the roles and responsibilities of some departments involved in NRW reduction activities e.g. Technical Services Department and NRW Department.

Some areas with poor service delivery by the utility company are put on 'Suspended Billing' by the regulatory body, leading to a huge amount of water being supplied to these areas without collecting any revenue in return.

Further, it was noted that meter readers stay in one branch for far too long which provides an avenue for them to be involved in malpractices by conniving with the customers to alter the meter readings or sometimes even deliberately putting wrong Figures in exchange with a bribe. The NRW Strategy including its contents are not well known at branch level with some staff members literally denying ever seen it, at the same time there's no proactivity in active leakage control and repairing of leakages because the necessary materials to carry out these activities

are in constant short supply (a leak on supply lines may even take 7 days to be repaired – leading to too many ‘temporal works’ e.g. using rubber bands).

Transport for the field workers was also discovered to be a big challenge, coupled with bad attitude of some company personnel. On the other hand, water usage by the fire engines is one area which contributed quite a substantial amount of unbilled authorised consumption, where the estimated number of fire incidents in the city were not tallying with the amount of water drawn by the fire department for such incidences.

Lusaka Water and Sewerage Company has a total of 97,477 registered customers, of which 47,215 are metered and 50,262 are unmetered. Of the metered connections, 44,392 are billed, and for the unmetered connections, 47,257 are billed. Hence 94% (Figure 5.2) of the total connections are billed and only 6% are unbilled owing to several reasons for that including statutory obligation as directed by the regulatory body – NWASCO.

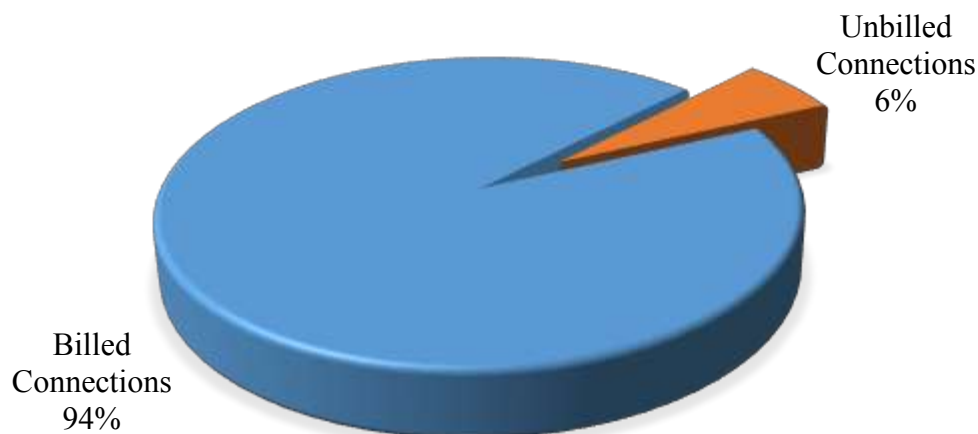


Figure 5.2: Billed Vs. Unbilled Connections

From Table 4.8, it can be seen that only 47,215 connections are metered, leaving the other 50,262 unmetered, giving a metering efficiency of 48% which is far from the 100% metering ratio recommended by IWA. But Figure 5.2 indicate that 94% of the connections are billed which implies that majority of the customers are on a ‘fixed charge’ system, which is not recommended because it’s not cost reflective and people tend to misuse water without reporting

leakages on their properties because they know that the bill is fixed no matter the amount of water used.

The components of non-revenue water are Real or physical losses, Apparent or commercial losses and Unbilled Authorised Consumption, each amounting to 45%, 38% and 17% respectively as shown in Figure 5.3. With the largest component of non-revenue water being real losses (45%) and the least being unbilled authorised consumption (17%).

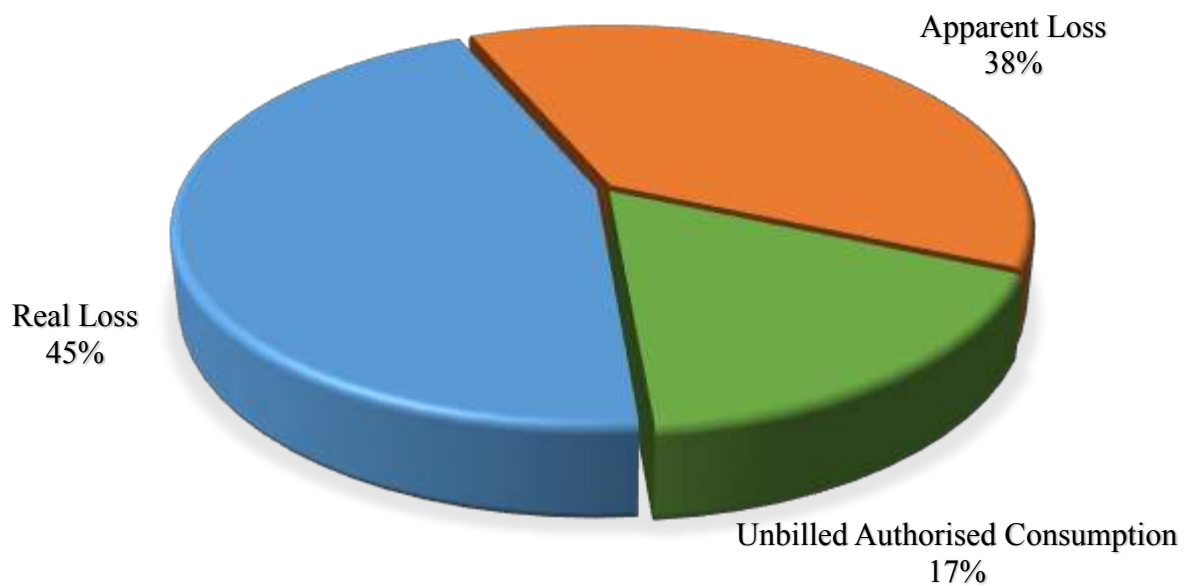


Figure 5.3: Components of Non-Revenue Water

Figure 5.3 shows that the Unbilled Authorised Consumption category contributes the least to non-revenue water, hence water loss through this category is lower than the other two categories. But in instances of a disaster where water is drawn by the Disaster Management and Mitigation Unit and at times misuse by the fire engines, a considerable amount of water is lost. The other major contributor of water losses in this category is the water being used at LWSC's own premises and previously in staff members' homes, though this situation was stopped and each staff is made to pay for the water they use. This has extended to other public institutions e.g. schools, colleges, hospitals as well as other government departments which initially used to get free water are now being billed. Therefore, water loss in this category is easier to control because the sources are well known and easier to apply some corrective measures, except fire engines which up to now still misuse water since they are protected by law so it's very difficult to monitor and correct their water use.

Figure 5.4 shows that the major source of real losses is the poor state of the infrastructure which leads to frequent leakages and pipe bursts. Pressure management and bad attitude or negligence of some members of staff have a low effect on the quantity of real losses. Pressure in the system has a low effect on the occurrence of leakages and pipe bursts mainly because initially the water network was designed for fewer customers compared to the current situation. Hence the average system pressure in the network is not the same as when the system was installed.

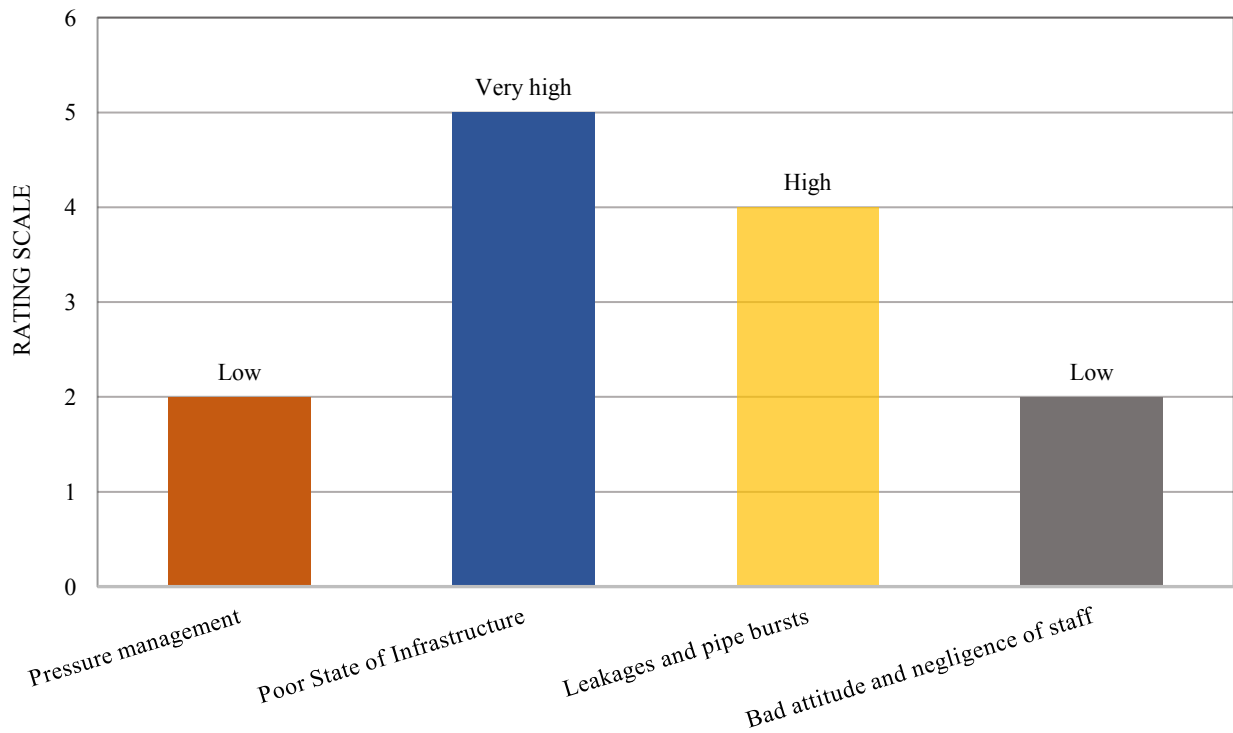


Figure 5.4: Sources of Physical Losses (Scale: 5 = very high, 4 = high, 3 = Moderate, 2 = low, 1 = very low)

On the other hand, metering errors contribute the highest to apparent losses though the contribution from water theft is also high. The contribution to apparent losses by human errors and computing errors is very low as can be seen in Figure 5.5. Metering errors are very prominent because of the occurrence of stuck meters and defective meters. A shortage of storage facilities in Lusaka has led to water from boreholes to be pumped directly into the water network causing the water meters to get stuck due to the sediments in the underground water.

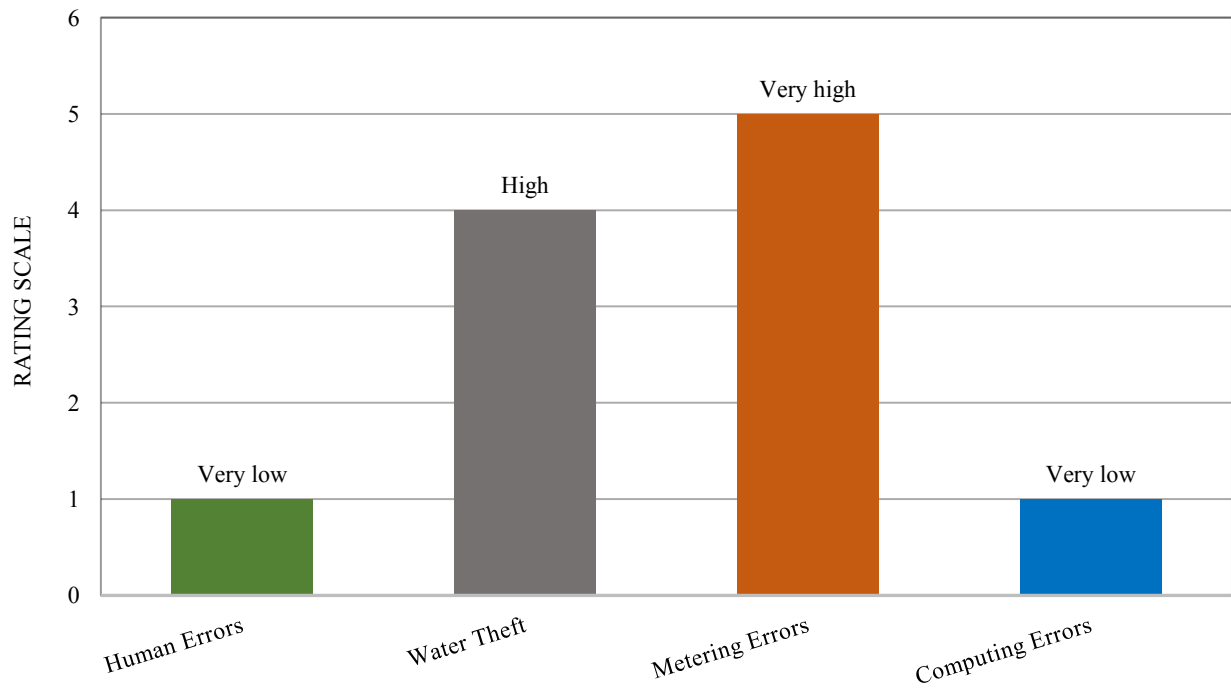


Figure 5.5: Sources of Apparent Losses (Scale: 5 = very high, 4 = high, 3 = Moderate, 2 = low, 1 = very low)

Water theft is also rampant in Lusaka where people have made meter bypasses or at times connive with some dishonest members of staff from LWSC, especially meter readers, to record wrong readings. This is partly because meter readers are left to be in one branch for too long where they end up making relations with the customers in the field. Human errors have been reduced through the use of two meter readers taking readings at the same time then compare the Figures to ensure that they both have the same reading. In like manner, computing errors are very low because the company uses a computer software known as EDAMS to compute all the monthly bills for the customers so as to eliminate human error in the computations.

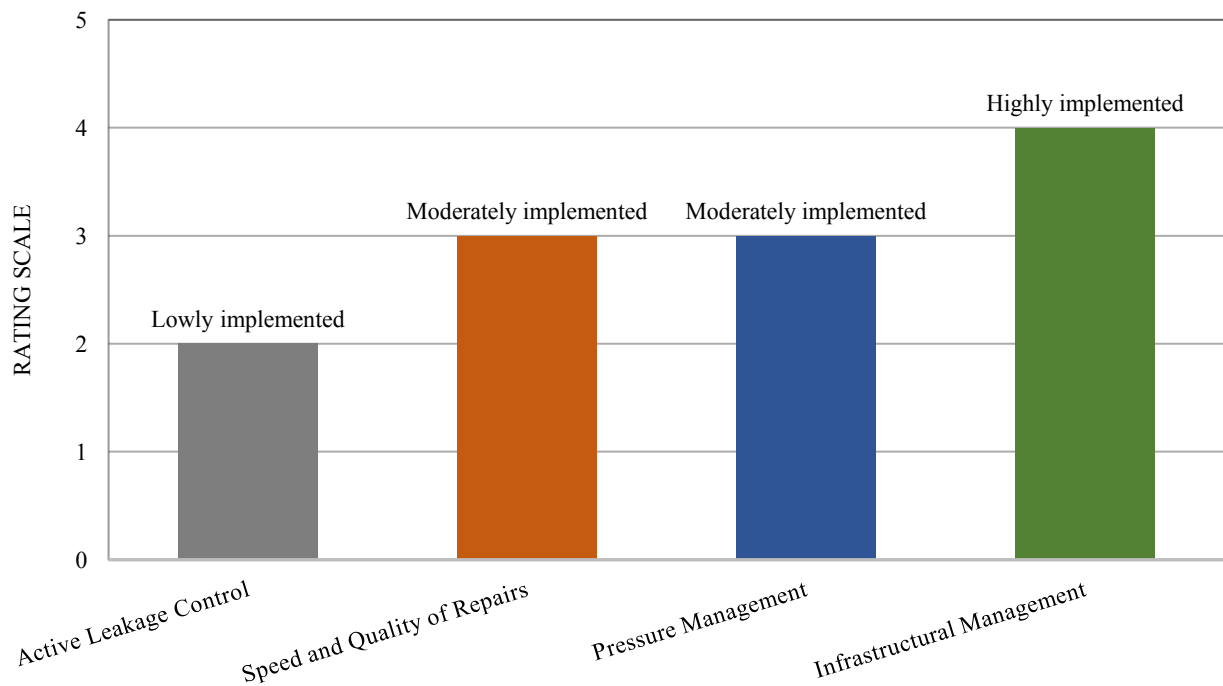


Figure 5.6: Level of implementation of management practices – Physical Losses

Though the company is on the right track in trying to reduce non-revenue water, it was discovered in this research that the implementation of the management practices in reducing non-revenue water is not in accordance with the recommended ‘Good Practices’ by the IWA.

As can be seen from Figure 5.6, Infrastructure Management is highly being implemented currently because from Figure 5.4 it was shown that the current state of the infrastructure is very poor which has led to a high number of leakages and pipe bursts. These major improvements in infrastructure have been necessitated through the ongoing projects under the Millennium Challenge Corporation through the Millennium Challenge Account Zambia involving the installation of a new water line from Iolanda in Kafue to Water Works, Stuart’s Park and Chelstone storage facilities in Lusaka, as well as the replacement of the entire water networks in about 14 selected districts within Lusaka.

To the contrary, active leakage control is non-existent in all the areas where the company operates. Therefore, there’s only passive leakage control where only the reported leaks and bursts which appear on the surface are attended to, though there are some efforts to locate new leaks using personnel from the Technical Services Department which is centralised making it practically impossible to attend to all the requests as and when required. Locating of new

underground leaks only takes place if there's an observed drastic drop in system pressures or no water from taps when pumping from the storage facility or borehole is underway.

Pressure management and Speed and Quality of repairs are moderately being implemented. Pressure management, in the case of high system pressure, is not very common because the current number of customers connected to the same old water network is way above the designed number mainly due to the rapid expansion of the city in the recent past. On the other hand, the Speed and Quality of repairs currently are poor and low because the materials to do these repairs are often times not available as and when required, leading to the use of temporal measures to seal off the leaks e.g. the use of rubber bands to temporarily close leakages. These temporal works may at times even stay for months before they are replaced with the right materials.

In the case of apparent losses as shown on Figure 5.7, reduction of computing errors has highly been implemented through the introduction of the computing software called EDAMS, which is used to do all the computations and billing.

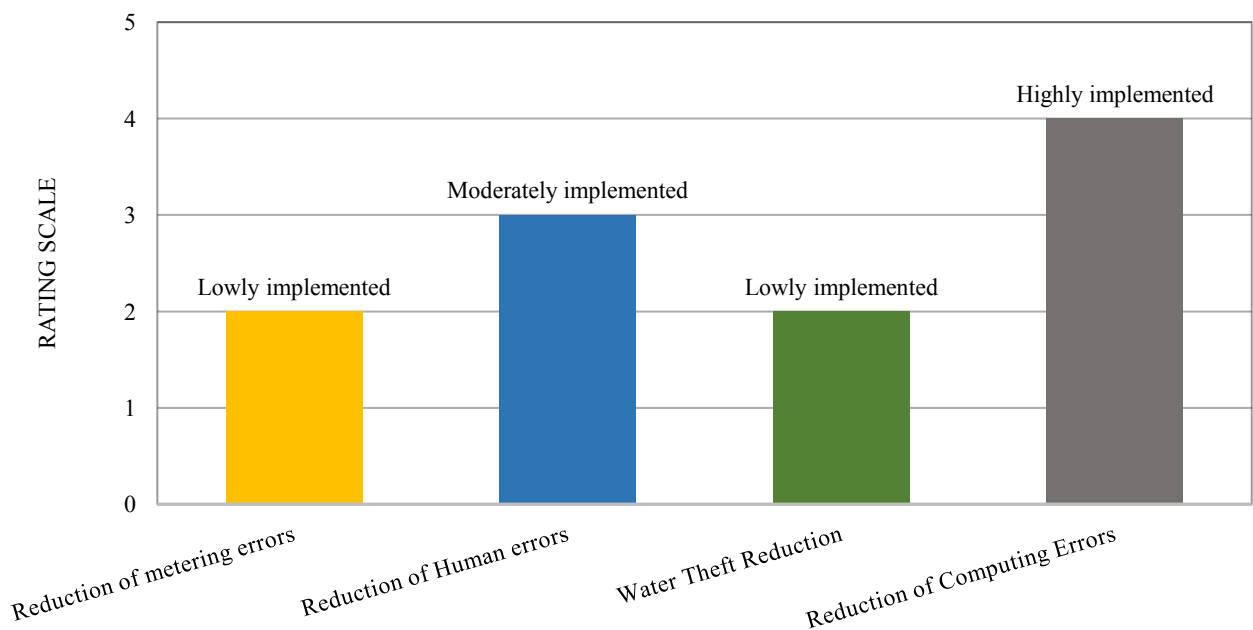


Figure 5.7: Level of implementation of management practices – Apparent Losses

Reduction of metering errors and water theft is lowly being implemented. Metering errors are considerably substantial because meters get stuck due to the presence of sediments from the water pumped directly into the system from boreholes. Some boreholes are not even metered so it is very difficult to determine how much water was supplied from those boreholes, leading to estimating the production and consumption for the given period of time.

In order to curb water theft, the company has created the Inspectorate Department which is mandated to carry out random checks on the properties to ensure that there is no water theft through illegal connections or meter bypasses. But this department has not yielded much success because it is centralised at head office, making it difficult for it to carry out its intended activities coupled with a shortage of personnel.

5.3 Annual Volumes of Water Sold (Branches & Peri-Urbans)

Lusaka town is divided into five (5) districts (Central, Chelstone, Kabulonga, Kabwata and Lumumba) which are made up of medium and high income areas, with Matero Zone being treated as a sixth district though it is comprised of low and medium income areas. On the other hand, low income areas known as Peri-Urbans are divided into three zones namely; Peri-urban East, Peri-urban South and Peri-urban West (see section 1.2.1 for the map).

During the period 2010 to 2016, as can be seen from Figures 5.8 to 5.12, there has been a drop in the total annual water sold to the customers.

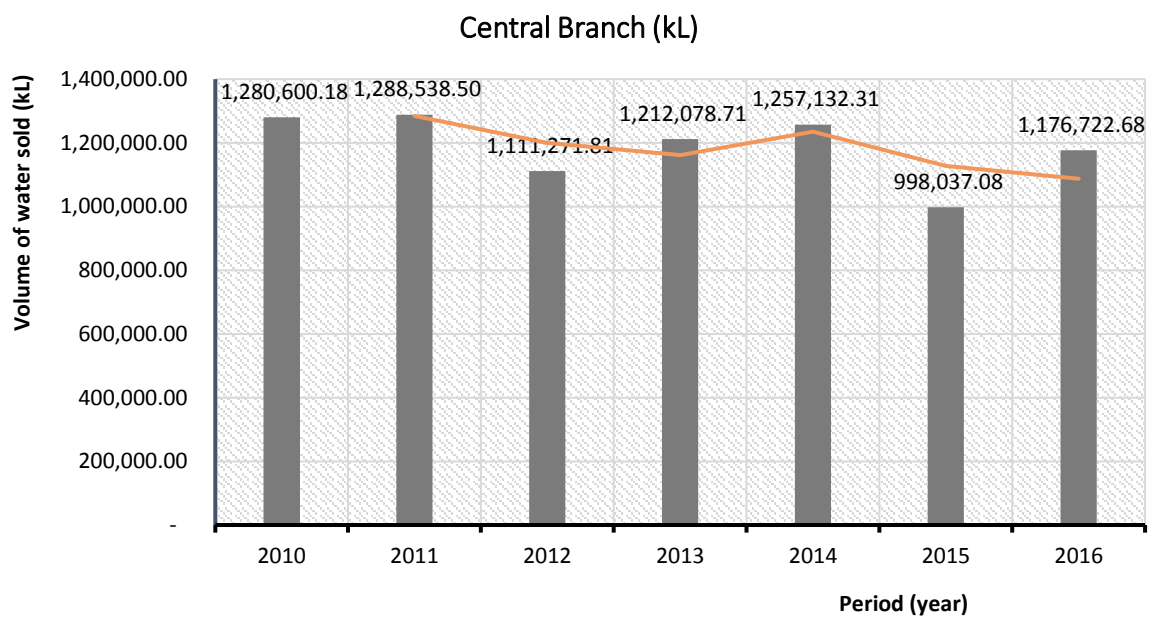


Figure 5.8: Average water sold for Central Branch (adopted from pre-paid metering report)

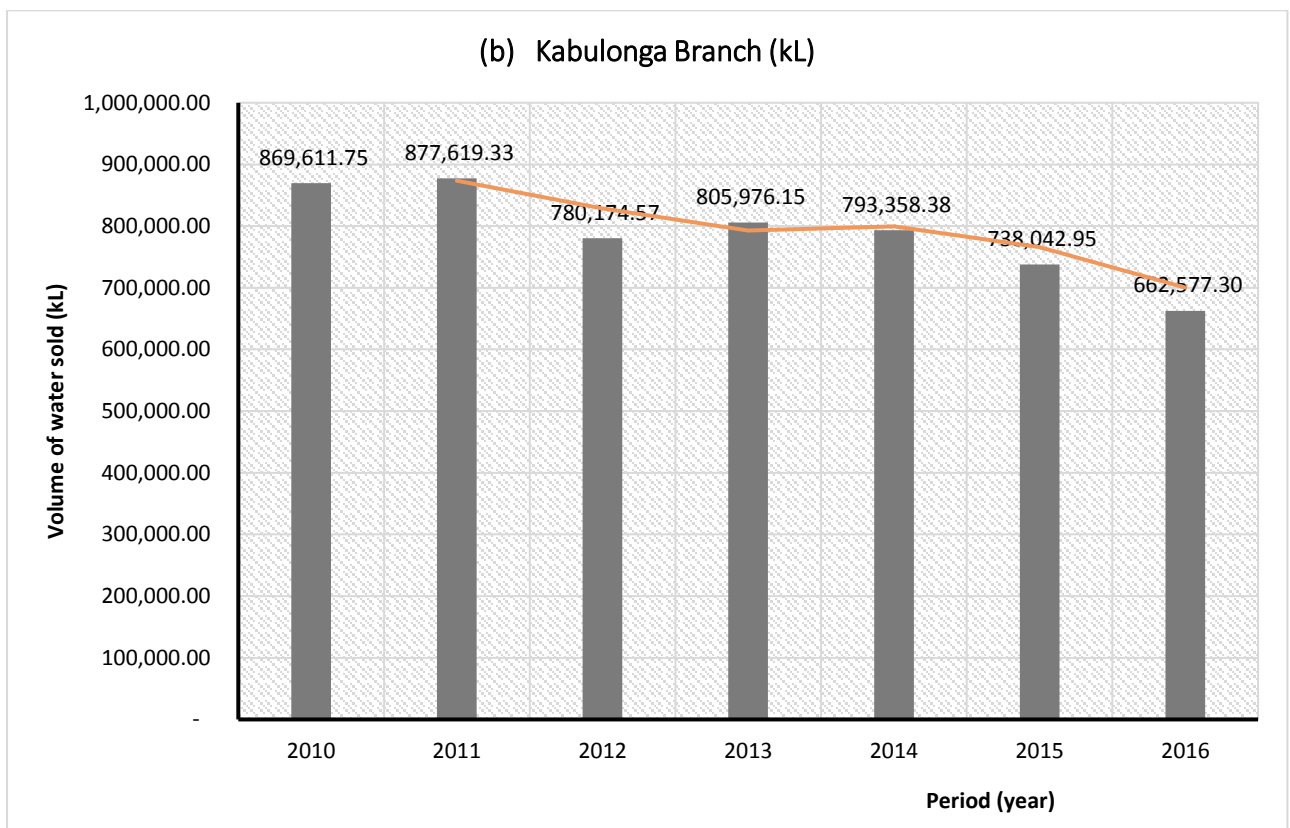
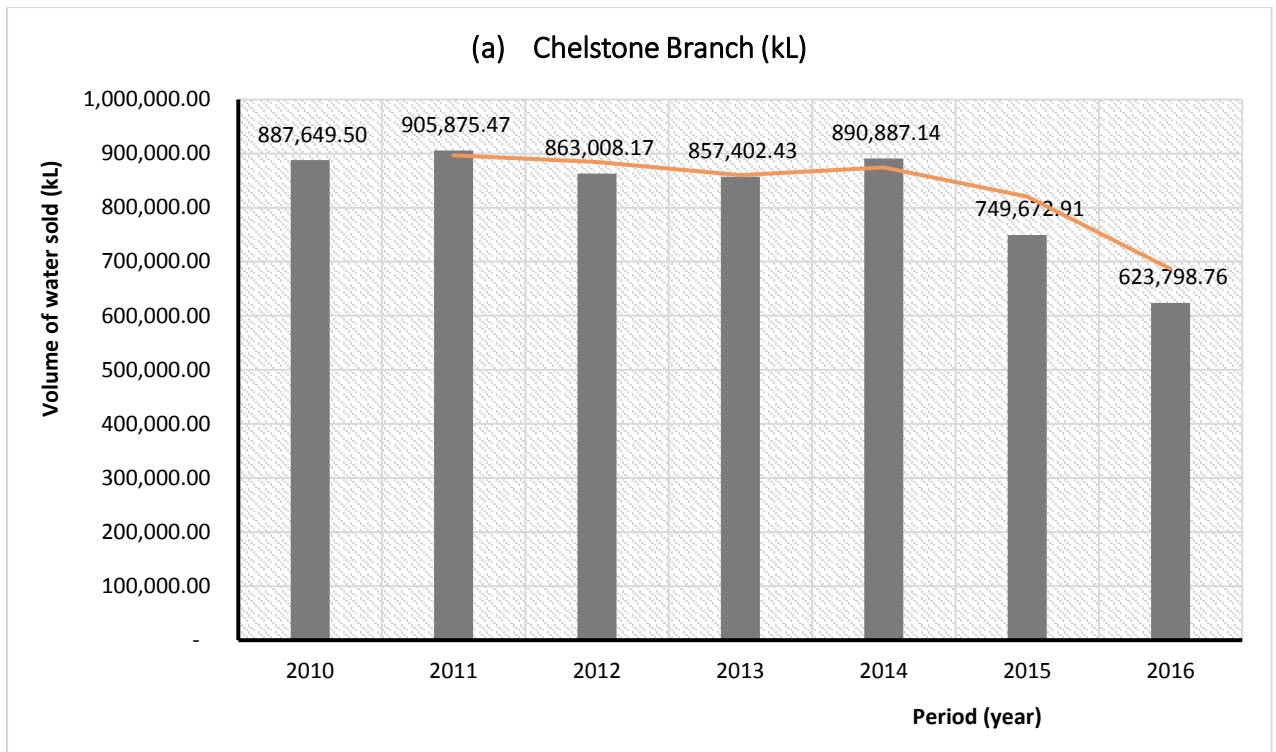


Figure 5.9: Average water sold for Chelstone and Kabulonga Branch (*adopted from pre-paid metering report*)

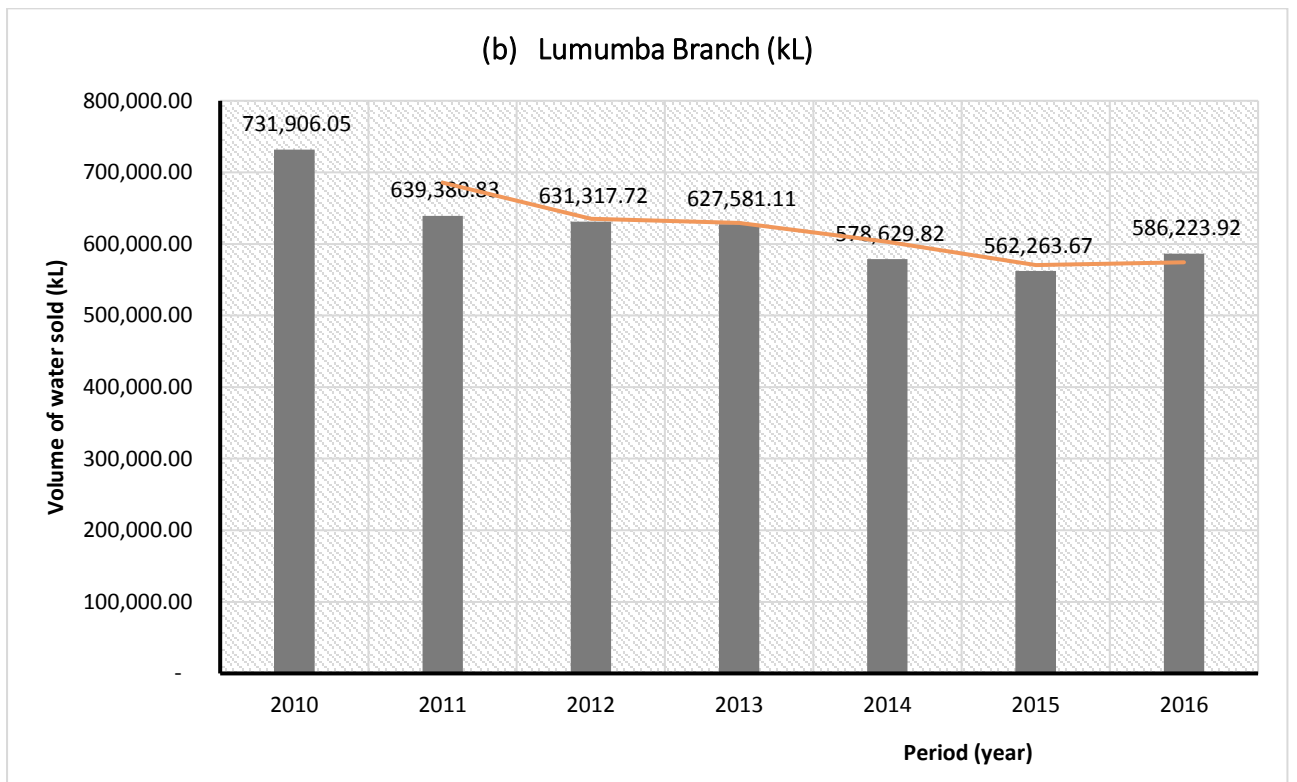
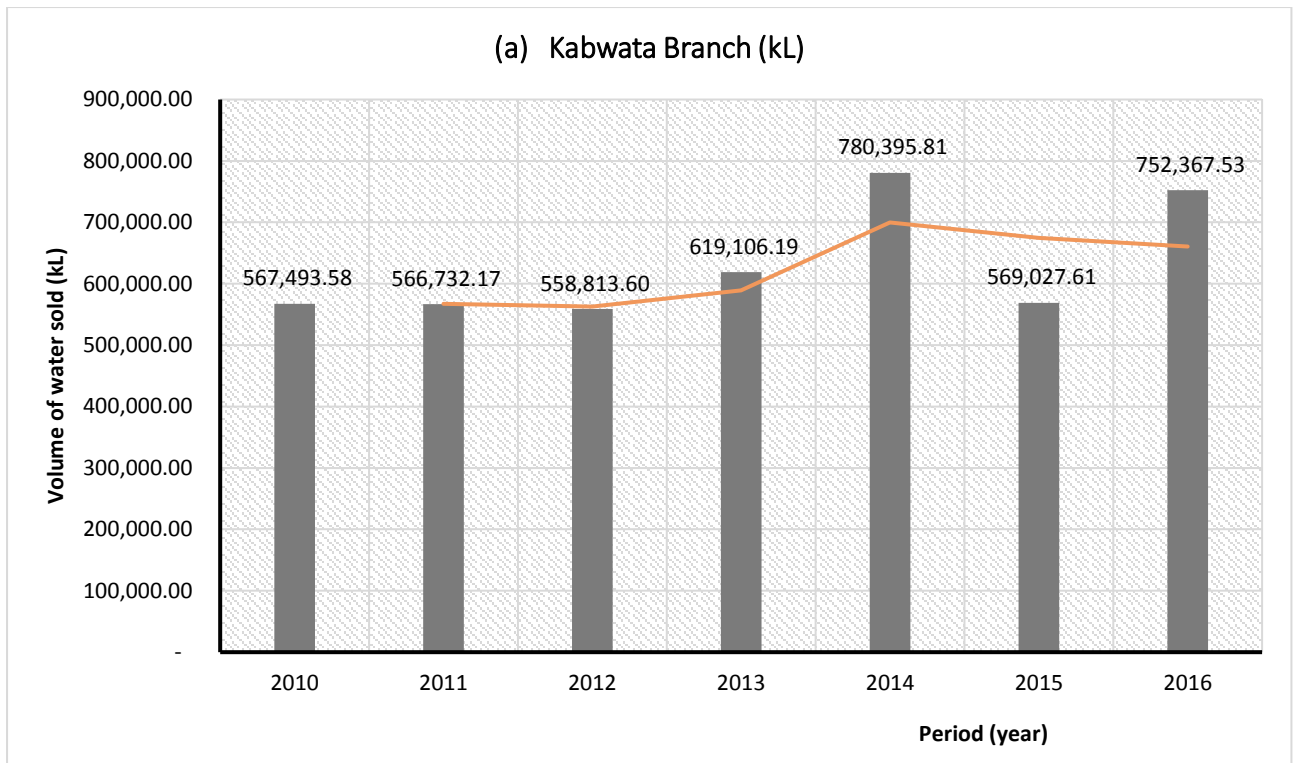


Figure 5.10: Average water sold for Kabwata and Lumumba Branch (*adopted from pre-paid metering report*)

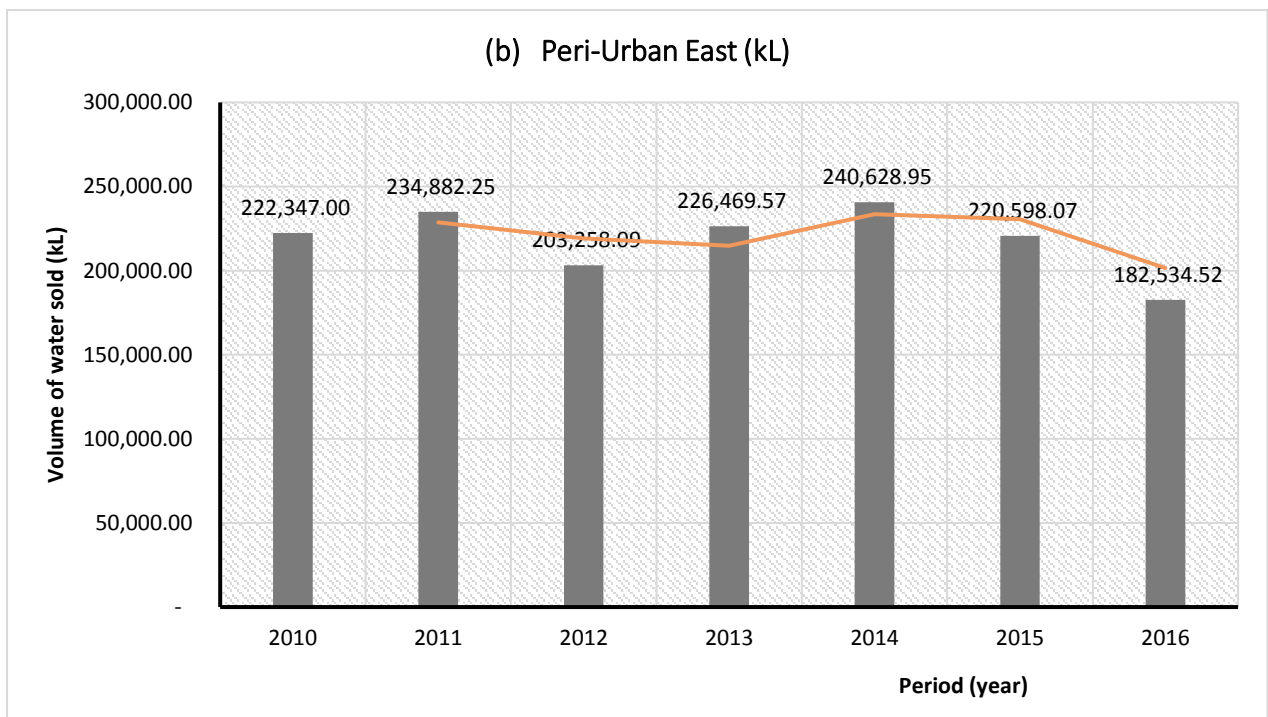
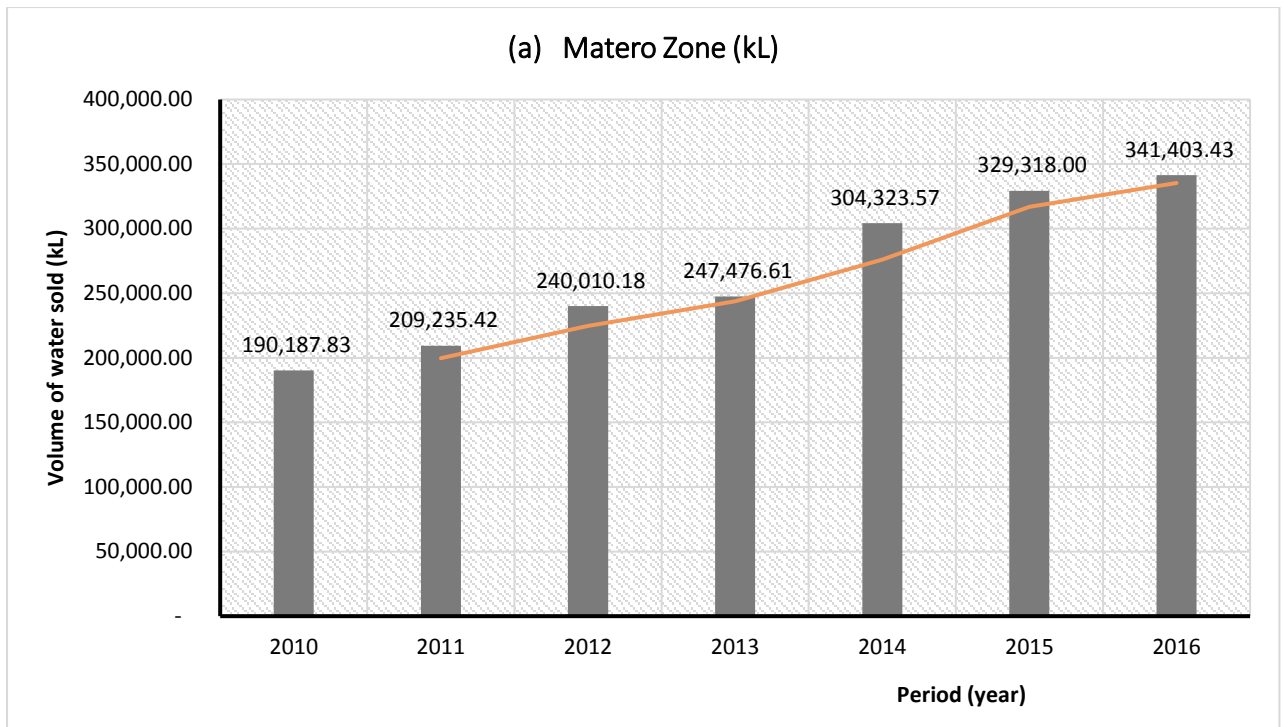


Figure 5.11: Average water sold for Matero Zone and Peri-Urban East (adopted from pre-paid metering report)

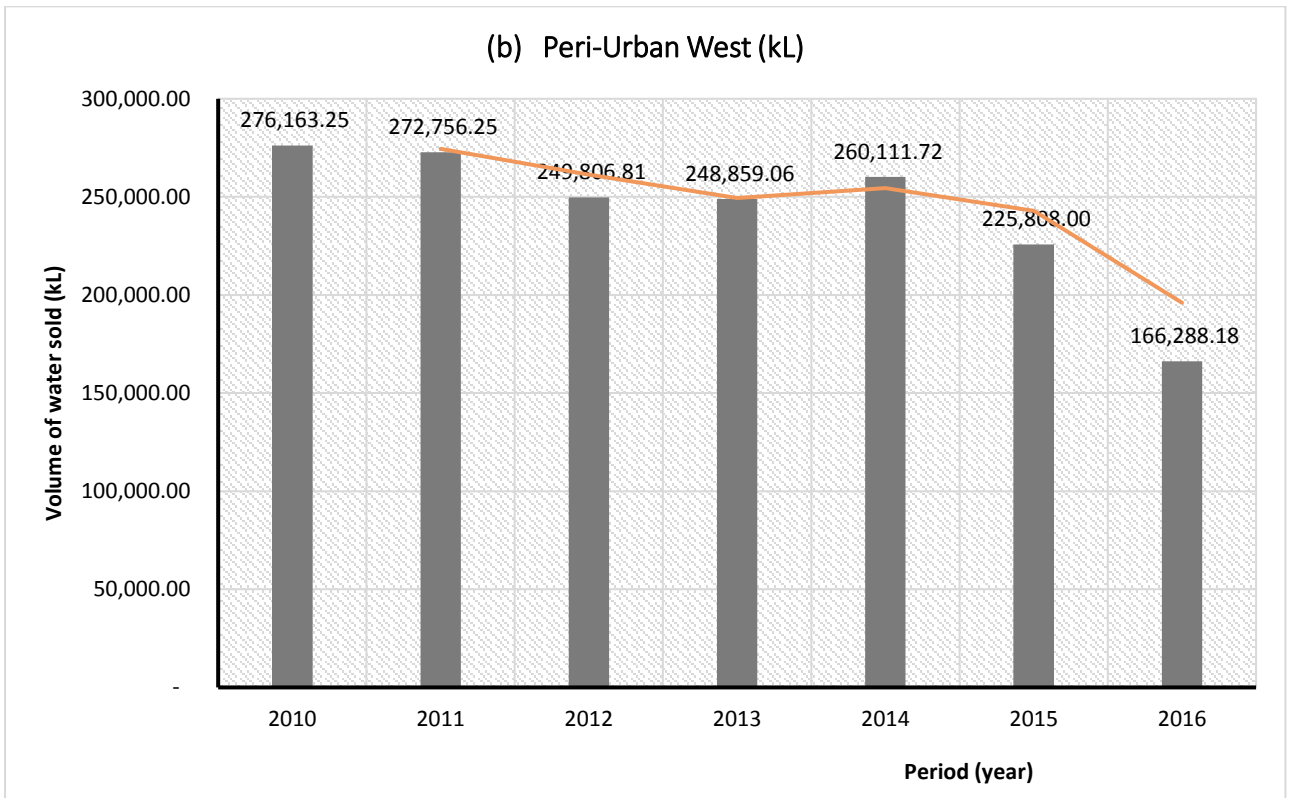
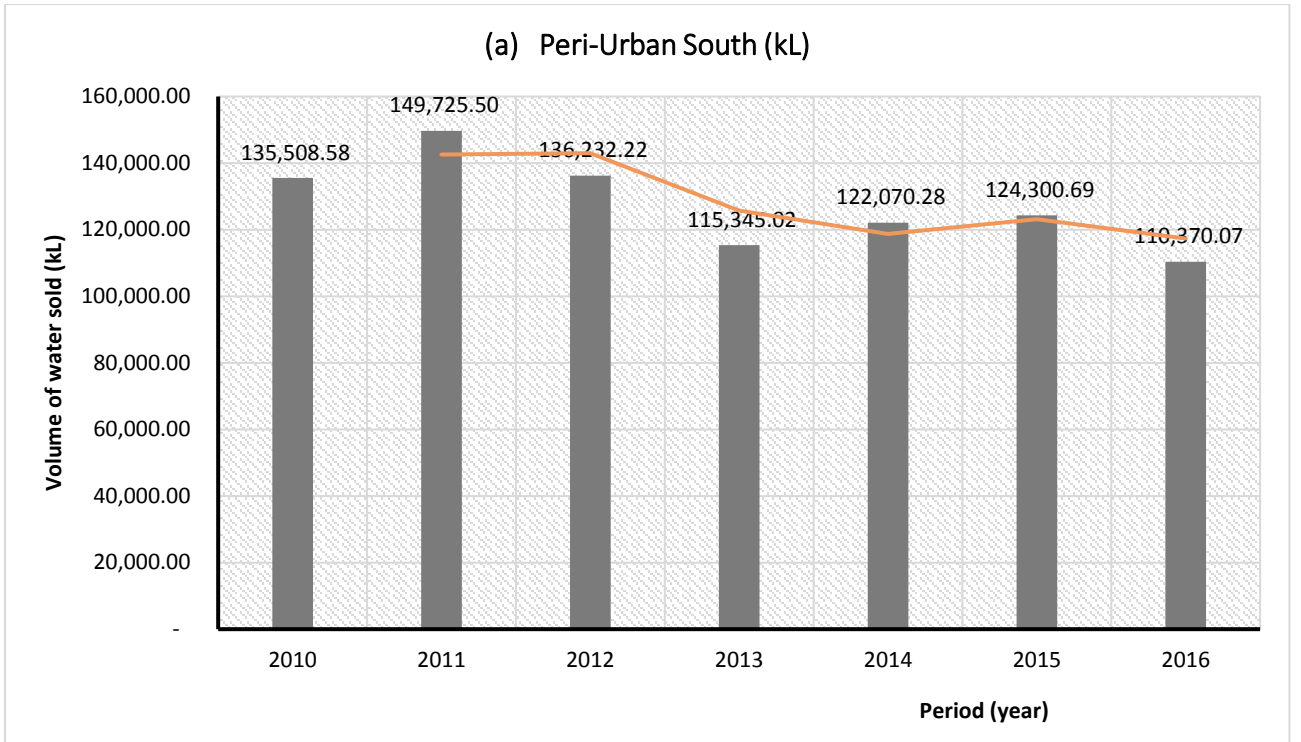


Figure 5.12: Average water sold for Peri-Urban South and West (adopted from pre-paid metering report)

Some districts (Central, Chelstone, Kabulonga and Lumumba) recorded an average decrease in the water sold of about 17%, while in other districts (Kabwata and Matero) there was an average increase of 39%. On the other hand, Peri-urban zones recorded an average decrease of 20%.

The districts which showed an increase in the water sold are those in the peripheral of the city whose borders keep on expanding due to the on-going construction of new residential houses. To the contrary, all other districts with fixed borders showed a decrease in the water sold. The decrease in water sold is not entirely as a result of Non-Revenue Water, but was partly due to the load shedding by the power supply company which affected the entire country from late 2015 to early 2017. The duration of load shedding in a day ranged from 4 to 8 hours, with 8 hours of blackouts being the most experienced in Lusaka.

The load shedding affected the entire economy which implies that the districts which recorded an increase in the water sold was entirely as a result of the new customers/connections. Hence it should be noted that load shedding had less impact on the amount of water sold compared to the effects caused by the existence of non-revenue water in the system e.g. through the poor state of the infrastructure. Therefore, the 6% overall decrease in the water sold indicate an impending problem which need urgent attention if the company is to operate profitably.

Table 5.1 gives more information on the observed trends in the annual water sold for the period 2010 to 2016:

Table 5.1: Changes in annual water sold between 2010 and 2016

Branch Name	Approximate Percentage Increase/Decrease (%)	Average (%)
Central Branch	-15	- 6%
Chelstone Branch	-25	
Kabulonga Branch	-20	
Lumumba Branch	-9	
Kabwata Branch	16	
Matero Zone	63	
Peri-urban East	-13	
Peri-urban South	-16	
Peri-urban West	-31	

Source: Compiled by author

Figure 5.13 shows the combined annual total volumes of water sold for all the branches and peri-urbans in Lusaka town during the period 2010 to 2016.

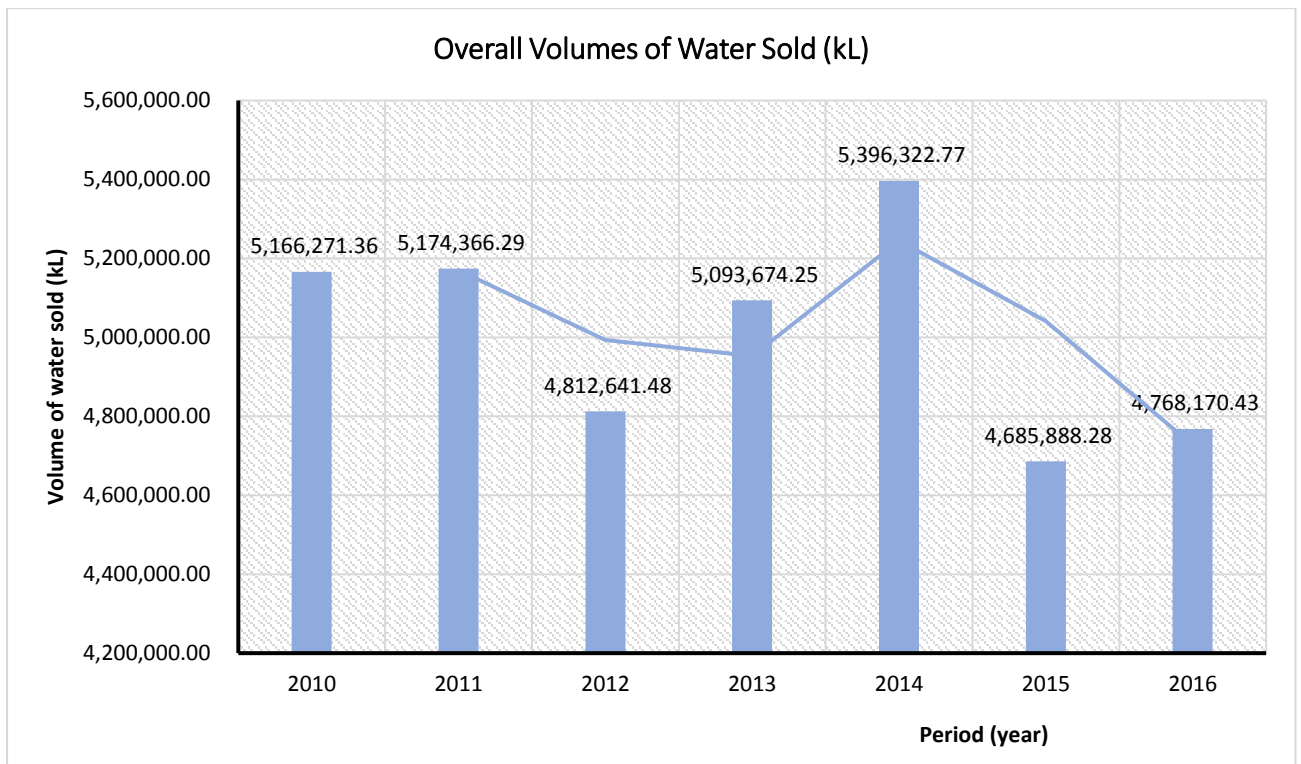


Figure 5.13: Overall Water sold for LWSC (adopted from pre-paid metering report)

5.4 Annual NRW for the Duration 2011 - 2016

As can be seen from Figures 5.14 to 5.16, there was a very minimal reduction in non-revenue water for the period 2011 to 2016. The observed trend in the level of non-revenue water showed that the higher the production so was the non-revenue. But on the other hand the billed quantity showed drastic changes from year to year, with years like 2012 (Figure 5.14) having a lower billed quantity than the quantity of non-revenue water, and 2011 (Figure 5.14) had NRW below zero which is practically impossible. To some extent, these situations are indicative of errors in the raw data used to calculate NRW by the company.

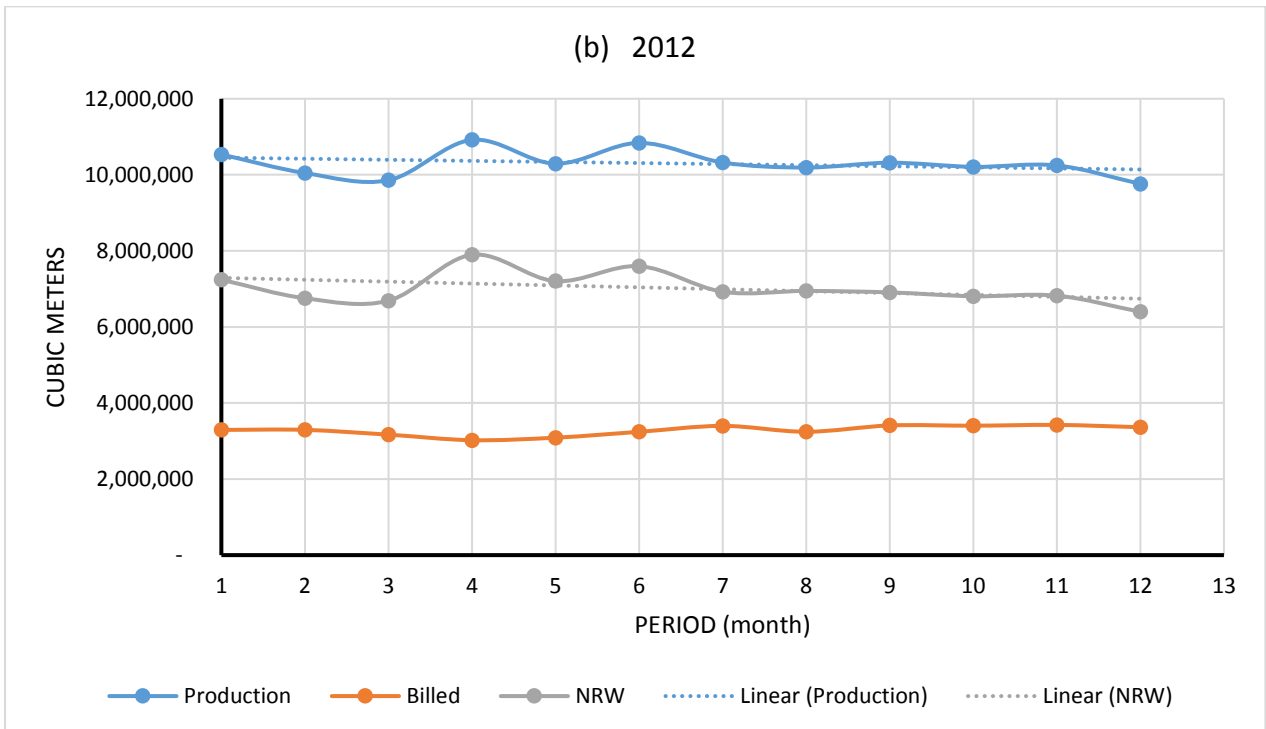
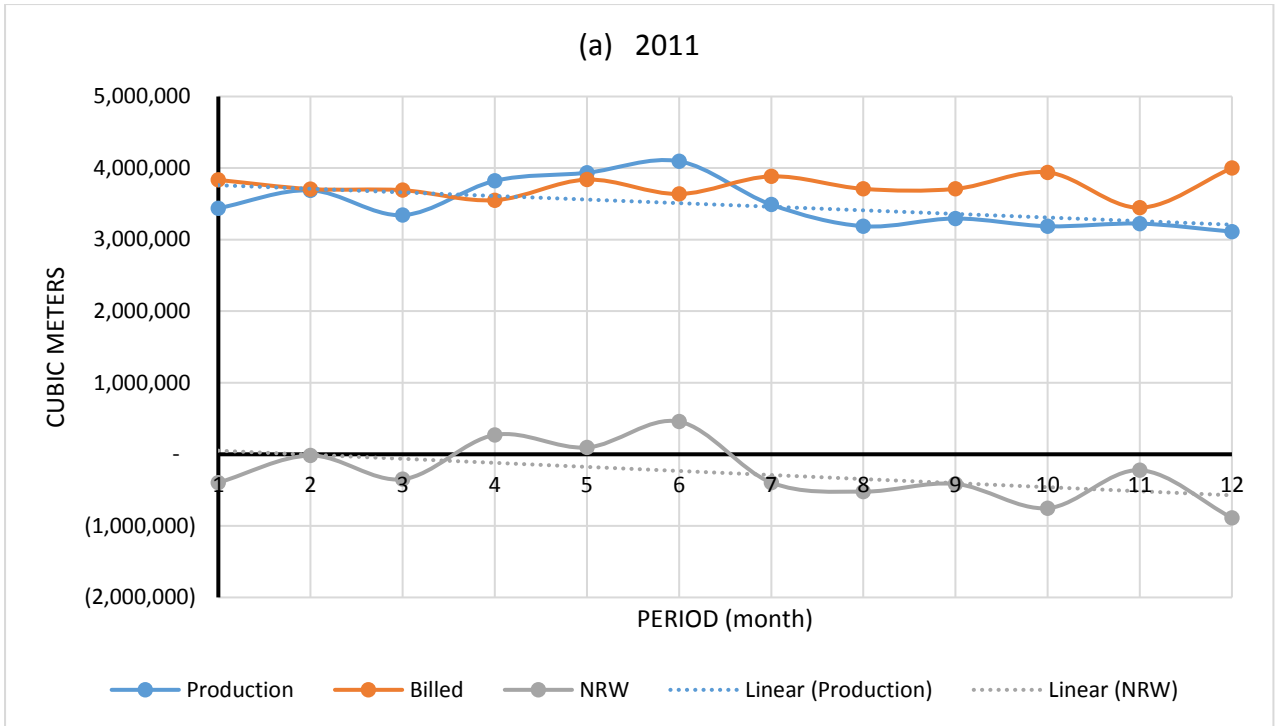


Figure 5.14: NRW for 2011 and 2012 (adopted from NRW Report)

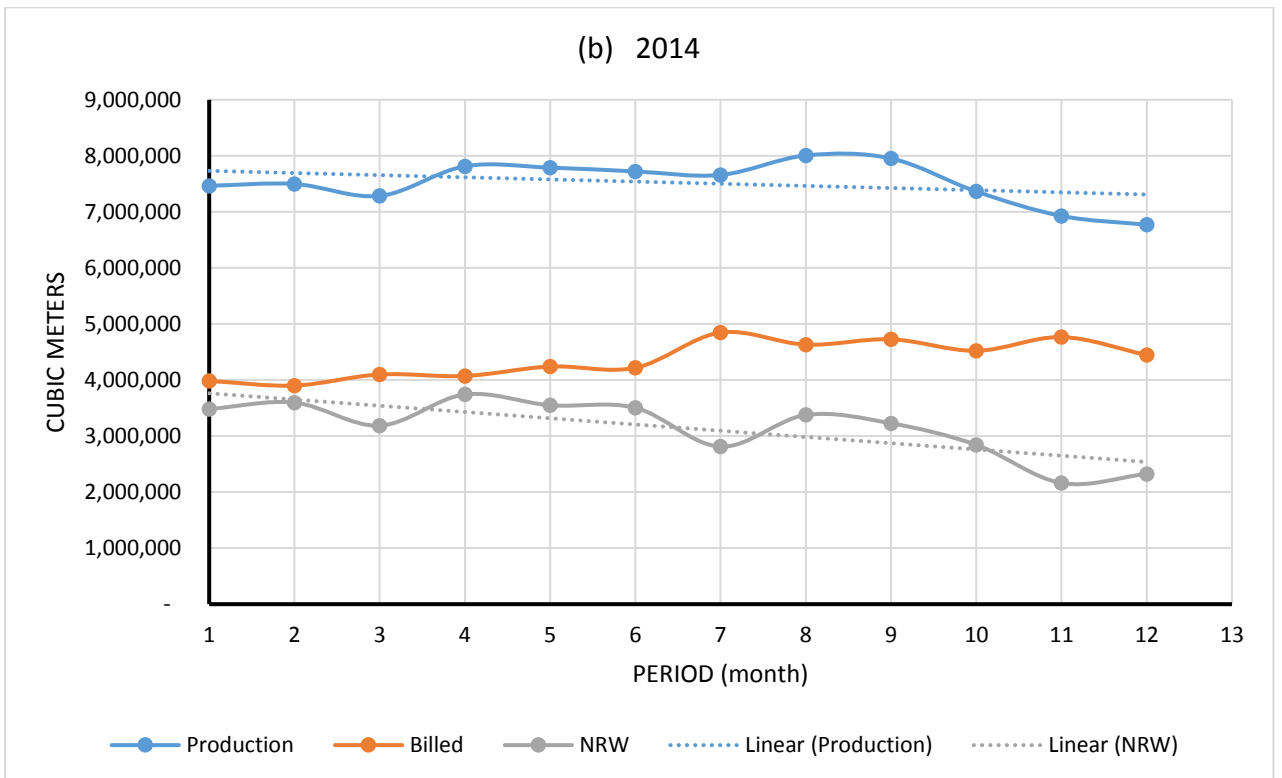
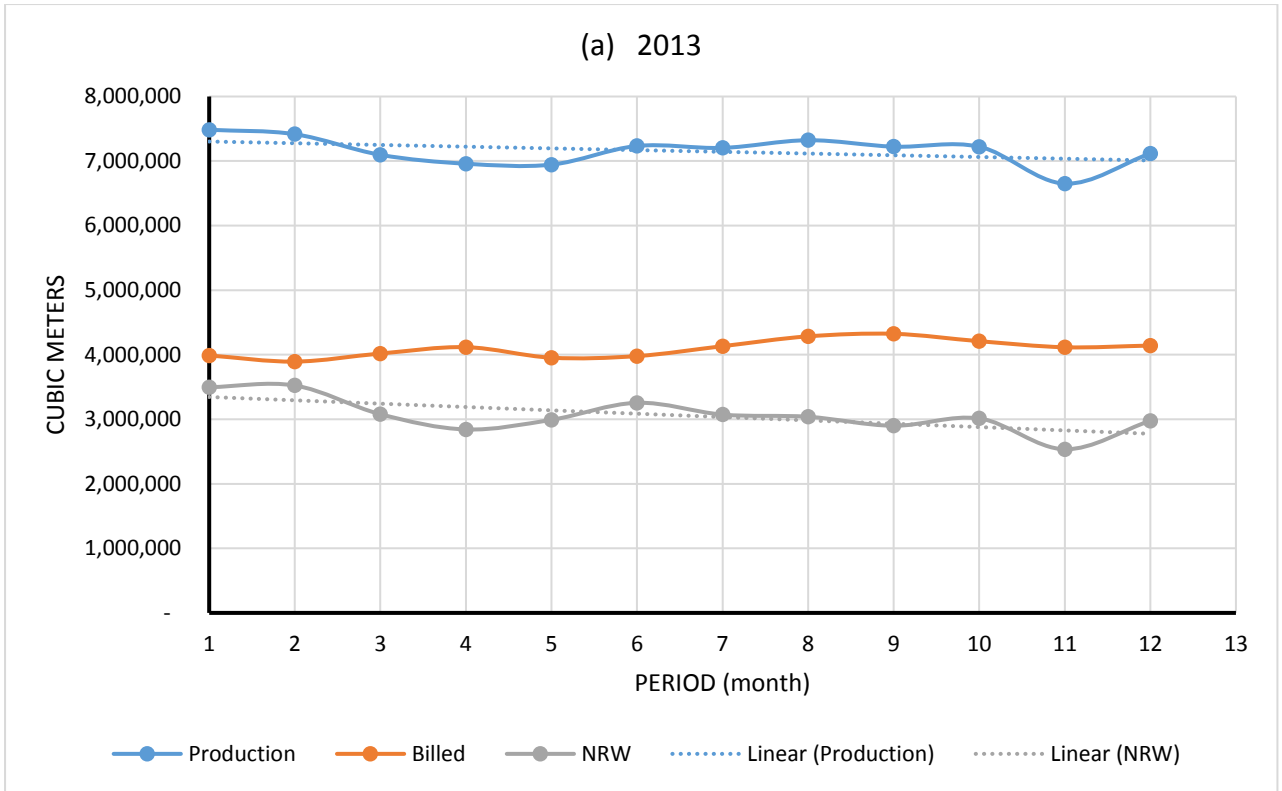


Figure 5.15: NRW for 2013 and 2014 (adopted from NRW Report)

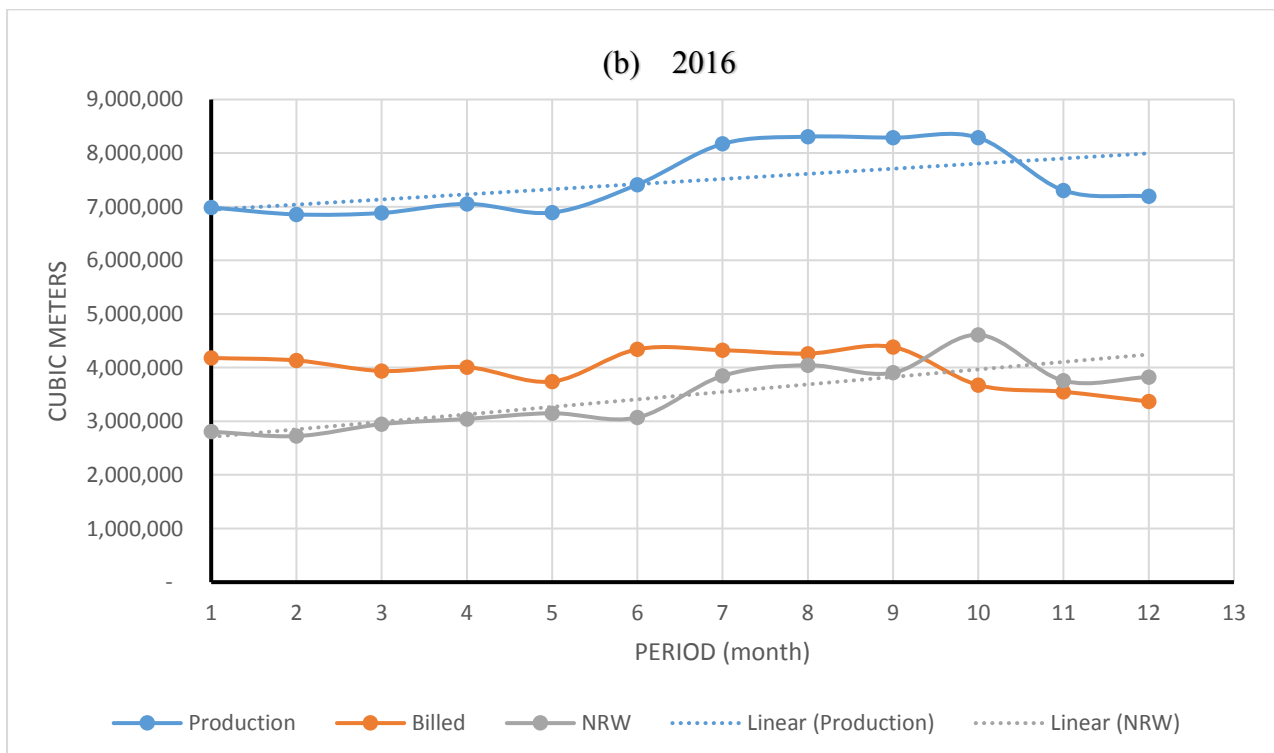
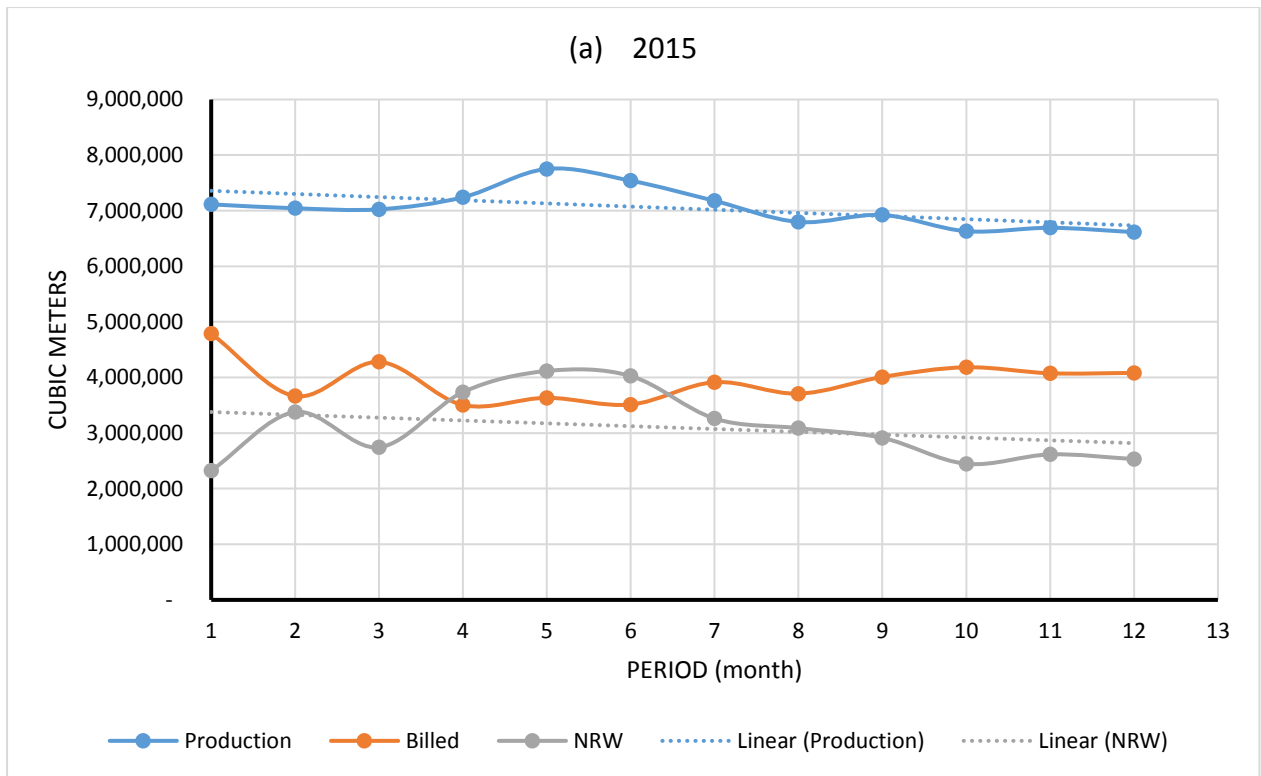


Figure 5.16: NRW for 2015 and 2016 (adopted from NRW Report)

The fact that the trend in non-revenue water is very much comparable with the production curve entails that the sources of non-revenue water in the water network has been in existence for a

considerable period of time. As it can be deduced that the more the production the more the water losses, which is an indication that the sources of both real and apparent losses hasn't received much attention in terms of repairs and replacement of the leaking pipes or appurtenances.

Though the quoted value of non-revenue water for Lusaka Water and Sewerage is 44%, it has very low confidence levels because only 48% of the whole water network is metered, implying that water consumption from the other 52% of the network is estimated. Not all boreholes have bulk meters and not all bulk meters are functional. The current situation in the company is that water from some boreholes is pumped directly into the network without knowing the quantity being supplied due to the absence or defective bulk meters. Therefore, the 45% non-revenue water is merely a 'guess' regardless of the method of estimation applied. This is because majority of the network is unmetered jeopardising the process of estimation regardless of the accuracy of the estimation method.

5.5 Annual Collection Efficiency and Cash Inflow

Different authors have indicated the importance of having a very prudent and functional revenue collection system if the company is to operate profitably. As stated earlier in section 2.10.2, the benchmark for collection efficiency is 85%, which is a lower limit. Therefore, anything below 85% is said to be unacceptable by NWASCO.

There is a direct proportionality relationship between collection efficiency and cash inflow, as can be observed from Figure 5.17 and Figure 5.25 below. The annual collection efficiency for the period from 2010 to 2016 were as follows; 71%, 77%, 96%, 98%, 89%, 84% and 74% respectively, with an average of 84%. This indicate that the collection efficiency benchmark was only achieved in the years from 2012 to 2014, with the highest being 98% in 2013 and lowest being 71% in 2010. Collection efficiency is independent of the volume of water supplied or billed, but rather indicate the ratio of the actual revenue collected from all the billed properties against the expected revenue according to the monthly bills issued to the customers.

Therefore, regardless of the amount of water consumed by the customer, the collection efficiency is expected to be near perfect because anything less will be indicative of a failure by the company to collect revenue or a defective revenue collection system. In the case of Lusaka Water and Sewerage Company, the fact that 98% was achieved in 2013 but dropped by 9% to

89% in 2014 and continued to fall up to 2016 – 74% (Figure. 5.17) is evidence enough to deduce that the trend was a failure on the management team and not the revenue collection system.

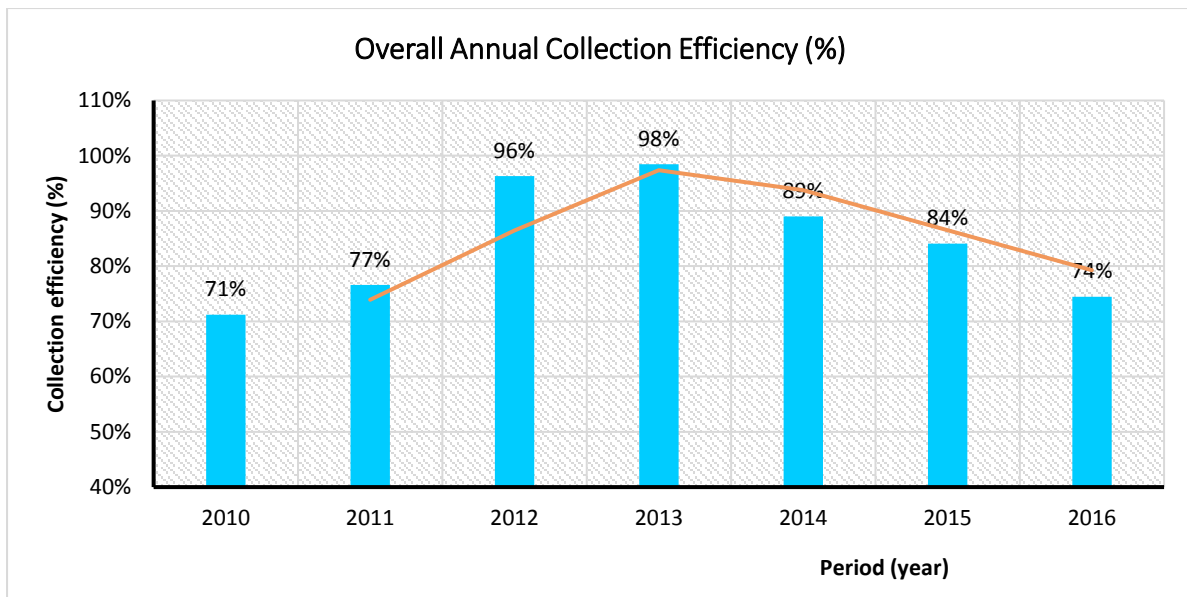


Figure 5.17: Collection Efficiency (adopted from pre-paid metering report)

In like manner, the cash inflows (Figure 5.18) displayed a comparatively similar behaviour to that of the collection efficiency as expected, with the highest revenue of 202.5 million Kwacha in 2013 and lowest revenue of 100.1 million Kwacha in 2010, with an average annual cash inflow of 161.2 million Kwacha.

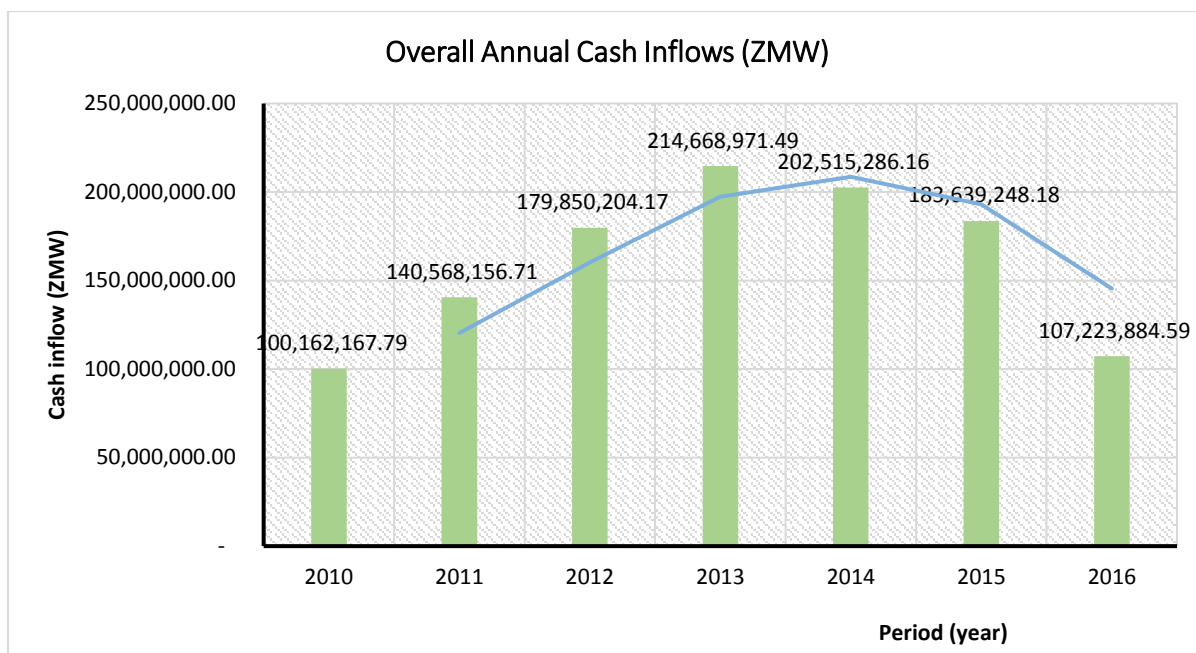


Figure 5.18: Cash Inflow (adopted from pre-paid metering report)

Table 5.2 gives a summary of the annual revenue collected by Lusaka Water and Sewerage Company from 2010 to 2016. With the help of the average non-revenue water, it was shown that the company lost a total of about 474 million Kwacha from 2010 to 2016.

Table 5.2: Summary of the cash inflows

Year	Revenue Collected (K)	Average Revenue collected (K)	Collection efficiency (%)	Billed Amount (K)	Average amount billed (K)
2010	100,162,167.79	161,232,559.87	71	141,073,475.76	188,726,288.04
2011	140,568,156.71		77	182,556,047.68	
2012	179,850,204.17		96	187,343,962.68	
2013	214,668,971.49		98	219,049,970.91	
2014	202,515,286.16		89	227,545,265.35	
2015	183,639,248.18		84	218,618,152.60	
2016	107,223,884.59		74	144,897,141.34	

Source: Compiled by author

CHAPTER SIX: SUMMARY, CONCLUSION AND RECOMMENDATIONS

7.1 Summary

Most if not all of the existing literature, used in this research, about the management of Non-Revenue Water attested to the fact that the water sector is one of the highly regulated sectors in Zambia and the world at large. A lot of studies have been done in both developed and developing countries which have further revealed that the management of non-revenue water and development of non-revenue water strategies is only achievable if the ‘good practices’ recommended by the International Water Association (IWA) and other scholars on the subject are correctly implemented. Therefore, in order for any water utility to effectively rectify the problem of non-revenue water, a systematic approach in line with the IWA recommendation has to be followed.

This study has further proved that water provision in lower income countries like Zambia is one of the biggest challenges they face mainly due to regulatory weaknesses, lower water tariffs and unsustainable technologies used in water abstraction.

The performance of LWSC was evaluated based on the benchmarks set by the National Water Supply and Sanitation Council (NWASCO) which are also in line with the IWA benchmarks for developing countries. The following observations were made:

- a) Lusaka Water and Sewerage Company developed ‘The NRW Strategy’ to work as a guide in the reduction of Non-Revenue Water. The strategy emphasizes the accurate determination of all parameters in the system (production, supply and consumption volumes). But currently, more emphasis has been put on improved NRW awareness, accuracy of measurements, improved reporting systems and operational efficiencies in responding to pipe bursts, leakages and meter problems. Hence the strategy has not yielded the desired results because the recommended ‘Best Practices’ have not been implemented and undertaken simultaneously as advised.
- b) Lusaka Water and Sewerage Company has embarked on certain measures to ensure that the targeted results in the Non-Revenue Water Strategy are met. Some of the measures include but not limited to the creation of the; Non-Revenue Water Department to spearhead the NRW reduction and management which initially used to be under the

Technical Services Department, Inspectorate Department which is mandated to curb water theft and other illegal activities.

- c) Since the amount of revenue lost by the company is directly proportional to the amount of water being lost in the system and inversely proportional to the collection efficiency. The lower the collection efficiency the higher the revenue lost. In like manner, the higher the NRW levels, the higher the revenue lost. Therefore, as shown in Figure 5.18, approximately an average of 67.8 million Kwacha was lost annually from 2010 to 2016. The average billed amount was determined to be 188.7 million Kwacha while the average actual revenue collected was 161.2 million Kwacha (Table 5.2).
- d) Recommendations are elaborated in section 7.3.

7.2 Conclusion

The findings in this research reveal that the management of NRW in Lusaka is not fully being done in accordance with the NWASCO and IWA recommendation on the ‘best practices’ in managing NRW. This can be ascribed to a number of factors apart from the known fact that the water network is dilapidated and needing urgent attention in terms of its complete replacement. The following are some of the conclusions based of the data analysed:

- The 48% metering ratio makes it almost impossible to achieve any tangible non-revenue water reduction. Since 94% of the connections are billed, majority of them are on ‘fixed charge’ which makes it very difficult to determine the true amount of water being consumed by the customers;
- Not all boreholes are metered and not all metered boreholes have functional bulk meters, which jeopardise the whole process of determining the amount of non-revenue water because the production volumes are a ‘mere guess’, which further translates into the non-revenue water value being wrong as well, hence the 44% NRW is not a true reflection of what is on the ground;
- The low metering ratio has caused the continued expressing of NRW as a ‘percentage’ of system input volume as a performance indicator, which many scholars have discouraged as it is misleading and imprecise. This is because the method is only precise in systems which are fully metered and with a constant consumption, which is not the case with the water supply system in Lusaka;

- Due to the shortage of water storage facilities to meet the demand, LWSC has resorted to directly inject water from the boreholes into the network thereby causing meters to get ‘stuck’ due to the soil particles in the underground water sources; and
- The implementation of the recommended management practices in managing non-revenue water is not being done correctly, Therefore, the ‘Non-Revenue Water Strategy’ of 2013 has not yielded the anticipated results due to some of the challenges alluded to above, hence its performance on reducing non-revenue water can be said to have no impact on the levels of non-revenue water (as indicated in Figure 3.3).

7.3 Recommendations

The following are some of the most urgent recommendations based on the observations and evidence found in this research:

1. There’s need to clearly define the roles and responsibilities of the Technical Services Department, NRW Department and Inspectorate Department with regard to the management of non-revenue water.
2. NRW Department and Inspectorate Department should be decentralised to branch level because their roles are highly required at the grassroots level.
3. Instead of expanding the water network in unmetered fashion, the company should first consider metering the existing connections before rushing into making new connections.
4. LWSC should consider ‘Yard Metering’ in Peri-Urbans to ensure that people pay for the water they use, thereby making it cost reflective.
5. LWSC should consider shifting around the meter readers after a given period of time to prevent them from conniving with the customers in water theft or any other illegal activities.

7.3.1 Future Research Work

This research work has demonstrated that the management of non-revenue water involves a wider spectrum of stakeholders than just the company management staff. Therefore, the following are some of the recommendations for any future research work concerning the topic of non-revenue water management:

- A wider sample size should be considered, including staff members from the Ministry of Water Development, Sanitation and Environmental Protection and the Water Resource Management Agency and other staff members of the water utility (Unionised - technicians, plumbers , meter readers and administrative support staff);
- Consider a more detailed determination of the quantities of the components of non-revenue water using a water balance; and
- Do a thorough investigation of the unbilled authorised consumption of water sent into peri-urbans.

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APPENDICES

Appendix A: Questionnaire

Instructions: *The researcher is humbly requesting you to answer the following questions as truthfully as possible based on your experience and knowledge of how things are done at Lusaka Water and Sewerage Company. No part of this questionnaire requires you to indicate your identity in any form. Therefore, you have been selectively chosen to help the researcher with information regarding the questions below:*

- Rank the three components of NRW shown in the table below in order of the magnitude of their contribution to NRW, using the scale indicated below (with 3 being the highest contributor and 1 the lowest).

Scale: (3 = high, 2 = moderate, 1 = low)

- Physical (real) Losses
- Commercial (apparent) Losses
- Unbilled Authorised Consumption

Respondent No.	NRW Components		
	Real Losses	Apparent Losses	Unbilled Authorised consumption
N1			

- Rank the indicated causes of physical losses using the indicated scale below by ticking in the appropriate box once per item:

Weighting: (5 = very high, 4 = high, 3 = Moderate, 2 = low, 1 = very low)

Sources of Physical Losses	Weighting				
	1	2	3	4	5
Pressure Management					
Poor State of Infrastructure					
Leakages and Pipe Bursts					
Bad Attitude and Negligence					

- Rank the indicated causes of commercial losses using the indicated scale below by ticking in the appropriate box once per item:

Weighting: (5 = very high, 4 = high, 3 = Moderate, 2 = low, 1 = very low)

Sources of Commercial Losses	Weighting				
	1	2	3	4	5
Human Errors					
Water Theft					
Metering Errors					
Computing Errors					

4. According to your observation and experience, rate the level of implementation of the indicated non-revenue water management practices by Lusaka Water and Sewerage Company in Lusaka, using the indicated rating scale:

- 5 – very highly implemented
- 4 – highly implemented
- 3 – moderately implemented
- 2 – lowly implemented
- 1 – not implemented

a) Real Losses

Management Practice	Rating				
	1	2	3	4	5
Active Leakage Control					
Speed and Quality of Repairs					
Pressure Management					
Infrastructural Management					

b) Apparent Losses

Management Practice	Rating				
	1	2	3	4	5
Reduction of metering errors					
Reduction of Human errors					
Water Theft Reduction					
Reduction of Computing Errors					

Appendix B: Semi-Structured Interview Guide

1. REAL LOSSES

- **Active Leakage Control Programme;**
 - i. What method do you use to determine NRW? e.g. IWA standard water balance, e.tc
 - ii. What performance indicators do you use, and why?
 - iii. How do you conduct the activities for leakage control (ALC)?
- **Speed and Quality of Repairs;**
 - i. How long does it take to repair leakages? (total days from the day it is reported)
 - ii. Do you use any specialised equipment to detect leakages?
- **Pressure Management;**
 - i. Do you consider pressure management as one way of reducing NRW? If yes, how is it achieved? And how has it worked out thus far?
- **Infrastructure Management;**
 - i. Is there an existing plan or program for maintaining or improving the infrastructure?
 - ii. How is infrastructure management achieved in your company?

2. APPARENT LOSSES

- **Reduction of metering errors;**
 - i. How often do metering errors occur?
 - ii. How do you detect them?
- **Water Theft (unauthorised consumption);**
 - i. How is water theft being addressed in your company, in line with non-revenue water management?
- **Reduction of Human Errors;**
 - i. At what stage do human errors mostly occur? i.e. meter reading, data entry, etc.
 - ii. What's the impact and magnitude of its contribution on NRW?
- **Reduction of Computing Errors;**
 - i. How are the computing or accounting errors being addressed in order to reduce the overall level of non-revenue water in your company?

3. UNBILLED AUTHORISED CONSUMPTION

- i. What are some of the examples of this kind of consumption found in Lusaka?
- ii. How is it being managed?

4. GENERAL QUESTIONS

- i. Are you aware of the existing strategy to reduce NRW?
- ii. What measures have you put in place to achieve the set targets in the strategies?
- iii. Have you established an independent NRW audit team to monitor progress in the NRW strategy implementation?
- iv. Are there any capacity building programmes for NRW? If any, how often?