UNIVERSITY OF ZIMBABWE

Pressure Management as a Tool for Reduction and Control of Real Water Losses for Kasungu Water Supply Scheme in Malawi

By

Richman Kalua

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

Department of Civil Engineering
Faculty of Engineering

July 2009

UNIVERSITY OF ZIMBABWE

Pressure Management as a Tool for Reduction and Control of Real Water Losses for Kasungu Water Supply Scheme in Malawi

Supervisors

Eng. Z. Hoko (University of Zimbabwe)

Eng. B. Nkhoma (African Development Bank Group, Malawi)

Department of Civil Engineering
Faculty of Engineering

July 2009

DECLARATION

I, Richman Jimmy Chizala Kalua, do confirm that this is my own work and that the use of all materials from other sources has been properly and fully acknowledged. No part of it has been submitted previously for a Degree at any other University.

I am responsible for the research and its articulation alone. In no way do any of the persons mentioned in the acknowledgement bear any direct responsibility for this work.

…………………………………………………………………………………………..

JULY 2009

ABSTRACT

Research has shown that effective management of water resources for urban water utilities worldwide still remains a challenge. Pressure management is one of the tools that is known to control water leakages in piped water supply systems. A study was carried out on Kasungu Water Supply Scheme in Malawi from February to April 2009 to investigate the potential of pressure management as a tool for the reduction and control of real water losses. The study also assessed the viability of pressure management and its impacts on service quality. Levels of unaccounted-for water (UFW) for Kasungu Water Supply Scheme in the period July 2007 to June 2008 were reported to be 27% on average with a maximum of 37% in May 2008. An area called Kasungu ADD was selected for pressure and flow measurements to determine the variation of leakage under different pressures and the impact of pressure management on service quality. The study showed that 66% of the total non-revenue water in the scheme is lost through leakage and that leakage in the distribution system is reduced by 38% when pressure is reduced by 46%. At 38% inlet pressure reduction minimum night flows (MNF) were reduced by 34%. However the time required to fill a 20 litre bucket during the peak period, a measure of service quality, increased by 9% at critical points of the system Pressure management was found to have a payback period of 20 months compared to pipe replacement which had a payback period of 205 months. It was concluded that pressure management is a viable tool for controlling water losses in the scheme. It is recommended that the supply area should be pressure zoned and use of appropriate pressure controllers be implemented in the distribution system to improve management.

Keywords: Leakage, minimum night flow, non-revenue water, payback period, pressure management, service quality, water supply system

DEDICATION

To my mum and dad for seeing me this far and my brother Gift,

your endurance during my absence cannot be overlooked.

ACKNOWLEDGEMENTS

First and foremost, I am very thankful to my God Almighty, without whose mercy I am but nothing. May all the glory be unto You, Lord.

My special thanks should go to WaterNet for providing me a scholarship to study this Regional Masters Programme in Integrated Water Resources Management (IWRM) at the University of Zimbabwe (UZ).

I am greatly indebted to my supervisors Eng. Z. Hoko and Eng. B. Nkhoma for the excellent supervisory work and guidance during the compilation of this dissertation. Your critiques and advice made my research exercise to be one of the most educating and satisfying undertaking in my life.

To all IWRM Lecturers in the Department of Civil Engineering at UZ, visiting and specialisation Lecturers, I say thank you for sharing your knowledge.

I am also indebted to my employer, the Central Region Water Board particularly the former Acting General Manager, Mr. Z. Medi, and the incumbent Chief Executive, Mr. P. Makonyola, for granting me a study leave and support during data collection respectively. My sincere thanks would not be complete without mentioning Mrs. H. Somanje – Kasungu Water Supply Scheme Manager, Mr. N. Musiyazviriro – Bye-Laws Inspector, Mr. A. Phiri – Water Assistant and Mr. P. Kapakasa – Tracer for a job well done. Keep it up! Kasungu Water Supply Scheme student plumbers, Raphael Sambani and Philip Mathawe, you surely deserve a pat on your back.

Lastly, my gratitude should go to all my fellow classmates especially James Kushe and Dwight Kambuku for their valuable assistance rendered during compilation of this thesis. To my great friends Chimwemwe Luhanga and Ruth Chipeta, I say you are friends indeed!

CONTENTS

DECLARATION i

ABSTRACT ii

DEDICATION iii

LIST OF TABLES vii

LIST OF FIGURES viii

LIST OF APPENDICES ix

LIST OF ACRONYMS xii

1.0 INTRODUCTION 1

1.1 Background 1
1.2 Problem Statement 2
1.3 Justification 3
1.4 Research Objectives 4
1.4.1 Main Objective 4
1.4.2 Specific Objectives 4

2.0 LITERATURE REVIEW 5

2.1 Introduction 5
2.2 Water demand management 5
2.3 Water demand management in southern Africa region 6
2.4 Water Demand Management in Malawi 7
2.5 The Benefits of Implementing Water Demand Management 8
2.6 Real water losses 9
2.6.1 Determining real water losses 10
2.6.2 Detailed quantification of real loss components 12
2.7 Apparent water losses 15
2.8 Leakage control concepts 15
2.8.1 Active and passive leakage control 15
2.8.2 Economics of leakage control 16
2.9 Pressure management 17
2.9.1 Methods of pressure management 18
2.9.2 Pressure – leakage Theory 19
2.9.3 Benefits of Pressure Management 19

3.0 STUDY AREA 21

3.1 Description of the site 21
3.2 Population 21
3.3 Land use 22
3.4 Socio-economic activities 24

3.5 Background Information to Kasungu Water Supply Scheme 25
3.6 Water supply system for Kasungu 25
3.7 Kasungu Agricultural Development Division (ADD) area 26
3.8 WDM initiatives in Kasungu Water Supply Scheme 27
3.9 Sanitation Situation in Kasungu Town Assembly 27
4.0 MATERIALS AND METHODS 29
4.1 Research Design 29
4.1.1 Data Collection 29
4.1.2 Data Analysis 32
5.0 RESULTS AND DISCUSSION 34
5.1 General Information 34
5.1.1 Water production 34
5.1.2 Water consumption 34
5.1.3 Metered connections 35
5.1.4 Billing and metering system for Kasungu Water Supply Scheme 36
5.2 Water loss assessment for Kasungu Water Supply Scheme 37
5.3 Impact of pressure on real water losses 39
5.4 Impact of pressure management on customer service quality 45
5.5 Cost – benefit analysis of pressure management 46
6.0 CONCLUSIONS AND RECOMMENDATIONS 50
7.0 REFERENCES 51
8.0 APPENDICES 59

LIST OF TABLES

Table 2.1: International Water Association (IWA) 'best practice' Water Balance 12

Table 2.2: Key stages in ELL process 17

Table 3.1: Population growth for Kasungu Town Assembly 21

Table 3.2: Projected population and growth rate for Kasungu 22

Table 3.3: Length of distribution pipes by diameter and pipe material 26

Table 5.1: Average daily water production for Kasungu..34

Table 5.2: Average daily water consumption for Kasungu 34

Table 5.3: Number of metered connections in Kasungu...36

Table 5.4: Number of connections per consumer category 36

Table 5.5: Minimum night flows and their pressures of occurrence 43

Table 5.7: Payback period analysis results 47

LIST OF FIGURES

Figure 3.1: Map of Kasungu Town Assembly..23

Figure 3.2: Land Use Map of Kasungu Town Assembly 24

Figure 3.2: Schematic layout for Kasungu Water Supply Scheme......................................28

Figure 4.1: Schematic layout of Kasungu ADD area 31

Figure 5.1: Water consumption among various consumer categories 35

Figure 5.2: Total water produced, billed and UFW for Kasungu 38

Figure 5.3: Water balance results for Kasungu for 2008 39

Figure 5.4: Water balance results for Kasungu ADD area 40

Figure 5.5: Pressure and Flows against date/time at 65 m inlet pressure setting...............41

Figure 5.6: Pressure and Flow against date/time at 50 m inlet pressure setting 41

Figure 5.7: Pressure and Flow against date/time at 40 m inlet pressure setting 42

Figure 5.8: Pressure and Flow date/time at 30 m pressure setting......................................42

Figure: 5.11: Real Water Loss Programme for Kasungu Scheme 49

LIST OF APPENDICES

Appendix B: Duration of Reported Leaks and Apparent Water Loss Parameters 60

Appendix C: Bucket test results...61

Appendix D: Calculation of Real Losses in Kasungu ADD...62

Appendix E : Pipe laying and pressure management investment cost data..........................64

Appendix F: Calculation of Water Losses due to Pipe Replacement...................................66

Appendix H: Night Pressure and Flow Results 69

Appendix F: Customer Survey Questionnaire 76

DEFINITIONS OF SELECTED TERMS

Apparent Losses	Are water losses arising from unauthorised consumption and metering inaccuracies (Lambert, 2003).
Authorised Consumption	Is the annual volume of metered and/or non-metered water taken by registered/authorised customers, the water supplier and others implicitly or explicitly authorised to do so. It includes water exported, and leaks and overflows after the point of customer metering (Lambert, 2003)
Leakage	Is one of the components of the total water lost in a network, and comprises the physical losses from pipes, joints and fittings, and also from overflowing service reservoirs (Farley, 2001).
Non-Revenue Water	Is difference between volume of water put into a water distribution system and the volume that is billed to customers. Non-revenue water comprises three components: physical (or real) losses, commercial (or apparent) losses, and unbilled authorized consumption (Kingdom et al., 2006).
Real Losses	Annual volumes of water lost through all types of leaks, bursts and overflows on mains, service reservoirs and service connections, up to the point of customer metering (Lambert, 2003). Real losses represent the physical water losses (i.e. leakage) from the pressurized system, up to the point of measurement of customer use (McKenzie et al., 2002)
Service Level	Is the standard of water supply service offered to consumers (Nkhoma, 2004).

System Input Volume Is the annual volume input to that part of the water supply system to which the water balance calculation relates (Liemberger, 2003).

Unaccounted-for Water The difference between the volume of water put into the supply system and the authorised volume used by the consumers (DFID, 2003).

Water Balance It is the accounting for the measured volume of potable water put into a water distribution system (Nkhoma, 2004).

Water Demand Management Is the development and implementation of strategies aimed at influencing water demand in order to achieve water consumption levels that are consistent with equitable, efficient and sustainable use of the finite water resource (IUCN-WaterNet, 2003)

LIST OF ACRONYMS

AC	Asbestos Cement
ADD	Agriculture Development Division
ALC	Active Leakage Control
CRWB	Central Region Water Board
DFID	Department for International Development
DMA	District Metered Area
GOM	Government of Malawi
IUCN	World Conservation Union
IWA	International Water Association
NGO	Non- Governmental Organisation
NRW	Non-Revenue Water
NSO	National Statistics Office
PLC	Passive Leakage Control
PVC	Polyvinyl Chloride
SADC	Southern African Development Community
RSAP	Regional Strategic Action Plan
TLF	True Loss Factor
UARL	Unavoidable Annual Real Losses
UFW	Unaccounted-for Water
WDM	Water Demand Management

CHAPTER 1

1.0 INTRODUCTION

1.1 Background

Water, though a renewable resource, is finite, seasonally distributed, becoming scarce and competed for by individuals and various social and economic sectors of production and services (Ng'ong'ola, 1999). This scenario calls for efficient use and effective management of water resources to ensure its long-term sustainability and to satisfy the demand for water for the above stated sectors. Studies have shown that water loss (unaccounted-for water) is a problem for all water utilities (Balkaran and Wyke, 2003). Water loss as defined by Lambert (2003) is the difference between system input volume and authorised consumption consisting of real and apparent losses. Similarly, unaccounted-for water is difference between the volume of water put into the supply system and the authorised volume used by the consumers (DFID, 2003). Apparent losses consists of unauthorised consumption and metering inaccuracies while real losses are annual volumes of water lost through all types of leaks, bursts and overflows on mains, service reservoirs and service connections, up to the point of customer metering (Lambert, 2003). Apparent and real losses are also known as commercial and physical losses respectively (Kingdom et al., 2006). A combination of water losses and unbilled authorised consumption forms non-revenue water (NRW). Non-revenue water (NRW) in developed countries lies between 15% and 30% but elsewhere it is likely to be in the 30% to 60% range (Ismail and Puad, 2006). Khatri and Vairavamoorthy, (2007) report that in developing countries water losses ranges from 40% to 60% of the total water supplied while in Southern Africa urban water supply utilities unaccounted-for water ranges from 16% to 65% (DFID, 2003). In Malawi, the average level of unaccounted-for water in urban water utilities range from 20% to 30% and can go up to 51% in some urban areas served by Regional Water Boards (Mulwafu et al., 2003).and for Kasungu Water Supply Scheme[1] it averages 27% (Metaferia and Hydroconsult, 2008). Proposed targets for unaccounted-for water for well performing water supply utilities lie between 15% and 25% for developing countries (Tynan and Kingdom, 2002; van der Zaag, 2003; Gumbo, 2004). It can be concluded therefore that effective management of water resources for urban water utilities especially for developing countries still remains a challenge. The major sources of

[1] The scheme is in Malawi under Central Region Water Board which has 19 Water Supply Schemes spread in 9 districts in central region of Malawi.

unaccounted-for water in the majority of African cities are leakage and illegal abstractions (DFID, 2003).

One of the ways in which efficient and sustainable use of water resources can be achieved is through application of water demand management (Mwendera et al., 2003). Water demand management (WDM) is defined as the development and implementation of strategies aimed at influencing water demand in order to achieve water consumption levels that are consistent with equitable, efficient and sustainable use of the finite water resource (IUCN-WaterNet, 2003). Mckenzie et al. (2002) identified two broad categories of water demand management for water supply utilities namely infrastructure and water system demand management, and customer demand management, which when combined forms total water demand management. Pressure management is one of the tools that have been identified to reduce high levels of real water losses in infrastructure and water system demand management (Thornton, 2003; Nkhoma et al., 2005; Marunga et al., 2006).

Kasungu Water Supply Scheme located in the central region of Malawi has an average water production capacity of 3,165 m^3/day against a current demand of 5,032 m^3/day (CRWB, 2007). The water produced is distributed through an old water supply network system that losses 27 % of the water (Metaferia and Hydroconsult, 2008). The high water loss in the scheme is contributing to high operating costs as pumps are run for 24 hours to suffice current total water demand which is higher than current production capacity and has also resulted in poor service quality as water is supplied an average of 18 hours/day to some customers in the area (CRWB, 2007). The elevation difference between the service tanks and the distribution system in the scheme range from 30 m to 65 m. This huge elevation difference results in high pressure in distribution system. It is against this background that a study was carried out in Kasungu Water Supply Scheme from January 2009 to May 2009 to investigate the potential of reducing real (physical) water losses through pressure management in order to have efficient and effective utilization of water resources in Kasungu.

1.2 Problem Statement

Kasungu Water Supply Scheme currently records high levels of unaccounted-for water figures in its water supply schemes by international standards. From July 2007 to June 2008 Kasungu Scheme produced 1.1 million cubic metres (equivalent to 3,165 m^3/day) out of which the volume consumed was 0.8 million cubic metres (equivalent to 2,237 m^3/day) representing an unaccounted-for water of 29% (Metaferia and Hydroconsult, 2008). The impact of static pressures on levels of unaccounted-for water being experienced in Kasungu is not known. Solutions that are applied to alleviate the problem of high unaccounted-for water in the scheme have been servicing and replacement of faulty meters and replacement of very old pipes (CRWB, 2006). This is also evidenced by lack of pressure controllers in the distribution network. Hence the potential reduction in high levels of unaccounted-for water that can be realised from implementation of pressure management is also not known.

Marunga et al. (2006) in studies to investigate the potential use of pressure management as a water demand management tool for the city of Mutare in Zimbabwe, carried out bucket tests only on highest and lowest points in the research area to investigate the effect of pressure management on service delivery. Critical points in a water supply system are generally the highest point in the system, the point most distant from the source, or a combination of the two depending upon local topography (McKenzie, 2002). Therefore, both of the above points need to be tested when investigating the effect of pressure management on service delivery hence findings by Marunga et al. (2006) requires validation.

1.3 Justification

Kasungu Water Supply Scheme has an average unaccounted-for water of 27% (Metaferia and Hydroconsult, 2008). This figure is high compared to both regional and international standards. Gumbo (2004) proposed an unaccounted-for water of not more than 20% for southern African region while van der Zaag (2003) and Tynan and Kingdom (2002) suggested that the level of unaccounted-for water for a well performing water utility in a developing country should lie between 15% - 25% including 5% treatment losses.

Ismail and Puad (2006) indicated that high levels of NRW only have a negative impact on the utility's finances by increasing operating costs and reducing revenues in cases where a utility has surplus water resources and result in water shortages during peak demand periods thus reducing the level of service provided to customers in cases where the utility has no surplus water resources. In Kasungu Water Supply Scheme, high UFW is contributing to increase in operating costs and result in lowering water supply service standards. For instance in 2007, Kasungu recorded a lower average service level of 18 hours per day for some customers in its supply area

(CRWB, 2007) compared to a service level of 24 hours per day proposed by Tynan and Kingdom (2002). Non-continuous supply of water in a water supply system increases the risk of contamination due to infiltration of polluted ground water.

1.4 Research Objectives

1.4.1 Main Objective

The main objective of the research was to investigate the use of pressure management as a tool for real water loss reduction and control in Kasungu Water Supply Scheme.

1.4.2 Specific Objectives

The specific objectives were:

- To ascertain the current level of unaccounted-for water through real losses in Kasungu Water Supply Scheme.
- To investigate the impact of pressure management on levels of real water losses in the water supply reticulation system.
- To investigate the impact of pressure management on customer service quality.
- To carry out cost – benefit analysis of pressure management as a tool for leakage reduction and control.
- Develop a real water loss management programme for Kasungu Water Supply Scheme

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Introduction

For the past many years, the predominant approach to water resource development focused on developing new supplies and structures to exploit available water supplies in order to meet water needs an approach commonly referred to as supply orientated approach (Arlosoroff,1997). However, as pointed out by McKenzie et al. (2002), of late there has been a clear move away from this traditional approach of water resource development to one of water conservation to meet the ever growing water demands in most parts of the world. The shift came in the realisation that in many parts of the world there is severe and permanent water stress and countries cannot sustain indefinitely the ever rapidly increasing demands for water (McKenzie, 2002). Since water is known to be a finite, vulnerable and essential resource, which requires to be managed in an integrated manner, water conservation and demand management measures for reduction of water losses and efficient water utilisation in all spheres of the water sector are becoming increasingly important and being promoted world over (Savenije and van der Zaag, 2002).

2.2 Water demand management

Water demand management (WDM) is the development and implementation of strategies aimed at influencing water demand in order to achieve water consumption levels that are consistent with equitable, efficient and sustainable use of the finite water resource (IUCN-WaterNet, 2003). Water demand management is another approach to water resources management that contrasts with the traditional supply management, which aims at increasing the supply whatever the demand, since it targets the water user rather than the supply of water to achieve more desirable allocations and sustainable use of water (Savenije and van der Zaag 2002). Savenije and van der Zaag (2002) further state that demand management should not be seen as merely aiming at reducing demands or achieving higher water use efficiencies, but it should also promote equity and environmental integrity. Although detailed figures are not available, it is stated that WDM measures are 70% to 80% cheaper than the construction of additional dams, well fields and associated water transfer schemes and in urban settings, the savings may be as high as 90% (Arntzen, 2003).

McKenzie et al. (2002) identified two broad categories of WDM namely infrastructure and water system demand management, and customer demand management. Infrastructure and water system management involves optimising the efficiency of the water supply system whilst customer demand management involves influencing the efficient use of water by customers. A combination of the two broad categories above forms total water demand management. A vital component of water demand for a water supply system is water losses in treatment, transmission and distribution systems. Water losses in treatment, transmission and distribution system are termed real or physical water losses (Lambert, 2003; Kingdom et al., 2006).

2.3 Water demand management in southern Africa region

Water demand management in Southern African Development Community (SADC) started through the formulation and implementation of SADC Regional Strategic and Action Plan (RSAP) 1999 – 2004 for integrated water resource development and management (Arntzen, 2003). According to Arntzen (2003) the plan cites delayed investment costs and reduced environmental costs associated with supply expansion as major reasons for WDM and it has separate sections on water demand management, water conservation and sustainable development. In 2000 SADC formulated a SADC Protocol on Shared Watercourse Systems which is wholly based on the IWRM approach though the Protocol does not mention this explicitly (Sandström and Singh 2004). The Protocol seeks to facilitate the establishment of shared watercourse agreements through river basin commissions; advance sustainable, equitable and reasonable use of shared water; integrated, coordinated and environmentally sound development and management; harmonise legislation and policies; promote research, technology development, and information exchange on shared watercourses Arntzen (2003). WDM is an integral and indispensable part of IWRM (Arntzen, 2003). Therefore by formulating a Protocol which is based on IWRM approach SADC is also facilitating the promotion of WDM at a regional level.

Mwendera et al. (2003) noted that while some countries are practising WDM, there is generally low level of adoption of WDM in various sectors within the region. However, according to Sandström and Singh (2004) some countries in Southern Africa by May 2004 were at different stages of implementation of WDM. Namibia and South Africa were quite advanced with clearly formulated policies and strategies. Botswana was in the process of formulating policies and strategies while Zimbabwe had just approved a new Water Act (1998) and a new Integrated Water Management Strategy, which creates a good platform for WDM implementation. Most other countries had not yet formulated specific WDM policies and strategies, but were exploring opportunities to do so.

2.4 Water Demand Management in Malawi

Malawi has, in recent years, undertaken a number of reforms in the water sector to meet changing national and international needs and priorities (Mkandawire and Mulwafu, 2006). The reforms include new water policies and legislation, decentralization of government functions and efforts to harmonise policies in the natural resources area. The country developed its first water resources management policy in 1994 which was revised in 2000 and 2004 to strengthen the water resources management and address all aspects of water development and service delivery using integrated water resources management (IWRM) principles (GOM, 2004). However the management of water resources in the country are still being guided by the Water Resources Act (1969) which is quite old. According to Mulwafu et al. (2003), the Act has been criticized for its deficiencies, particularly the lack of a schedule on offences and penalties; its inadequate provisions concerning water rights, water harvesting, water saving and water transfer; its failure to provide for stakeholder participation; and its failure to recognize recent international treaties and conventions to which Malawi is a signatory. A new Act which addresses these deficiencies was drafted in 1999 and still awaits parliamentary enactment.

GOM (2004) points out a number of problems and challenges in water resources management that compels the need to promote WDM in Malawi. These include serious water resources degradation in catchments, inadequate water supply and sanitation services coverage, increasing water demand as a result of increasing population pressure, extreme climatic events such as inadequate rainfall resulting in drought. Chavula (2002) observed that several water supply schemes are old and hence prone to high water losses through leakage.

Some aspects of WDM are being practiced in Malawi more especially by private sector consumers though existing conditions on the ground prevent its increased expansion as a strategy for promoting an efficient and equitable use of existing water resources (Mulwafu et al., 2003). Among private sector enterprises, WDM is motivated by the desire to minimize water bills with the objective of maximising profit by minimizing the cost of production. Lacking the profit motive, public sector institutions only institute WDM during those times when there is a shortage of supply of water or when the water delivery system has broken down Chavula (2002).

According to Mulwafu et al. (2003) main constraints to WDM application in Malawi are belief that water must not be paid for, high percentage of poor people, conflicting organizational interest on provision of water, the desire to protect the environment, weak institutional linkages, poor financial capacity, use of old technology and equipment to supply water, inadequate staffing level in policy institutions, lack of awareness on economic value of water, lack of enabling policy and legal environment, and strong political influence in WDM undertakings. The mentioned constraints to WDM call for the implementation of effective measures to redress the situation, so that WDM can be used as an effective tool for managing the water resources that the country has.

2.5 The Benefits of Implementing Water Demand Management

A major benefit of water demand management as identified by McKenzie et al. (2002) is that it delays expensive water resources development projects by 'creating' a source of water supply. As pointed out by Hazelton et al. (2002) effective implementation of WDM in a water utility also results in significant reductions of unaccounted-for water and water demands with no deterioration in life style thus resulting in reduced amount of water that has to be delivered. Reducing the volume of water that has to be delivered, WDM in the short run brings financial savings to the water supply utility through reductions in treatment and pumping costs (Robinson, 2003). There is, however, an argument that costs of constructing a new water infrastructure are bound to rise if they are delayed by adopting WDM strategies (van der Zaag, 2003). Robinson (2003), however, argued that such rises are only nominal as projected prices would be purely due to inflation. It can therefore be concluded that implementing WDM measures provides a much cheaper source of water than investing in a new source of supply and results in reduced water production costs to water utilities. According to Hazelton et al. (2002) benefits derivable from effective implementation of WDM at utility level include:

- a significant reduction of capital requirements for expansion of new sources of water supply,

- a reduction in the quantity of pollutants produced and, therefore the requirements for new or expanded waste management systems,
- the stimulation to the development and adoption of new technologies,
- the promotion of financially and environmentally sustainable water systems,
- the possibility of expanding coverage of available water development funds, thus enabling the sector to expand its water supply systems to other sections of its operations.
- reduced costs to the treatment of wastewater due to reduced flows to the treatment works.

Some of the compelling factors for implementing WDM according to Tsinde Consultants (2002) are as follows:

- Water resources are limited whereas the use of water is ever increasing
- Water shortages are already occurring world-wide and is one way of ‘sourcing’ water
- Financial constraints limit development of new water sources
- Costs of developing new water resources are ever increasing since the cheapest sources of water have already been developed

2.6 Real water losses

Real water losses represent the annual volumes of water lost through all types of leaks, bursts and overflows on mains, service reservoirs and service connections, up to the point of customer metering (Lambert, 2003). Real water losses represent the physical water losses from the pressurized system, up to the point of measurement of customer use (McKenzie et al., 2002). Physical losses comprise leakage from all parts of the system and overflows at the utility’s storage tanks and they are caused by poor operations and maintenance, the lack of active leakage control, and poor quality of underground assets (Kingdom et al. 2006).
Real water losses are expressed in the following ways (Liemberger and Farley, 2005):

- Litres/service connection/day
- Litres /km of mains/day – used only if service connection density is less than 20/km
- Litres /service connection/day/m pressure
- Litres /service connection/day/m pressure – used only if service connection density is less than 20/km

- Infrastructure Leakage Index (ILI) – ratio of Current Annual Real Losses (CARL) to Unavoidable Annual Real Losses.

According to Liemberger and Farley (2005) litres/service connection/day and litres/km of mains/day are basic level indicators and are best of the simple 'traditional' performance indicators, useful for target setting, limited use for comparisons between systems while litres/service connection/day/m pressure and litres/service connection/day/m pressure are intermediate level indicators and are useful for comparisons between systems. Being a ratio, the ILI has no units and facilitates comparisons between countries that use different measurement units (U.S., metric or imperial), thus ILI is the most powerful indicator for comparisons between systems (Liemberger and Farley, 2005).

2.6.1 Determining real water losses

Real water losses are determined through a number of approaches namely Component Analysis, 'Bottom – Up' analysis of night flows and 'Top – Down' calculation of an annual International Water Association (IWA) water balance or a combination of two or more of the above approaches (Fanner, 2003; Lambert, 2003; Liemberger and Farley, 2005).

According to Fanner (2003) Component Analysis approach uses numbers, average flow rates and average run-times of different types of leaks and bursts (background, reported and unreported) on different parts of the distribution infrastructure (mains, service reservoirs, and different sections of service connections). A component analysis model breaks down the overall volume of real losses into its constituent components for each element of the system infrastructure, based on their most influential parameters and is also useful for evaluating leakage management options (Fanner, 2003; Lambert, 2004).

Estimation of the real loss component using the 'Bottom – Up' approach involves subtracting legitimate night consumption (assessed and measured) for the customers connected to the mains in the zone being studied from measured minimum night flows. The minimum night flow (MNF) is the lowest flow into a zone or district metered area and in urban situations this normally occurs between around 12:00 and 04:00 hours (McKenzie et al., 2002). According to McKenzie et al. (2002) during the MNF period, authorized consumption is normally at a minimum and therefore real losses are at their maximum percentage of the total flow. The result obtained from subtracting the legitimate night consumption from the minimum night flow provides an estimation of the volume of real losses during the MNF period (Fanner, 2003). The benefits of the bottom-up real loss assessment are that it provides an independent determination of the volume of real losses and, if this analysis is undertaken across the whole distribution system, also facilitates collecting the field data required for determining the pressure/leakage relationship (N1) and the infrastructure condition factor (ICF) (Fanner, 2003). Real losses assessed through the IWA Best Practice 'Top-Down' annual water balance (Table 2.1), does not provide any information on the components of this total volume of real losses as it does not break down real losses into the volume of real losses due to detectable bursts, (that can potentially be managed through speed and quality of repairs, and active leakage control) or real losses due to background losses (that can only be reduced by pressure management or infrastructure renewal) (Fanner, 2003). Fanner (2003) further state that the analysis also provides no information on the volumes of real losses from the various elements of infrastructure, which is required to develop appropriate loss management strategies. For these reasons, it is recommended that, if possible, the top-down annual water balance is undertaken in conjunction with the other two assessment methods.

The steps for calculating real water loss using IWA water balance are as follows:

- Step 1: Obtain System Input Volume
- Step 2: Obtain Billed Metered Consumption and Billed Unmetered Consumption and add together to calculate Billed Authorised Consumption and Revenue Water
- Step 3: Calculate the volume of Non-Revenue Water as System Input Volume minus Revenue Water.
- Step 4: Obtain Unbilled Metered Consumption and Unbilled Unmetered Consumption and add together to calculate Unbilled Authorised Consumption.
- Step 5: Add volumes of Billed Authorised Consumption and Unbilled Authorised Consumption to calculate Authorised Consumption.
- Step 6: Calculate Water Losses as the difference between System Input Volume and Authorised Consumption.
- Step 7: Assess components of Unauthorised Consumption and Metering Inaccuracies by best means available, and add these to calculate Apparent Losses.

- Step 8: Calculate Real Losses as the difference between Water Losses and Apparent Losses

Table 2.1: International Water Association (IWA) 'best practice' Water Balance

<table>
<tr><td rowspan="9">System Input Volume
M^3/year</td><td rowspan="4">Authorized Consumption
M^3/year</td><td rowspan="2">Billed Authorized Consumption
M^3/year</td><td>Billed Metered Consumption</td><td rowspan="2">Revenue Water
M^3/year</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption
M^3/year</td><td>Unbilled metered Consumption</td><td rowspan="7">Non-Revenue Water
M^3/year</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="5">Water Losses
M^3/year</td><td rowspan="2">Apparent Losses
M^3/year</td><td>Unauthorized Consumption</td></tr>
<tr><td>Metering inaccuracies and Data Handling Errors</td></tr>
<tr><td rowspan="3">Real Losses
M^3/year</td><td>Leakage on Transmission and/or Distribution Mains</td></tr>
<tr><td>Leakage and Overflows at Utility's Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to point of Customer Metering</td></tr>
</table>

(Adopted from McKenzie and Seago, 2005)

2.6.2 Detailed quantification of real loss components

The first step to take in the detailed quantification of real losses is to obtain the total volume of real losses from water balance (Liemberger and Farley, 2005). This gives a feeling of the magnitude of real losses. Thereafter real losses should be computed using component analysis.

Key data required for computation of component analysis include total length of pipe network and number of service connections, average service connection length between curb-stop and customer meter, total number of distribution mains repairs per year (reported and unreported), total number of service connection repairs per year (Reported and unreported), average system pressure across the entire network, estimates of the time periods for Awareness, Location and Repair duration, and estimates of utility storage tank leaks and overflows. Reported bursts are those events that are brought to the attention of the water utility by the general public or the water utility's own staff while unreported bursts are those that are located by leak detection teams as part of their normal everyday active leakage control duties Liemberger and Farley, (2005). McKenzie et al. (2002) argue that awareness duration for reported bursts is generally very short, probably not more than 24 hours and will depend on the active leakage control (ALC) policy. They further state that location of a reported leak generally does not take much time since it is visible and repair duration depends on the utility’s repair policy and capacity. As the average pressure is a key parameter in any real loss analysis, it is worth undertaking some detailed work to obtain a good estimate of the average pressure and pressures should be calculated as 24-hour averages values (McKenzie et al., 2006).

Another important step to in the determination of real loss components is calculation of leakage from background losses (Liemberger and Farley, 2005). Morrison (2004) state that leakage is split into two main components namely background leakage and annually occurring bursts (sometimes referred to as breaks). According to Morrison (2004) background leakage is the aggregation of sources of loss from all fittings on the network that are individually too small to be detected while burst leakage is the loss of water resulting from annually occurring holes/fractures in the network pipe work, including customer service connections, which can be located using a range of specialised equipment. Background losses are based on the simple concept that no system can be entirely free from leakage even a new one and that every system will have some level of leakage which cannot be reduced any further (McKenzie et al., 2002). According to McKenzie et al. (2002) Allan Lambert proposed a concept of Unavoidable Annual Real Losses (UARL) based on the fact that no system can be entirely free from leakage. After careful analyses of many systems throughout the world, Allan Lambert developed the following equation for UARL (McKenzie et al., 2002):

$$UARL = (18 * Lm + 0.8 * Nc + 25 * Lp) * P \qquad (1)$$

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

L_m = Length of mains (km)

N_c = Number of service connections (main to meter)

P = Average operating pressure at average zone point (m)

L_p = Length of unmetered underground pipe from street edge to customer meter (km)

The equation is based on an average length of pipe from the water main to the customer meter of 10 m and the Lp term in the equation is therefore only used in cases where the customer meter is located in excess of 10 m from the water main (McKenzie et al., 2002). However, according to Seago et al. (2004) it is impossible to reduce water losses to a level determined through UARL calculation in practice. Accordingly target loss factors (TLFs) were proposed to adjust values derived from UARL calculation. A range of TLF factors of 2 to 5 were proposed where a factor of 2 is for a water system in sound physical condition and a factor of 5 is for a water system in very poor condition (Seago et al., 2004).

Real water losses also occur on overflowing storage tanks and old underground storage tanks Losses from old underground tanks may be determined using level drop tests. Once all the components mentioned above are quantified, the excess losses can be calculated as the difference between real losses from annual water balance and known real loss components.

A further important step to take in the determination of volume of real losses is to measure pressure and flows into a zone or district metered area (Morrison, 2004). Assuming that no district metered area established, areas of the distribution network have to be selected which can be temporarily isolated and supplied from one or two inflow points only (McKenzie et al., 2002). Suitable areas need to be selected in various parts of the distribution system, with the objective of obtaining a representative sample of the system. In these areas, 24 hour inflow measurements are carried out with portable flow measurement devices along with pressure measurements where pressures are recorded at the zone inlet point(s), at the average pressure point and at the critical pressure point (McKenzie et al., 2002). The estimation of the real loss component at minimum night flow is carried out by subtracting an assessed amount of legitimate night consumption for each of the customers connected to the mains in the zone being studied and the result obtained consists predominantly of real losses from the distribution network (Morrison, 2004). The daily level of real losses obtained from the minimum night flow analysis can be determined by applying the fixed area and variable area discharge (FAVAD) principles and simulating leakage over the full 24 hour period (Farley, 2001).

2.7 Apparent water losses

Apparent water losses are water losses arising from unauthorised consumption (theft or illegal use) plus all technical and administrative inaccuracies associated with customer metering (Lambert, 2003). According to McKenzie et al. (2002) apparent losses in water utilities range from less than 10% for a well-managed system to more than 80% for a system experiencing major problems with household leakage and high levels of non-payment for services. McKenzie et al. (2002) further observed that in areas of low payment or where a flat rate tariff is used, the apparent losses tend to be relatively high since there is little incentive to manage or reduce them.

McKenzie et al., (2002) observed that assessment of the apparent losses is difficult and subjective exercise and an estimate should be made from local knowledge of the system and an analysis of technical and administrative aspects of the customer metering system. It was further noted that reducing apparent losses would often result in higher income to the water supplier while reducing real losses will reduce the volume of water required by the water supplier.

2.8 Leakage control concepts

2.8.1 Active and passive leakage control

According to Thornton et al., (2002), Active Leakage Control (ALC) is the proactive approach of sending leak detection and repair teams into areas to search for and repair unreported bursts and leaks and Passive Leakage Control (PLC) involves the passive approach of waiting for leaks to be reported after which the leak repair teams are dispatched to locate and repair reported bursts and leaks. ALC has two main methods namely regular survey and leakage monitoring (Liemberger and Farley, 2005). According to Liemberger and Farley (2005) regular survey is a method of starting at one end of the distribution system and proceeding to the other using one of the following techniques; listening for leaks on pipework and fittings reading metered flows into temporarily-zoned areas to identify high-volume night flows using clusters of noise loggers while leakage monitoring is flow monitoring into zones or district metered areas (DMAs) to quantify leakage and to prioritise leak detection activities. McKenzie et al. (2002) argues that PLC is apparently cheaper to operate and manage on short term basis compared ALC. However, the control measure suffers the disadvantage of permitting bursts and leaks to run for many months, if not years, before they are noticed and repaired resulting in huge water losses since a key factor in the leakage from a water supply system concerns the length of time over which a leak will run (McKenzie et al., 2002).

While ALC might be expensive to carry out frequently, McKenzie at al, (2002) observed that in some instances, it is cost effective to investigate a system every 6 months, than to carry out such investigations every two years or even longer. McKenzie at al. (2002) further argues that ALC does not necessarily require teams with sophisticated and expensive equipment. Personnel using low cost sounding sticks to detect the underground leakage or simply driving past or walking along the route of all water mains on a regular basis and recording any “visible” leaks that are evident may be employed. In cases where a water utility does not have sufficient funds to support even a low level form of ALC, a well managed and effective system for dealing with reported leaks will often provide a cost effective and reasonably efficient form of leakage management.

2.8.2 Economics of leakage control

Balkaran and Wyke (2003) defines economic level of leakage (ELL) as the level of leakage at which the additional cost of reducing leakage is equal to the additional benefit gained from further leakage reductions. It refers to that level of leakage at which it would cost more to make a further reduction in leakage than to produce water from another source. Key stages in determining ELL according to Balkaran and Wyke (2003) are outlined in Table 2.2.

Ramsey and Mobbs (2001) report that economic level of leakage is derived from a balance between resource availability and demand and the cost of water offset by the progressive cost of reduction. The cost of reducing leakage, according to Farley (2001), depends on factors such as age of the system and availability of local supplies of water. Reducing leakage below the most economic level can result in significant increase in costs (Balkaran and Wyke, 2003)

Table 2.2: Key stages in ELL process

Define area basis	**Decide zonal disaggregation (consistent water supply and leakage management areas)**
Establish the current position	Calculate current leakage (trunk mains and supply system, distribution mains and customer service pipes)
	Determine current policy minimum (existing policy)
Review future/alternative options	Establish leakage detection and repair costs (existing policy)
	Establish current and future supply/demand balance and alternative investment costs (resources and demand management)
	Consider new policy and technology options (for leakage management, pressure management, mains replacement, etc)
	Develop family of leakage/cost relationships
Calculate the economic target	Option 1 = leakage level output of least cost planning analysis (programme with lowest NPV)
	Option 2 = relationship between active leakage control cost curve and cost of Water

(Source: Balkaran and Wyke, 2003)

2.9 Pressure management

Pressure management can be defined as the practice of managing system pressures to an optimum level of service ensuring sufficient and efficient supply to legitimate uses and consumers, while eliminating or reducing pressure transients and variations, faulty level controls and reducing unnecessary or excess pressures, all of which cause the distribution system to leak and break unnecessarily (Thornton and Lambert, 2006).

2.9.1 Methods of pressure management

Thornton (2003) identified three categories of pressure management for leakage and demand reduction namely pressure reduction/sustaining, surge anticipation/relief and level/altitude control. The most common form control of the three is pressure reduction. Pressure reduction can be undertaken using various methods. Thornton et al. (2002) identified four forms of pressure reduction namely sectorisation, throttled line valve, pump and level control and automatic control valves (ACVs). Sectorisation involves dividing subsectors either naturally or by physical valving and in its simplest form does not require implementation of costly ACVs and controllers but is often incompletely efficient without them. Throttled line valve involves use of gate valves or butterfly valves to create a headloss and reduce pressure. It is the least effective method. However as the headloss created changes the system demand also changes. Pump control involves activating and deactivating pumps depending on system demand. The method is effective if the reduced level of pumping maintains tank levels. The method, however, may have adverse impacts on energy consumption levels as the pump may operate outside designed profiles as the pump is subjected to upstream valve throttling or demands outside design limits.
Automatic Control Valves involves use of automatic control valves which are hydraulically operated. They are effective for areas with low head losses, demand which do not vary greatly with the seasons, and uniform supply characteristics.

McKenzie et al. (2002) identified three types of automatic PRV controllers both electrically-operated and hydraulically-operated namely conventional/fixed outlet PRV, time-modulated PRV, and flow-modulated PRV. Conventional/fixed outlet PRV is simply a normal or conventional PRV, which is used to provide a continuous fixed pressure at the inlet to a zone. It is less expensive than the other forms of PRVs. Time-modulated PRV is the simplest form of advanced pressure control and also the least expensive. It is a timing device that can be attached to the controlling pilot on any conventional PRV to reduce the outlet pressure at certain times of the day. It is ideal for reducing excessive pressures at night when most of the consumers are asleep and the demand for water is minimal. Flow-modulated PRV is complex and provides greater flexibility and control than that offered by the simpler time-modulated controller. The flow-modulated PRV is very expensive and is approximately double the cost of the time-modulated version. It controls the pressure at the inlet point in accordance with the demand being placed on the system. During peak demand periods, the maximum pressure as dictated by the

PRV will be provided, while at low demand periods the pressure will be reduced to minimise excess pressure and the associated leakage.

2.9.2 Pressure – leakage Theory

One of the most important factors influencing leakage is pressure. It is generally accepted that flow from a hole in a pipe will react to pressure in accordance with normal hydraulic theory that indicates a square root power relationship between flow and pressure (i.e. the power exponent is equal to 0.5) whether the pipe is above ground or buried (Mckenzie et al., 2002). Lambert (2003), however, argues that the most appropriate general equations to use for simple analysis and prediction of pressure and leakage relationship whether for laboratory tests on individual faults in pipes, or for aggregate leakage from sectors of distribution systems is the equation:

$$Flowp1 = flowp2 * PCF \tag{2}$$

Where P1 = Pressure 1 (m)

P2 = Pressure 2 (m)

$Flow_{P1}$ = Flow at pressure P1 (m^3/h)

$Flow_{P2}$ = Flow at pressure P2 (m^3/h)

PCF = Pressure correction factor = $(P1/P2)^{pow}$

pow = power exponent. Ranges from 0.5 to 2.5 for a system with all pipe material being iron/steel and plastic respectively.

2.9.3 Benefits of Pressure Management

Pressure management aims at reducing excess pressure in a water distribution system, which, in turn, will reduce leakage as well as the frequency of pipe bursts (McKenzie et al., 2002). It is one of the simplest methods of reducing infrastructure system demand (DFID, 2003). As reported by McKenzie et al. (2002) high pressures increase losses of water through leaks and increase use when the amount of water use is based on time rather than volume of water discharged. Pressure management using not only pressure-reducing techniques but also pressure sustaining techniques, boosters, or flow control can ensure that the system distributes its resources as evenly as possible, providing required volumes for a majority of the customers (Thornton et al., 2002).

Additional benefits of pressure management according to Nkhoma (2004) and Thornton et al. (2002) in a water supply system include fewer customer complaints and improved level of service, promotes slower deterioration of the network, reduced insurance/compensation claims, reduced expenditure for network maintenance, results in fewer unplanned shutdowns of water supply, improvement in several performance indicators and finally reduced losses on the part of the utility in areas where the level of non payment is high due to political reasons. Economic benefit of pressure management have, for some 25 years, been based on the predicted reduction in flow rates of existing leaks and the value of the water thus saved (Thornton and Lambert, 2006).

According to Arntzen (2003) water losses were reduced from 30% to 9% in Botswana translating into money savings of Pula 21.5 million per annum through pressure management. In Windhoek, Namibia pressure management resulted in water savings equivalent to N$ 6.8 million per annum and delayed infrastructure investment by 10 years (Arntzen, 2003). McKenzie et al. (2004) report that implementation of pressure management in Khayelitsha townships in South Africa resulted in a drop of minimum night flow from 2500 m^3/h to 750 m^3/h and a total annual savings of 9 million Rand equivalent to 40% of original water supplied to the area immediately after implemention. Studies by Nkhoma et al. (2005) in Lilongwe, Malawi and Marunga et al. (2006) in Mutare, Zimbabwe showed that pressure management has a potential of reducing water losses by more than 25%.

CHAPTER 3

3.0 STUDY AREA

3.1 Description of the site

The area under study is located in Kasungu Township (Figure 3.1) about 127 km north of Lilongwe City along M1 road to Mzuzu in the central region of Malawi. Geographically Kasungu is located at latitude 33^{o} 29' 0" and longitude 33^{o} 48' 0". It has a land area of 36.78 km^{2}. The maximum and minimum elevation in the town is 1,451 m.a.s.l on top of Kasungu hill (which is inside the town boundary) and 1,020 m.a.s.l respectively. The area has an average rainfall of 763 mm/year with mean temperatures ranging from 9 ^{o}C in winter to 32 ^{o}C in summer.

3.2 Population

The population of Kasungu according to NSO (2008) is presented in table 3.1 below.

Table 3.1: Population growth for Kasungu Town Assembly

Census Year	1977	1987	1998	2008
Population	7200	11,591	27754	42351
Annual growth rate	-	5.1%	7.4%	4.3%
Average household size	4.1	4.4	4.9	5.8

(Source: NSO, 2008)

Table 3.1 above shows that the population growth rate for Kasungu town fell down from 7.4% to 4.3% between 1998 and 2008. Assuming that the population growth rate will continue to decrease and using population growth rates in Table 3.2 , the forecasted population for Kasungu for both high and low scenarios for 2015 is 65,143 and 62,333 respectively and for 2025 is 96,607 and 82,668 respectively. Although the population growth rate show a downward trend over the past decade, both economic and social growths have exerted an increasing water demand to meet their requirements and the increasing trend of water demand is expected to continue in the future.

Table 3.2: Projected population and growth rate for Kasungu

Year	High Scenario		Low Scenario	
	Population	**Growth Rate**	**Population**	**Growth Rate**
2000	29,300	6.0%	29,300	6.0%
2005	39,166	5.9%	39,140	5.8%
2010	51,236	5.3%	50,526	4.9%
2015	65,143	4.7%	62,333	3.9%
2020	80,482	4.1%	73,461	3.0%
2025	96,607	3.5%	82,668	2.0%

(Source: Metaferia and Hydroconsult, 2008).

3.3 Land use

Kasungu Town Assembly has total planned land area of approximately 36.8 km^2 (Metaferia and Hydroconsult, 2008). Figure 3.2 below presents land allocation for different use according to the structure plan of the town. Both Figures 3.1 and 3.2 shows that Kasungu Assembly has got two dams. However, the Assembly depends on Chitete dam only for water as the other dam is under private ownership. Chitete dam has a safe yield of 2.9 million cubic metres per annum which is equivalent to 6,700 m^3/day without considering evaporation and dead storage (Lahmeyer and JR International, 1994). According to Metaferia and Hydroconsult (2008) this safe yield was enough to cover water demand up to 2005. This means that provision of water supply services and management of water resources in Kasungu needs to be both effective and efficient to meet the current water demands required in the town assembly.

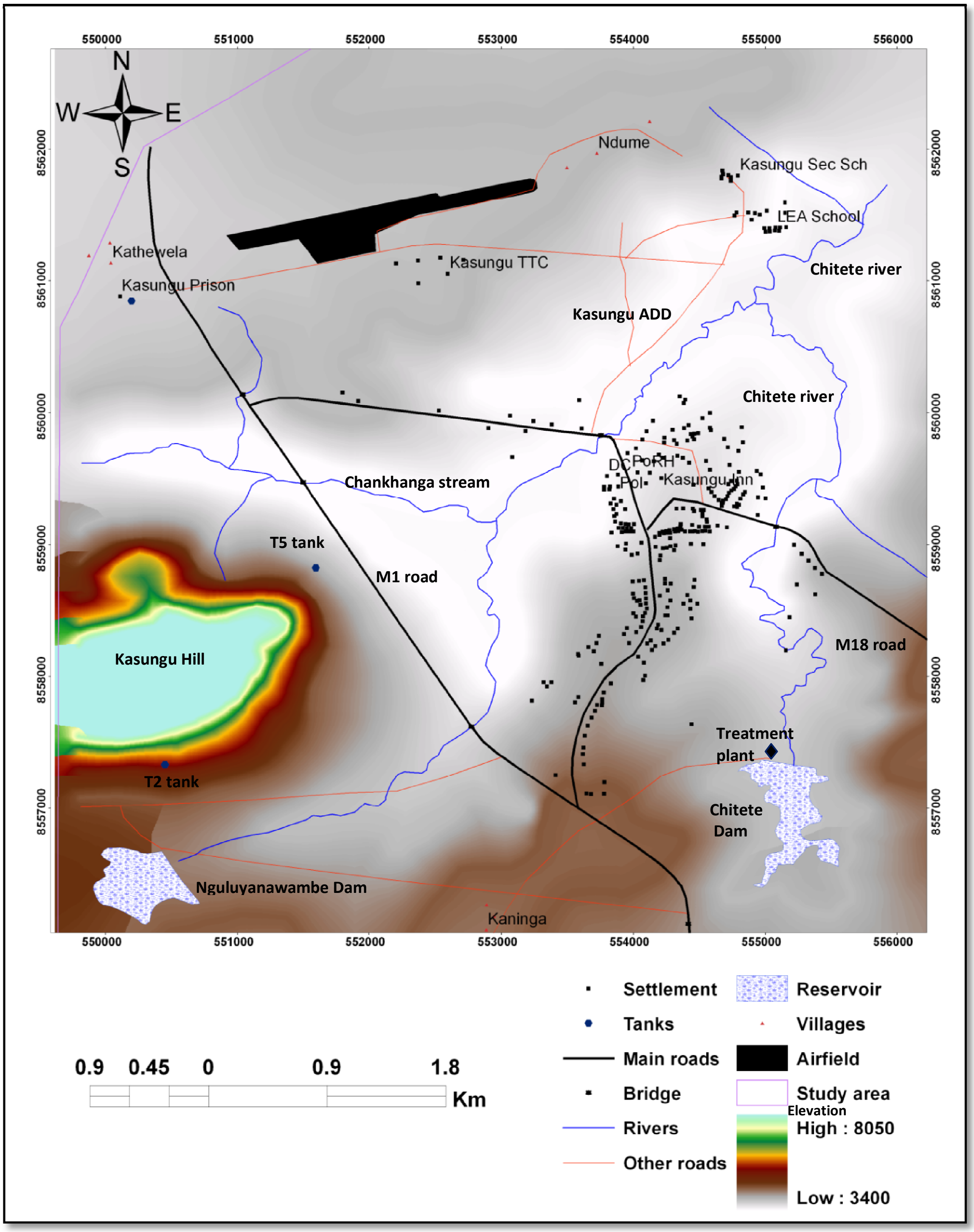


Figure 3.1: Map of Kasungu Town Assembly[2]

[2]Source: National Spatial Data Centre, Department of Surveys – Malawi

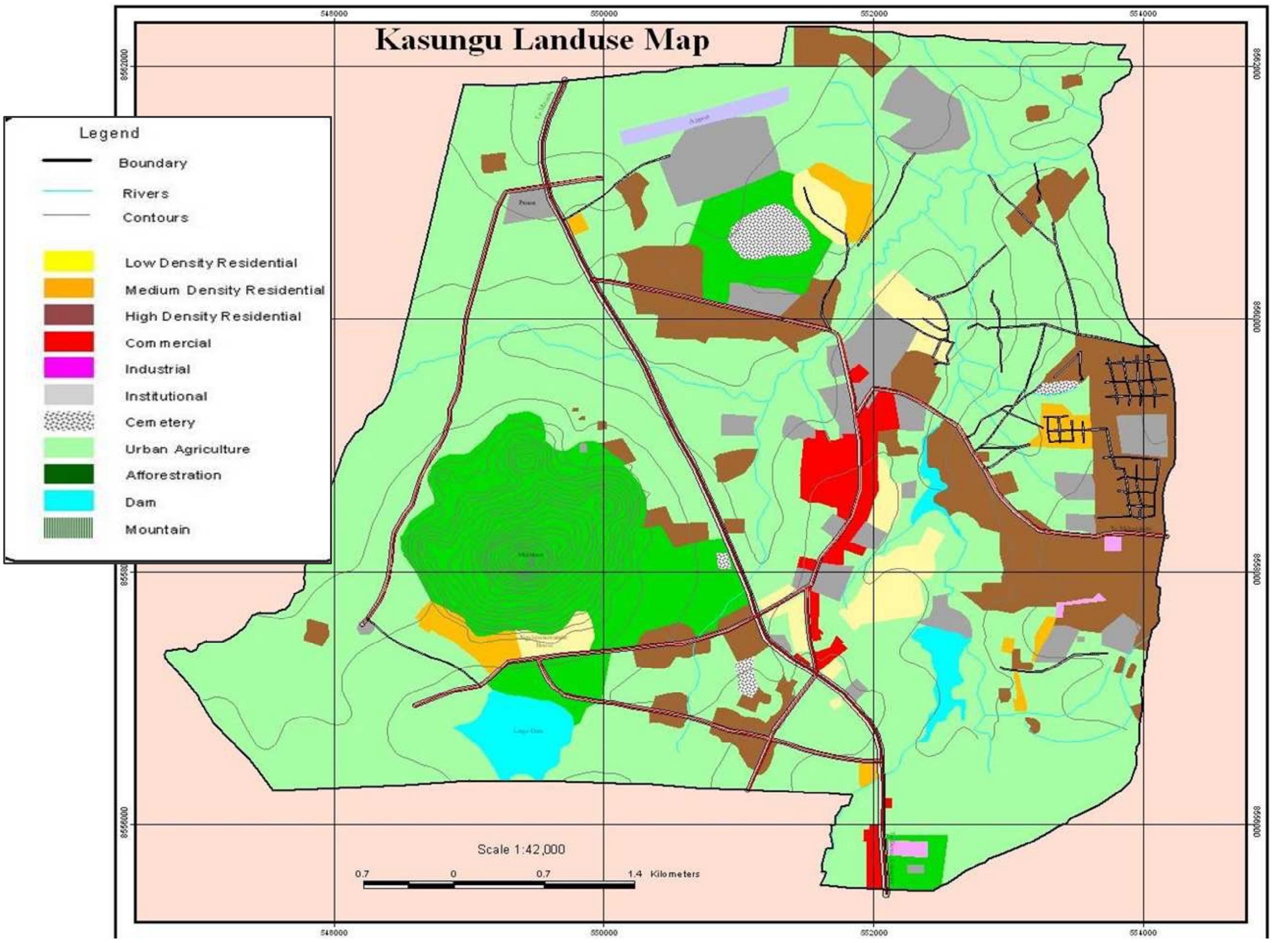


Figure 3.2: Land Use Map of Kasungu Town Assembly
(Source: Metaferia and Hydronconsult, 2008)

3.4 Socio-economic activities

Agriculture is the backbone of the economy in Kasungu. The Town is located in an agricultural area. The major cash crop grown is tobacco and this is followed by maize, which is a staple food crop for Malawi. In addition people in Kasungu keep a variety of livestock mainly for meat with very little dairy production. According to NSO (2005) Kasungu has an average income per capita of US$ 60 per month which is higher than similar towns in Malawi. Similar towns to Kasungu have an average per capita range of US$49 – US$55 (NSO, 2005). Main commercial companies operating in the Assembly include Press Corporation, Chipiku Stores, Southern Bottlers Limited, Arkay Plastics and Bata Shoe Company. The Assembly also has wholesalers and retailers' shops for different factory products. There is no heavy processing factory in Kasungu except for the light industries such as motor vehicle repair workshops, carpentry workshops, grinding mills, cooking oil manufacturing, warehousing hence the daily water demand is low compared to heavy industrialised areas like Lilongwe.

3.5 Background Information to Kasungu Water Supply Scheme

Kasungu Water Supply Scheme is one of the nineteen (19) water supply schemes operated under Central Region Water Board (CRWB). The Board was created in 1996 under the Water Works Act No. 17 of 1995 with financial assistance from the World Bank under the National Water Development Project (NWDP) 1 (Metaferia and Hydroconsult, 2008). The Act empowers CRWB to supply potable water and provide sanitation services in all the town and market centres in central region of Malawi except Lilongwe City where provision of such services are under the jurisdiction of Lilongwe Water Board. However the Board is yet to start providing sanitation services as these services are yet to be handed over to the Board from town assemblies.

Kasungu Water Supply Scheme was constructed some fifty years ago and had major rehabilitation and expansion works carried out during the period 1991 to 1993. The Scheme has a total of 34 employees with an operational efficiency of 13.4 staff/1000 connections (Metaferia and Hydroncosult (2008).

3.6 Water supply system for Kasungu

Kasungu Water Supply Scheme obtains water from Chitete Dam reservoir located at the south edge of the town. The dam has a total storage capacity of 5.84 million cubic metres and a safe yield of 2.9 million cubic metres at full supply (Lahmeyer and JR International, 1994). The scheme has one water treatment plant located close to Chitete Dam. According to CRWB (2007) the treatment plant has a design production capacity of 4,800 m^3/ day which is less than the projected 2015 demand of 13,329 m^3/day. With the operational problems being experienced currently, the treatment plant is reported to have a maximum water production capacity of 3,165 m^3/day. This water is distributed through an old distribution network that loses an average 27% of input system water due to leaks, incessant pipe bursts and inefficient water meters (Metaferia and Hydroconsult, 2008). The distribution network dates back to 1950's when the first water supply system was installed. The highest and lowest elevations in the distribution system are

1,090 m.a.s.l. and 1,025 m.a.s.l. respectively. The scheme has a total pipe length of 28,294 m excluding pipe diameters of less than 50mm (Metaferia and Hydroconsult, 2008). Out of the 28,294 m of pipe mains 22,886 m is polyvinyl chloride (PVC) pipes, 4,212 m is asbestos cement (AC) and 1,196 m is galvanized iron (GI) pipes. Table 3.3 below presents length of distribution pipes by diameter and pipe material.

Table 3.3: Length of distribution pipes by diameter and pipe material

Diameter (mm)	**Length of pipe by Pipe Material in m**			
	PVC	**AC**	**GI**	**Total Length**
50			952	952
63	1,308			1,308
80	1,465	1,270	244	2,979
100	1,1931	2,942		14,873
150	4,318			4,318
200	3,264			3,264
250	600			600
Total	22,886	4,212	1,196	28,294
% of Total	81%	15%	4%	100%

(Source: Metaferia and Hydroconsult, 2008)

The scheme has an estimated water supply coverage of 64% (defined by number of households and connections) and a total of 2,950 customer connections (CRWB, 2007). The remaining 36% of the town is supplied with water from other sources such as boreholes, rivers and wells. However it is the plan of CRWB to increase water supply coverage to 85% by 2015 and 100% by 2025. Kasungu has a moderately flat terrain with a pressure range of up to 70 m in the distribution network (Lahmeyer and JR International, 1994).

3.7 Kasungu Agricultural Development Division (ADD) area

Kasungu ADD Area was selected for the specific study area. The area has two main inflow pipelines, a 200 mm diameter asbestos cement (AC) pipe and a 110 mm polyvinyl chloride

(PVC). These pipelines interconnect to form a loop. Both pipelines have no bulk water meters to record water distributed to the area. The static head between the area and its service tank is 68 m (Lahmeyer and JR International, 1994). There are 210 properties (plots) in the area with 123 connections. Most of the yard connections in Juma section (a section within the area) are shared among 4 to 6 households. The area has a combination of medium and high density residential areas with a population of 1,260 people with an average of 6 people per plot (NSO, 2008). The total length of mains in the area is 5,300 m comprising mainly of Polyvinyl Chloride (PVC) pipes (Metaferia and Hydroconsult, 2008).

3.8 WDM initiatives in Kasungu Water Supply Scheme

In an effort to control infrastructure water demand, Kasungu Water Supply Scheme has a maintenance section headed by the Bye-Laws Inspector which carries out pipe replacement programmes and repairs to leakages and pipe burst of both transmission and distribution mains. The section has an office where all faults in the transmission and distribution system are recorded and passed on to the teams for repairs. The teams carry out passive water loss control within the minimum time possible. Throttling of in line valves in distribution network is also done to reduce the amount of water flowing into certain parts of the distribution system so that customers in other parts of the distribution system should also receive some water. The scheme also carries out retrofitting and plumbing repairs at customer premises at a fee which is dependent on the amount of work to be carried out. Inspections at customer premises are also performed to check illegal connections.

3.9 Sanitation Situation in Kasungu Town Assembly

Kasungu Town Assembly has no municipal sewerage system. According to Sogrea et al. (2002a) 80% of the residents in Kasungu rely on pit latrines, 18% use septic tanks and the remaining 2% (ADD area) have a sewerage system. The latrines are such that 70% are in reasonable condition while the remaining 30% need significant upgrading. Sogrea et al. (2002a) projected wastewater generation for Kasungu to be 3,603 m^3/day and 6,335 m^3/day for 2015 and 2025 respectively. With this projection a complete wastewater treatment system with waste stabilisation pond was proposed for the Assembly. This wastewater treatment project is yet to be implemented. Phase 1 of the project was to run up to 2015. Once implemented, the project will greatly increase the daily water demand in Kasungu.

The schematic layout of water supply system of Kasungu Water Supply Scheme is presented in the Figure 3.3. The water system layout is presented in appendix A.

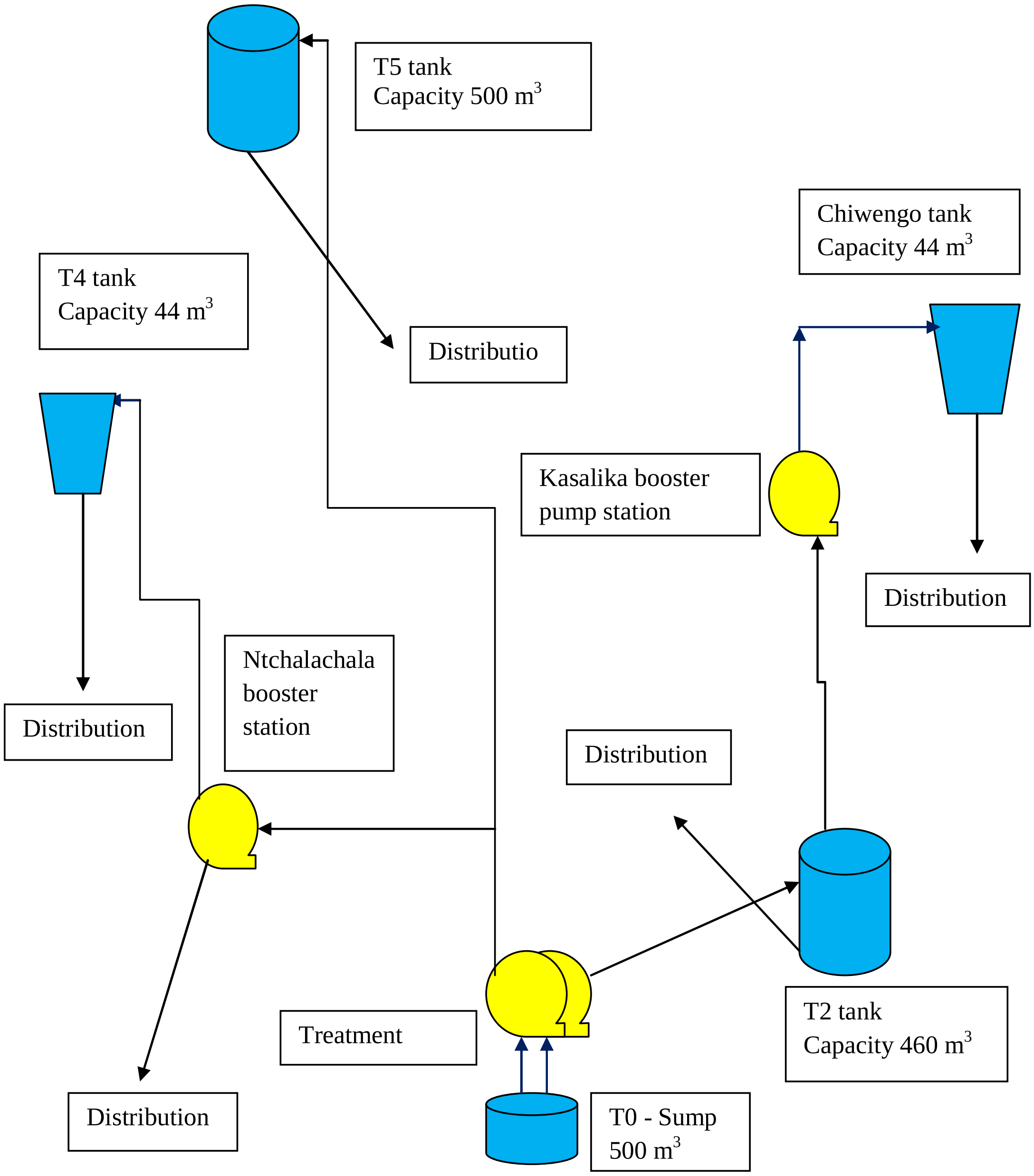


Figure 3.2: Schematic layout for Kasungu Water Supply Scheme (Not drawn to scale)

CHAPTER 4

4.0 MATERIALS AND METHODS

4.1 Research Design

4.1.1 Data Collection

A desktop study to obtain production and consumption figures for determination of current level of real losses in Kasungu was undertaken in January 2009. Data collected was from 2000. However, it is only data from January 2004 to March 2009 that was used in the water audit analysis since it is in this period where there is complete documented data. In addition meter readings were undertaken in Kasungu ADD (i.e. specific study area) from April 2009 to May 2009 for water audits. Capturing of basic information about Kasungu Water Supply Scheme from reports and engineering drawings for measurement of flows and pressures and their analysis was undertaken in February 2009. The basic information captured included length of mains, number of residential properties, number of connections, condition of the distribution network, population, and information on possible logging points.

Field measurements were undertaken to obtain data for assessment of impact of pressure management on real or physical water losses and service quality. Measurements for assessment of real losses were carried out based on the following steps as proposed by McKenzie et al. (2002):

Step 1: Selection of suitable pressure zone

An area named Kasungu ADD was selected as a specific study area based on the following characteristics:

- The area is discrete with only two main inflow pipelines of 110 mm diameter PVC and 200 mm diameter AC pipes.
- The area experiences higher minimum night flows than expected.
- It is a residential area with no industries or hospitals i.e. water consumption is purely domestic. The area was used as both the control and research area so as to have homogeneous conditions for both scenarios.

Step 2: Field investigations and retrofitting

Field investigations in the specific study area were carried out to select pressure and flow tapping points, check the working condition of control valves and fire hydrants (i.e. whether they are leaking), locate and obtain elevations of critical points in the network, determine the minor plumbing works required at selected household connections for logging purposes, and check the condition of meters (i.e. whether they are operational and their accuracy level). Meter accuracy was tested by filling a 20 l bucket and recording the volume change on the meter.

Step 3: Selection and installation of pressure controllers

Kasungu Scheme does not have pressure controllers such as pressure reducing valves to manage pressures. For Kasungu ADD, a gate valve (GV) installed on the 200 mm diameter AC pipe is used to control pressures in the area. For this research another 100 mm gate valve and a bulk water meter were installed on the 110 mm diameter PVC inlet pipe. The GV, installed 7 m upstream of the bulk meter to avoid turbulence flows from affecting meter readings, was used to vary pressures in the research area. The use of a gate valve to control pressures during the research period was due to the non-availability of pressure reducing valves (PRV) in the scheme and due to expensiveness of PRVs vis-à-vis budgetary limits of the research funding. Setting of inlet pressures on GV was done in combination with a 0 – 1000 KPa analogue pressure gauge. During the time of field measurements the 200 mm AC inflow pipeline was closed so as to have only one inflow pipeline.

Step 4: Logging of flows and pressures

Flows and pressures were logged at the inlet point of the specific study area using MultiLog data loggers as shown in Figure 4.1. Data was captured for a 24-hour period for 7 consecutive days for each scenario to ensure that varying daily demands and peak flows were taken into account as recommended by McKenzie et al. (2002). Minimum night flows (MNF) for the area were determined from the logged flows. Pressure settings used in the research were as follows:

- Water supply at low pressure set at 30 m head pressure downstream of the GV conducted from 12th – 16th April 2009.
- Water supply at low pressure set at 40 m head pressure downstream of the GV conducted from 15th – 21st April 2009.

- Water supply at normal pressure (before any pressure adjustment on the GV was done) set at 50 m head downstream of the GV conducted from 3rd – 9th May 2009, and
- Water supply at high pressure set at 65 m head at the downstream of the GV conducted from 6th – 12th April 2009.

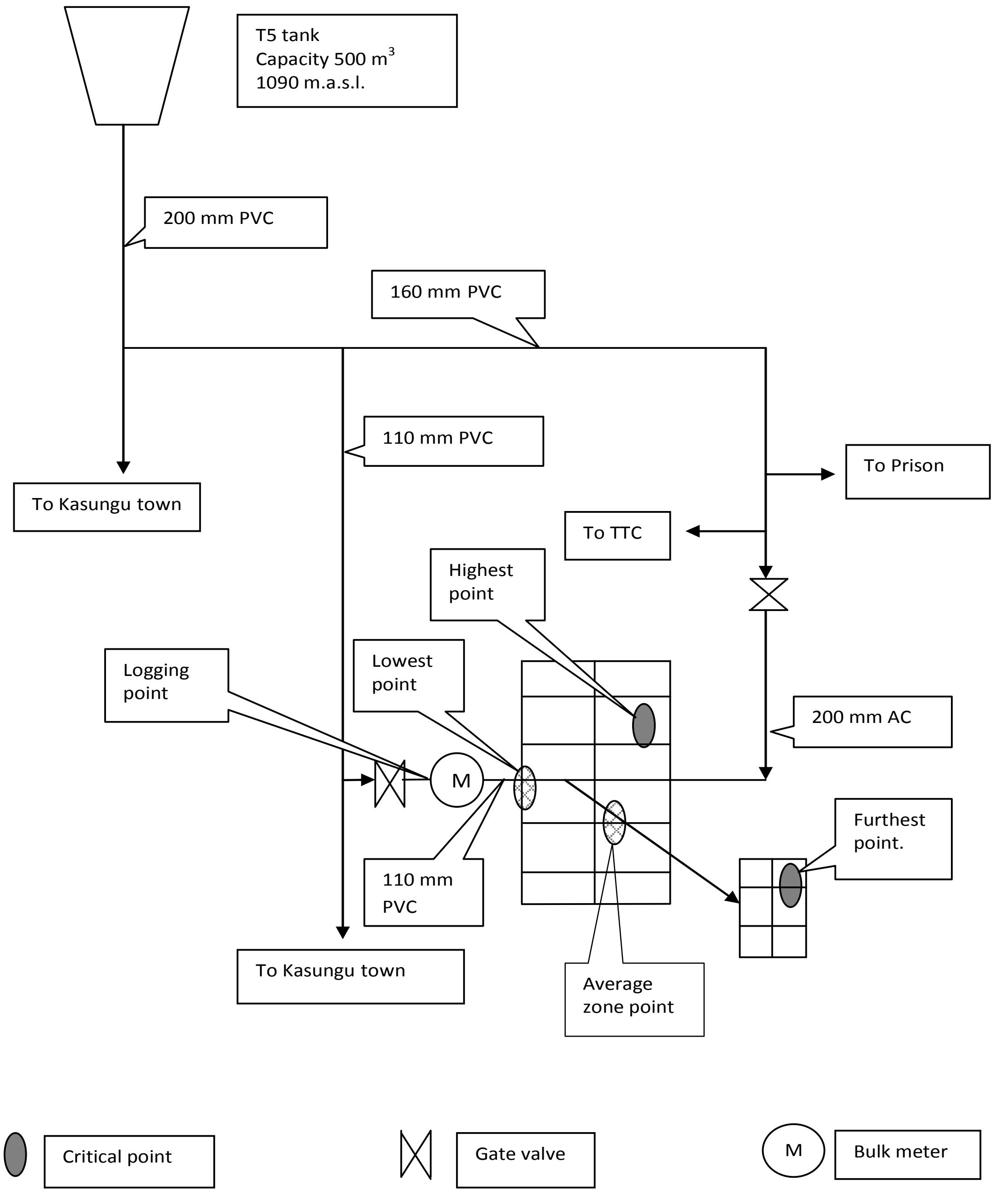


Figure 4.1: Schematic layout of Kasungu ADD area showing logging and critical points

Bucket tests as proposed by Marunga et al. (2006) were used to investigate the impact of pressure management on service quality. This involved recording the amount of time taken to fill a 20 litre bucket at highest point and furthest point from the inlet point of water supply network during peak demand periods (i.e. 6 a.m. to 7 a.m.), first with a tap open then with a shower open. Bucket tests were also conducted at lowest points of the water supply network. A total of 43 bucket tests were conducted during the research period. For each pressure setting, three bucket tests were conducted on three different points at each critical point (i.e. one bucket test on three different points at each critical point).

Historical data on pipe laying costs from past water supply projects in Malawi and consultancy report was collected for a cost-benefit analysis of pressure management as a tool for leakage reduction and control. Project reports in Malawi from which pipe laying cost data was collected included Design Management Group (2001), Norconsult and Bua Consulting Engineers (2006), Stantec and Chapita Consulting Engineers (2002) and Niras-Norconsult et al. (2001) consultancy report..

Semi-structured interviews were also carried out with both CRWB personnel and customers. For CRWB personnel interviews were aimed at knowing their understanding of water demand management, pressure and leakage relationship and how water audits and operations are carried out in the Scheme. Customer interviews were undertaken to know their perception on the quality of service provided by CRWB and coping mechanisms during times of short water supply. Sample questionnaires used in the research are given in appendix I.

4.1.2 Data Analysis

In order to determine the volume of water lost through real losses in Kasungu Water Supply Scheme water production and consumption data was analysed using EasyCalc software developed by Liemberger and Partners (2006). This software uses International Water Association (IWA) 'Best Practice' Water Balance and it quantifies data to 95% confidence limits. The method of analyzing water production and consumption data using customized software that quantify data to 95% confidence limits was stipulated by Lambert (2003). Output data was validated using Component Analysis as proposed by Fanner (2003). To determine volume of water lost through real losses in Kasungu ADD (i.e. specific study area) data recorded by MultiLog data loggers was imported into Microsoft Excel for analysis using both simple algorithms and statistical methods as suggested by Nkhoma et al. (2005). The extent of water losses through bursts and leaks in the distribution system was determined using EasyCalc software and analysis of minimum night flows as suggested by Lambert (2003). Statistical functions in Microsoft Excel were also employed to analyse data for assessment of impact of pressure management on service quality.

To assess the feasibility of pressure management as a tool for real water loss reduction, Payback Period was used as proposed by Thornton (2002). This was carried out using the expected amount of water saved from pressure management and pipe replacement at different water pressure scenarios. Pressure management was appraised against pipe replacement since it is the method that the scheme is employing to reduce real water losses. Only full implementation costs were considered in the investment appraisal analysis since other costs such as opportunity costs and externalities are often subjective.

CHAPTER 5

5.0 RESULTS AND DISCUSSION

5.1 General Information

5.1.1 Water production

Total annual water production data for Kasungu Water Supply Scheme obtained from monthly performance indicators records for a 5 year period is provided in Table 5.1 below.

Table 5.1: Average daily water production for Kasungu

Year	**2004**	**2005**	**2006**	**2007**	**2008**
Average daily water production (m^3/day)	2,974	3,032	2,961	2,918	3,165
% increase/decrease	-	1.95	-2.34	-1.45	8.5

The figures presented in Table 5.1 above are average daily production and do not reflect seasonal fluctuations. According to Kasungu Water Supply Scheme Monthly Performance Indicator Reports (2006) the drop in water production in 2006 was due to rainfall drought that was experienced in the area and in 2007 was due to frequent power outages and frequent pipe bursts of transmission mains from treatment plant to T4 and T5 tanks (Kasungu Water Supply Scheme Monthly Performance Indicator Report, 2007).

5.1.2 Water consumption

Water consumption data as obtained from billing records is provided in Table 5.2 below for a 5 year period.

Table 5.2: Average daily water consumption for Kasungu

Year	**2004**	**2005**	**2006**	**2007**	**2008**
Average daily water consumption (m^3/day)	2052	2062	2002	2128	2321
% increase/decrease		0.4	-2.9	6.3	9.1

A decrease in the amount of water billed in 2006 was due to a decrease production as pointed out in Table 5.1 above. Figure 5.1 below provides an overview as June 2007/July 2008 fiscal year of how water consumption was distributed among various consumer categories in Kasungu.

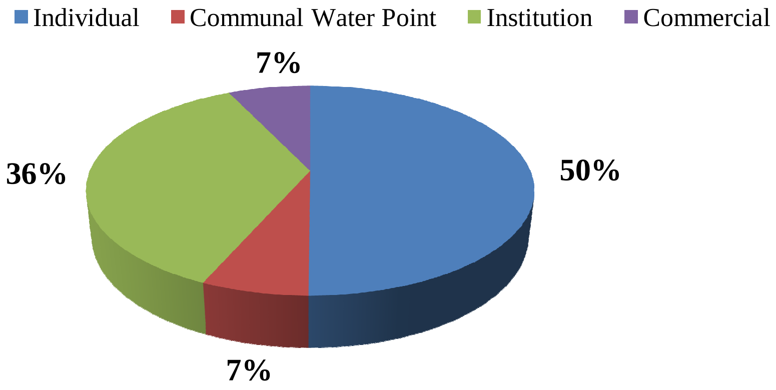


Figure 5.1: Water consumption among various consumer categories

Figure 5.1 above shows that major consumers of water in Kasungu are individuals consuming 50% of the distributed water followed by institutions at 36%. Institutions in Kasungu constitute only 4% of total number of customers, so the high consumption figure could be that, among other reasons, institutions are large water users and leaking plumbing fixtures, which as is the case in institutions are not immediately attended to. The current average water consumption for Kasungu town based on current population and consumption figures is 55 litres/person/day which differs from the projected 60 litres/person/day by Niras-Norconsult (2001). The difference in projected and actual consumption figures could be attributed to the shortfall in supply of water. The current water production does not match the current water demand due to operational problems being expeienced at the treatment plant resulting in less than 24 hours of water supply.

5.1.3 Metered connections

Data for total number of metered connections covering a 6 year period is presented in Table 5.3. In the 2007/2008 fiscal year Central Region Water Board (CRWB) procured 2000 water meters including connection materials in an effort to clear a huge number of backlog of new water connections in its water supply schemes (CRWB, 2008). Hence the rise in new water connections in 2008 in the scheme.

Table 5.4 provides an overview of how the metered connections (as of December 2008) were distributed among various consumer categories.

Table 5.3: Number of metered connections in Kasungu

Description	2003	2004	2005	2006	2007	2008
Total number of Metered connections	2062	2142	2238	2342	2429	2598
% increase/decrease in metered connections	-	3.9	4.5	4.4	3.7	7.0

Table 5.4: Number of connections per consumer category

Consumer category	Number of Connections	% of Total
Individual	2655	90
Communal Water Point	50	2
Institutional	110	4
Industrial/Commercial	135	5
Total Connections	**2,950**	

From Table 5.4 more connections are in the individual category and the least are in communal water points/kiosks. This is due to the fact that people prefer to have individual connections whether yard or in-house reduce distance to a water point and amount of time spent on fetching water. In addition the price of water at communal water points is higher than individual connections since communal water points in the scheme are run by private operators. CRWB privatised communal water points in its schemes to overcome the problem of non-payment of bills from these water points.

5.1.4 Billing and metering system for Kasungu Water Supply Scheme

Kasungu Water Supply Scheme bills water consumed by its customers through installed connection meters on monthly basis. Meter reading is done manually by meter readers who record readings into a field book and transfer these onto meter cards. Meter readings are then entered into a computer from meter cards by billing clerks for production of bills using Promun II software. It was found, however, that the distribution system has no bulk water meters to measure amount of water entering the distribution system from service tanks. With this situation it is difficult to easily locate where high leakage is taking place. Bulk meters are only installed on the transmission mains at the treatment plant to measure production. No meter is installed to measure amount of water used for backwashing filters at the treatment plant. The raw water meter at the treatment plant has been inoperative since 2001 hence process losses in the treatment plant are not computed. The scheme has no water abstraction pumps since water gravitates into the treatment plant from the reservoir from where raw water volumes into the treatment plant can be estimated.

The scheme records an average of 90 stuck meters in a month out of an average 2500 active connections representing a stuck meter percentage of 3.4%. It was observed that the stuck meters take an average of 4 to 5 months to be serviced, repaired or replaced. This means that customers with stuck meters are billed on estimates thereby compromising accuracy on volumes consumed. At the start of logging flows and pressure 7 stuck meters were identified through meter accuracy tests in the specific study area. All these were replaced as the scheme had a number of water meters in stock courtesy of NWDP II project.

5.2 Water loss assessment for Kasungu Water Supply Scheme

Water production and consumption records for Kasungu Scheme derived from monthly performance indicator reports and billing records for the period January 2004 to March 2009 were analysed and are presented in Figure 5.2. Details of water produced and billed are presented in appendix G. The unaccounted-for water (UFW) for the period under consideration ranged from 20% to 40%. As of March 2009 UFW was at 39%. The UFW during this period remained considerably high compared to the recommended standard range of 15% - 25% (Tynan and Kingdom, 2002; van der Zaag, 2003; Gumbo, 2004). The recent average monthly UFW for the scheme is at 34% which translates to a volumetric water loss of 31,620 m^3 per month. This amount of water lost translates to MK[3] 2,984,611/month (US$ 21,185/month) based on a current water tariff of MK 94.39/m^3 (US$ 0.67/m^3). An average tariff was used to translate water losses into monetary terms because some consumers in the scheme do not receive water throughout the day hence water lost

[3] MK stands for Malawi Kwacha – the official currency of Malawi

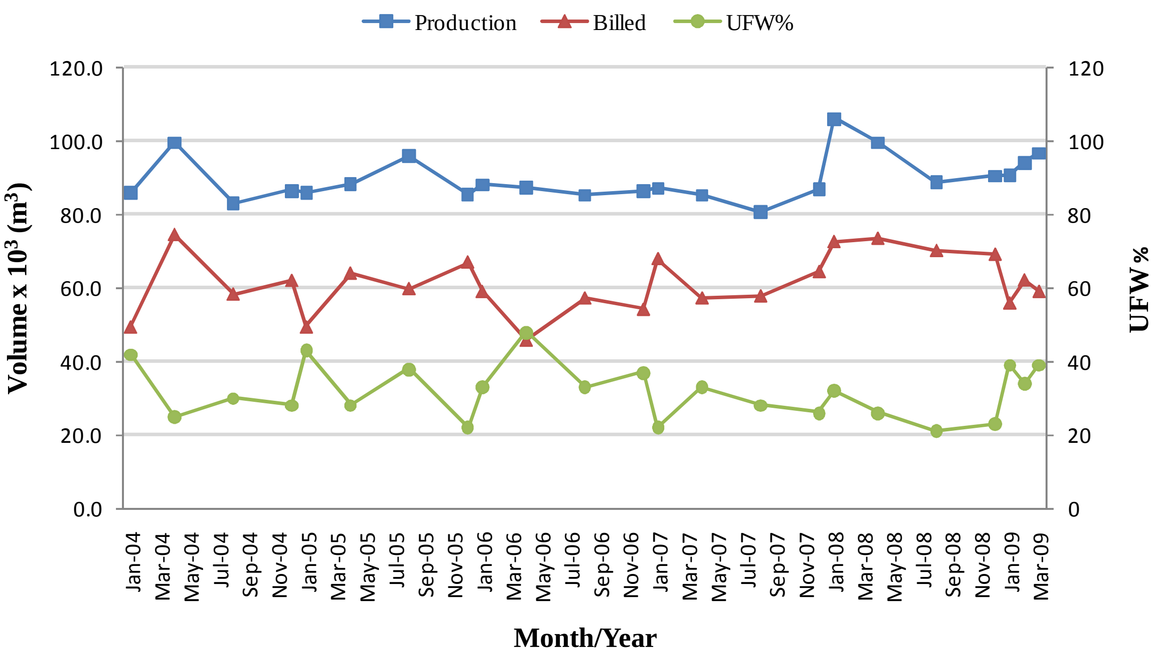


Figure 5.2: Total water produced, billed and UFW for Kasungu

Figure 5.3 and Figure 5.4 presents of results of water balance for Kasungu Scheme for the year ended 2008 and Kasungu ADD respectively determined using Easycalc software. Results for the water balance as presented in Figures 5.3 and 5.4 show that real (physical) losses in the Kasungu constitute 66% of the total non-revenue water for the scheme and 20% are apparent losses. As a percentage of system input volume real water losses constitute 26% and 19% for Kasungu ADD and for entire Kasungu Scheme. Generally real water losses of up to 15%, as a percentage of system input volume, are accepted as good performance on leakage management (Liemberger, 2002). Based on this benchmark it can be concluded that real water losses are high in Kasungu. Results of this research in section 5.3 showed that pressure management has a potential to reduce 37% of real water losses in the scheme. At 37% real water loss reduction Kasungu would save 79,292 m^3 of water lost per annum translating to an earning of MK 7,454,347/year (US$ 53,125/year) based on the current average tariff of MK 94.39/m^3 (US$ 0.67/m^3). It was observed that service tanks hardly fill in the scheme. This was attributed to low water production from the treatment plant compared to current water demand since all service reservoirs are still in good working condition. Thus it can be concluded that real losses in the scheme take place in transmission and distribution mains and service connections.

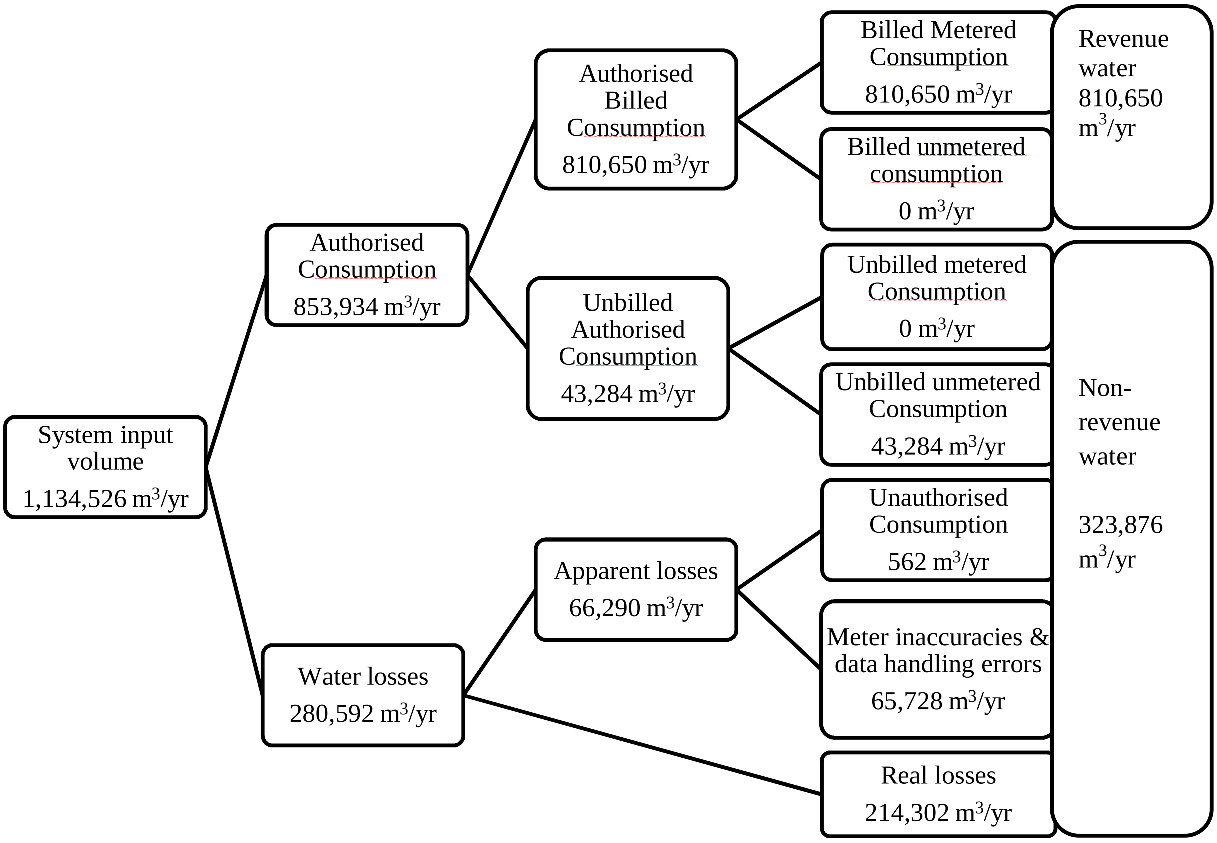


Figure 5.3: Water balance results for Kasungu for 2008

5.3 Impact of pressure on real water losses

Pressure and flow logging for Kasungu ADD area commenced on 4th April 2009 and were completed on 9th May 2009. Figures 5.4, 5.5, 5.6 and 5.7 presents scatter plots of pressure and flow measurements at 65 m, 50 m, 40 m and 30 m pressure settings respectively. Detailed night flow data on the variation of inlet pressures and flows with time during research period is provided in appendix H.

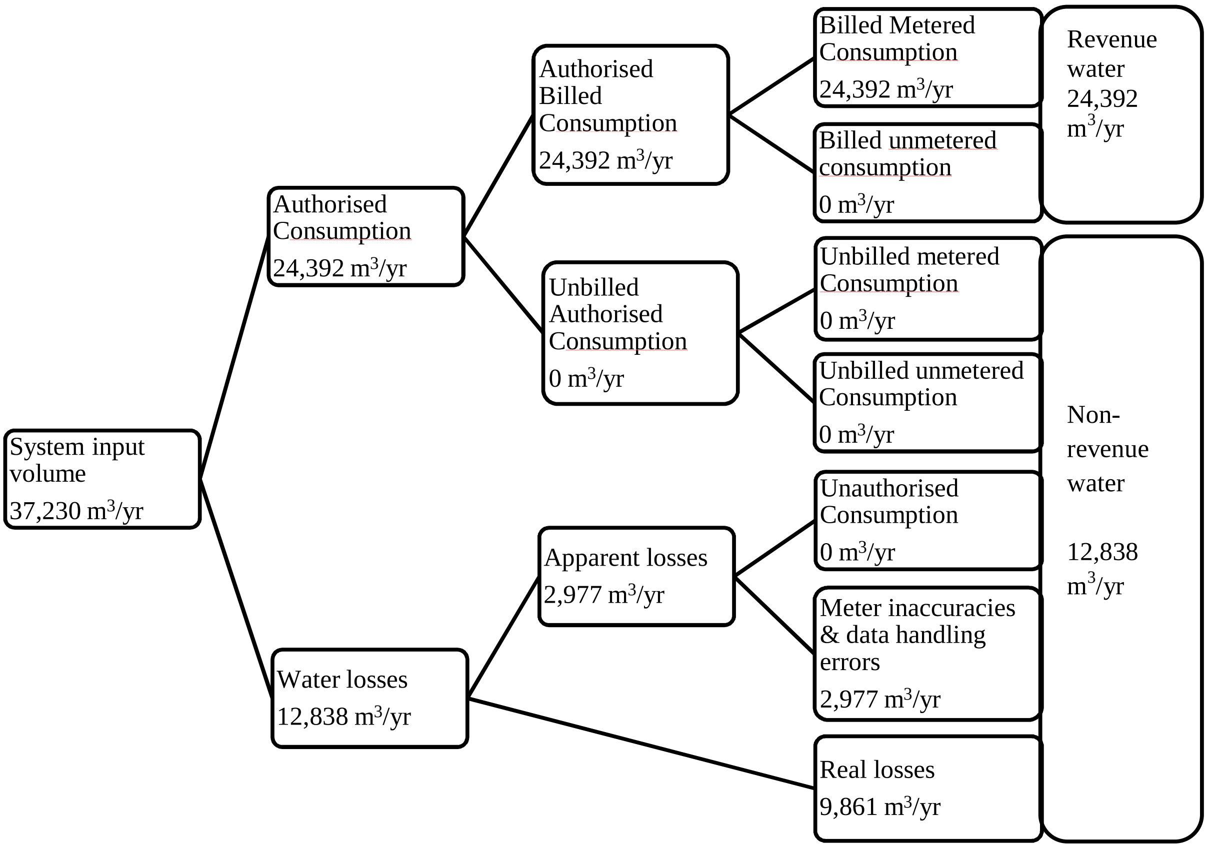


Figure 5.4: Water balance results for Kasungu ADD area

Figure 5.5 shows zero recordings for both pressure and flow on 4th May 2009 and zero for flow on 6th May 2009 and 9th May 2009. Zero pressure and flow were also recorded on 24th April 2009 during the 40 m setting as shown in Figure 5.6. On 4th May 2009 there was a pipe burst of 200 mm asbestos cement (AC) so the main isolating valve for Kasungu ADD was closed to unable repair works to take place. From Figure 5.5, the repair work took four hours to be completed. On 24th April 2009, 6th and 9th May 2009 power outages were experienced in the scheme hence water could not be pumped into the service reservoirs which in turn supply water into the distribution system. Power outages were known through machinery records at the treatment plant.

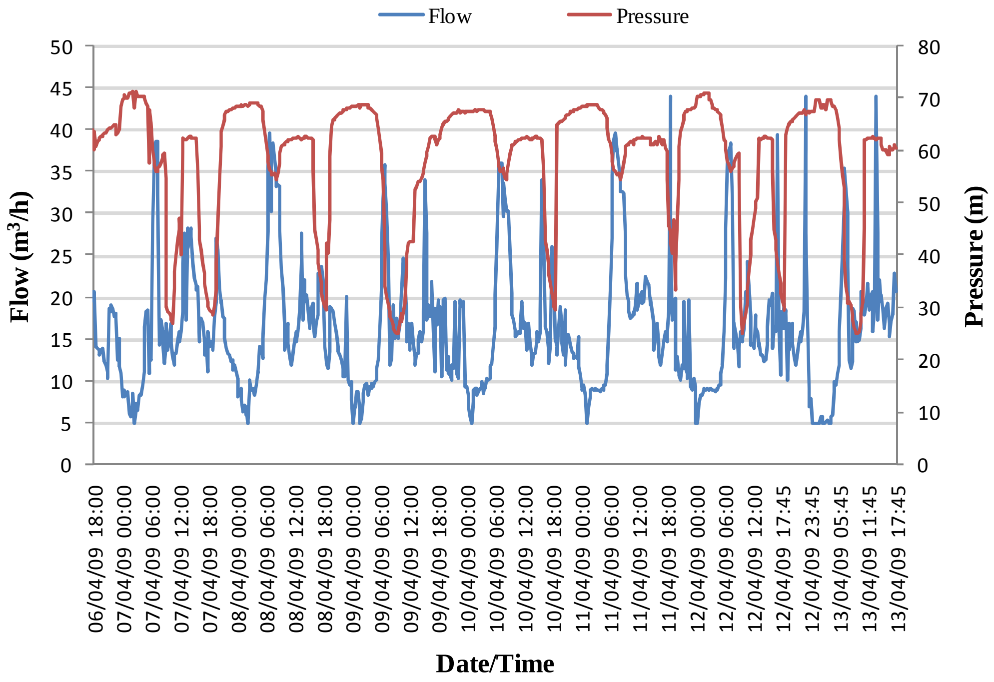


Figure 5.5: Pressure and Flows against date/time at 65 m inlet pressure setting

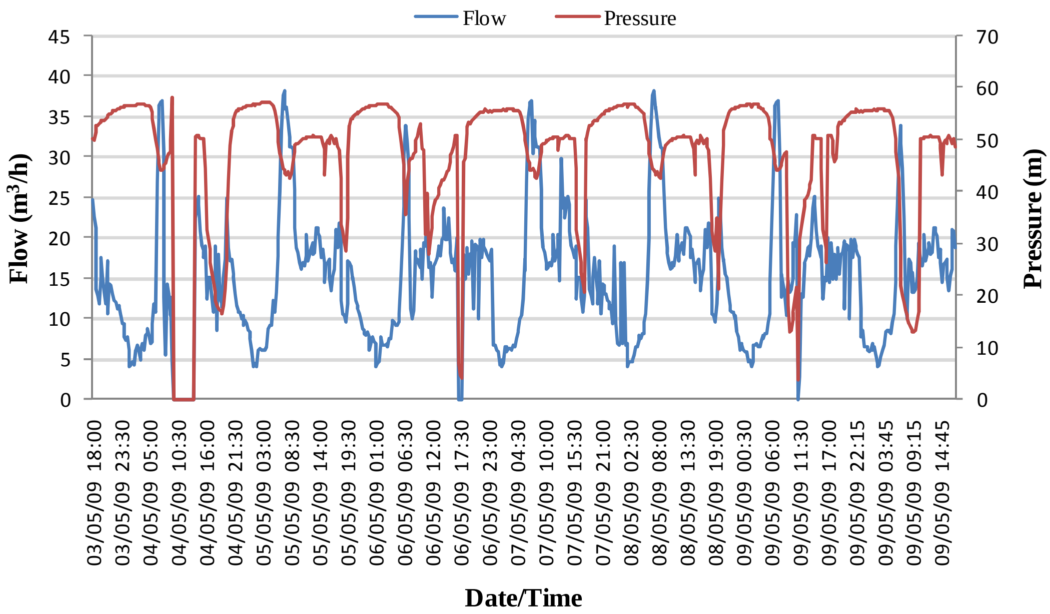


Figure 5.6: Pressure and Flow against date/time at 50 m inlet pressure setting

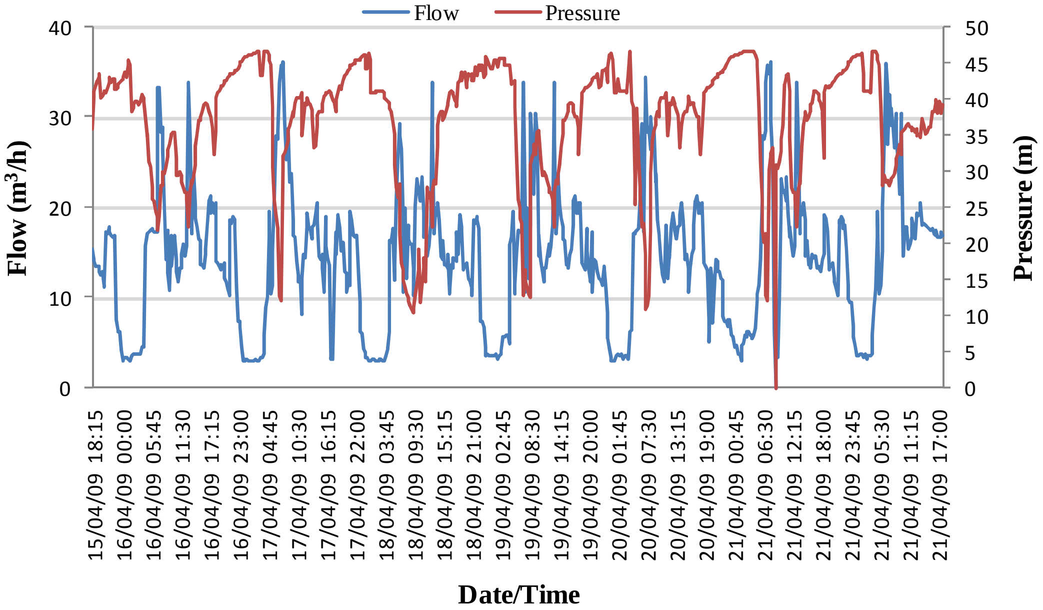


Figure 5.7: Pressure and Flow against date/time at 40 m inlet pressure setting

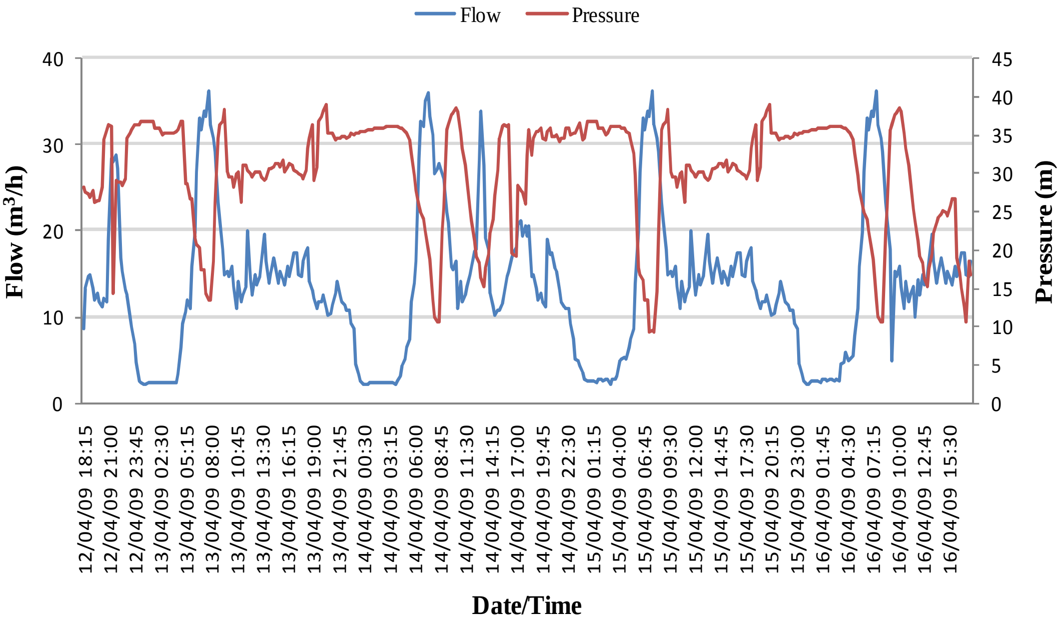


Figure 5.8: Pressure and Flow date/time at 30 m pressure setting

As can be noted from Figures 5.5 – 5.8 pressure variation was very high at each pressure setting because a gate valve was used to control pressure. This clearly demonstrates that use of gate valves to control pressure in pipelines is not a good idea as it is designed not for this purpose. It is therefore recommended that gate valves should not be used to control pressure in piped water supply systems.

Table 5.5 presents minimum night flows (MNF) at 65 m, 50 m, 40 m and 30 m pressure scenarios. The minimum night flow is the lowest flow into a zone or area occurring between 12 a.m. and 4 a.m. (McKenzie et al., 2002).

From Table 5.5 by adjusting inlet pressure from 65 m to 30 m, the average pressure at which MNFs were recorded reduced from 68.20 m to 36.70 m translating into a 46% reduction. The adjustment also resulted in 38% reduction in average MNF (i.e. from 4.87 m^3/15 min to 3.0 m^3/ min). However, adjusting pressure from 65 m to 30 m resulted in consumers at highest and furthest point not to receive water during peak demand periods (i.e. 6 a.m. to 7 a.m.). The inlet pressure was then adjusted to 40 m and it was observed that at this pressure setting no supply interruptions were experienced at highest and lowest points during peak demand periods. At 40 m pressure setting (38% reduction), the average pressure at which MNFs occurred were reduced by 36% (i.e. from 68.2 m to 43.6 m) and average MNF reduced by 34% (i.e. from 4.87 m^3/15 min to 3.2 m^3/ 15 min).

Table 5.5: Minimum night flows and their pressures of occurrence

Pressure setting (m)	**Range of recorded occurrence pressure for MNF (m)**	**Average recorded occurrence pressure for MNF (m)**	**MNF range (m^3/15 min)[4]**	**Average MNF (m^3/15 min)**
65	67.60 – 68.70	68.20	4.86 – 4.87	4.87
50	55.80 – 56.70	56.30	4.14 – 4.16	4.15
40	40.80 – 46.40	43.60	3.00 – 3.31	3.20
30	36.00 – 37.40	36.70	2.89 – 3.10	3.00

A detailed analysis of the minimum night flows at 65 m and 40 m pressure settings using a method suggested by McKenzie et al. (2002) showed that the 38% reduction in operating pressure (i.e. from 65 m to 40 m) resulted in a 37% reduction in water loss per hour (i.e. from 2.95 m^3/h to 1.86 m^3/h). The hourly water loss reduction translates to a water saving of 26.2 m^3/day which accounts for 26% of total average daily measured inflow into Kasungu ADD.

[4] Pressure and flow data were recorded at 15 min intervals

Detailed calculations of water losses using analysis of minimum night flows are provided in appendix D.

Results of studies carried by Nkhoma et al. (2005) to investigate the potential of pressure management as an infrastructure water system demand management in Lilongwe, Malawi showed that 50% reduction in pressure resulted in a 25% reduction in real water losses. Studies by Marunga et al. (2006) in Mutare, Zimbabwe on potential reduction of leakage through pressure management showed that a 35% reduction in pressure resulted in 25% reduction in MNF. According to Kovac (2006) a night flow reduction of 24% and a total 24 hour inflow reduction of 11% were achieved after initial inlet night pressure was reduced from 71 m to 57 m in a pilot study to investigate the impact of pressure on real losses in the city of Zagreb, Croatia. A further reduction of inlet night pressure to 48 m resulted in a 39% and 14% reduction of night flow and total 24 hour inflow respectively translating into a water saving of 900 m^3/day (Kovac, 2006). McKenzie et al. (2004) report that Khayelitsha town in South Africa realised a water saving of 40% through pressure management. Results of studies by McKenzie et al. (2004), Nkhoma et al. (2005), Kovac (2006) and Marunga et al. (2006) compares well to results obtained in this study as in all cases it has been shown that leakages could be reduced by more than 25% through pressure management. Figure 5.9 shows a plot of measured minimum night flows against their respective recorded pressures.

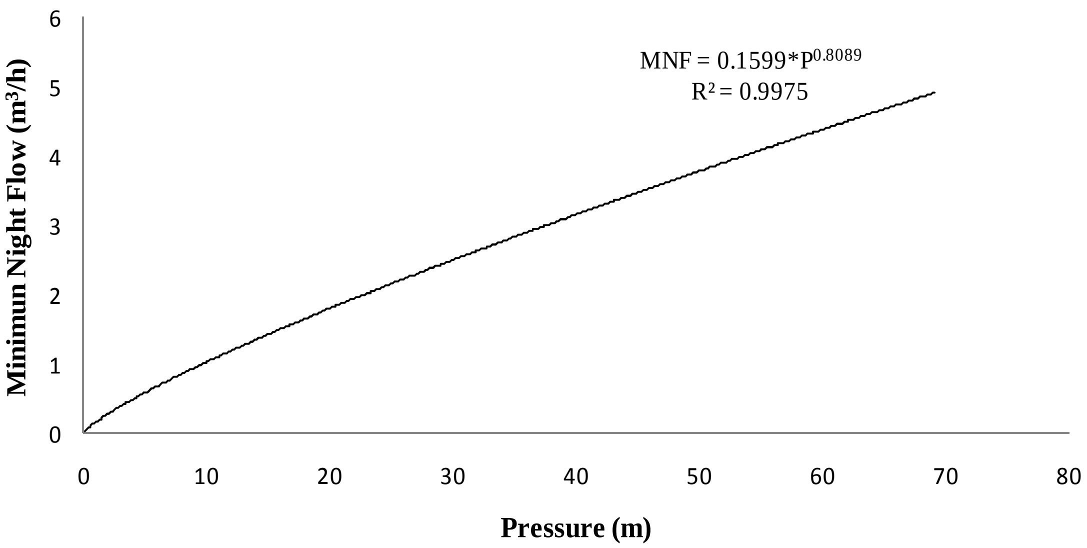


Figure 5.9: Minimum night flow (MNF) against Pressure
(MNF = Minimum night flow; P = Pressure)

From Figure 5.9 flows varied with pressure to a power exponent of 0.8089. This result agrees to Thornton (2003) that flow (L) varies with pressure (P) ^{N1}, where N1 is a power exponent depending on pipe material. McKenzie et al. (2002) report that power exponents in a water supply system range from 0.5 for a system with all pipe material being iron/steel to 2.5 for a system with all pipe material being plastic. Based on a general equation proposed by Lambert (2003) a universal equation for simple analysis and prediction of pressure and leakage in Kasungu ADD could be written as:

$$L_{p1} = L_{p2} * (P_1/P_2)^{0.8089} \quad (3)$$

Where L_{p1} = Flow at pressure 1 (m^3/h)

L_{p2} = Flow at pressure 2 (m^3/h)

P_1 = Pressure 1 (m)

P_2 = Pressure 2 (m)

5.4 Impact of pressure management on customer service quality

Figure 5.10 presents results of bucket tests carried out on critical points in Kasungu ADD to determine impact of pressure management on service quality. Bucket tests were carried out from 8th April to 3rd May 2009. Bucket tests were carried out mostly with a single tap only and thereafter with a tap and a shower both running at the same time in some few cases. The set up at consumer premises located at the critical points (i.e. the highest point and most distant point from the inlet point of water) is that they only have a single tap and do not have a shower. The idea of running both a tap and a shower at the same time was that during peak demand periods both the tap and shower are likely to be in use (Marunga et al., 2006). The current operation pressure range for Kasungu ADD is 55 m to 65 m.

As shown in Figure 5.10 longer filling times were experienced at furthest point at all pressure settings than at highest and lowest points. This was attributed to frictional losses in the supply system which resulted in a lower residual head at furthest point than at highest point. The furthest point is located at 1.9 km from the inlet point of water into Kasungu ADD area. No filling times are shown for the 30 m pressure setting at furthest point and highest point because there was no flow at these points during the peak demand periods.

The pressure setting was then adjusted to 40 m which resulted in no water supply interruptions at highest and furthest points during peak demand periods. With a change of operating pressure from 65 m to 40 m the bucket filling time increased by 8.8% at highest point and 3% at furthest point. It was observed, through interviews, that consumers at the two critical points were still comfortable with this filling time change. Therefore it was recommended that an operating pressure of 40 m be used in Kasungu ADD.

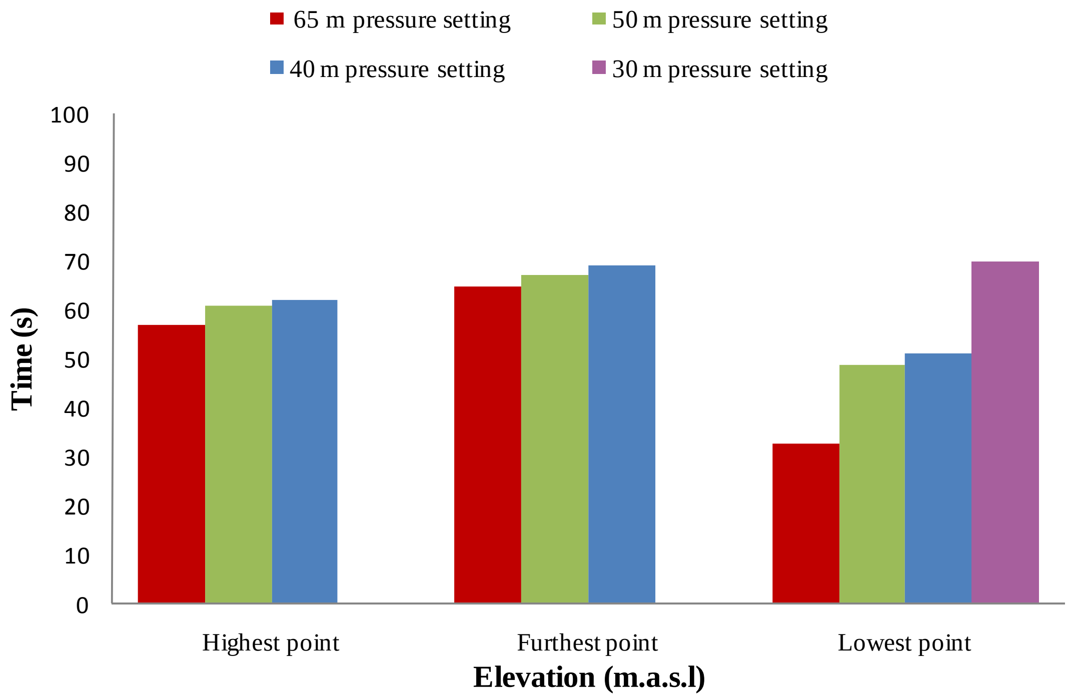


Figure 5.10: Time taken to fill a 20 l bucket during peak demand periods

5.5 Cost – benefit analysis of pressure management

A cost – benefit analysis was carried out to assess viability of investing in pressure management in Kasungu ADD. Pressure management was ranked against pipe replacement as it is one of the solutions being applied to solve the problem of high leakages in the scheme (CRWB, 2006). Regular payback period was used to appraise both pressure management and pipe replacement as proposed by Thornton (2002). The amount of water used in the calculation of payback period on pressure management was calculated from results in Appendix D while the amount of water used to appraise pipe replacement was calculated from results of water balance for Kasungu ADD

(Figure 5.4) and unavoidable annual real loss (UARL) equation 1 in section 2.7.2. A target loss factor of 2 was used to adjust the losses calculated using equation 1 to achievable real loss target as suggested by McKenzie and Lambert (2002). In both cases (i.e. pressure management and pipe replacement) an average water tariff of MK 94.39/m^3 (USD 0.67/m^3) was used to translate water savings into monetary savings.

Main distribution pipe sizes in Kasungu ADD area are 63 mm, 90 mm, 110 mm and 200 mm. Analysis of maintenance records for Kasungu showed that more bursts occur in the 200 mm diameter AC and 63 mm diameter PVC pipelines, therefore these were the pipelines that were considered when calculating investment cost on pipe replacement. Appendix E presents investment cost for pipe laying based on pipe laying cost data collected from some major water supply projects in Malawi. Investment cost for pressure management were based on the current cost for valve chamber construction and installation of associated fittings and a quotation (Appendix E) to purchase bulk water meter and fixed outlet pressure reducing valve from Anderson Engineering – one of the major supplier of water supply equipment in Malawi.
Table 5.7 provides a summary of results assessing the viability of pressure management. Detailed calculations on the pay back period are provided in appendix F.

Table 5.7: Payback period analysis results

Water saving due to PM per month at 40 m pressure (m^3)	**Water saving due to PR per month at 59 m AZP pressure (m^3)**	**Investment cost in PM (US$)**	**Investment cost in PR (US$)**	**Money earned from water saved due to PM per month (US$)**	**Money earned from water saved due to PR per month (US$)**	**Payback period (month)**	
						PM	**PR**
785	452	10,665	62,050	526	303	20	205

PM = Pressure Management PR = Pipe replacement AZP = Average zone pressure

Results of appraisal for pressure management and pipe replacement in Table 5.7 shows that pressure management has a short payback period than pipe replacement. Based on these results it can be concluded therefore that it is worth investing in pressure management in Kasungu scheme than in pipe replacement. Payback periods of 9 months and 16.8 months were achieved in case studies by Berea – Alexander Park District, Johannesburg, South Africa and Ramallah – Al Jalazon Refugee camp Water network, Israel after implementation of pressure management (Thornton, 2002).

5.6 Real water loss management programme

One of the most important step to take in the reduction and control of real water losses is to have a leakage management programme (Farley, 2001). It is through this programme that targets of real water losses can be made and appropriate methods developed for a successful real water loss management. This study therefore developed a real water loss management programme for Kasungu Water Supply Scheme based on results found in this study and as proposed by Ross-Jordan (2006). The programme is in four steps as follows and is summarised in Figure 5.11:

Step 1 Continual Scheme Assessment

It was found that interest and deeper understanding of water loss issues and how they impact on the scheme is minimal in Kasungu. This step should therefore involve awareness, training and information gathering, which can be carried out through site visits and desk studies and should cover the institutional, personnel, technical and financial aspects of water loss reduction and control programmes.

Step 2 Metering System

As already pointed out earlier in this document, Kasungu Scheme does not have distribution bulk metering system. This step should therefore strategise and plan on bulk metering, including their layout. Night flow analysis and water balancing should be done to identify areas of high leakages for urgent intervention.

Step 3 Field Tests and Observation

Under this step pipeline observations, meter accuracy, illegal connection surveys and operational pressure checks should be carried out. In addition leak detection methods and corrective actions in areas with high real water losses should be determined.

Step 4 Scheme Meetings

Under this step, scheme meetings should be held to report, discuss and strategise on real water loss control and develop understanding of real water loss issues amongst scheme staff. An assessment should also be made if an external assistance will be required.

Step 5 Monitoring and Evaluation

Monthly, biannual or annual monitoring and evaluation should be carried out in order to improve on methods of real water loss assessments and corrective actions in use.

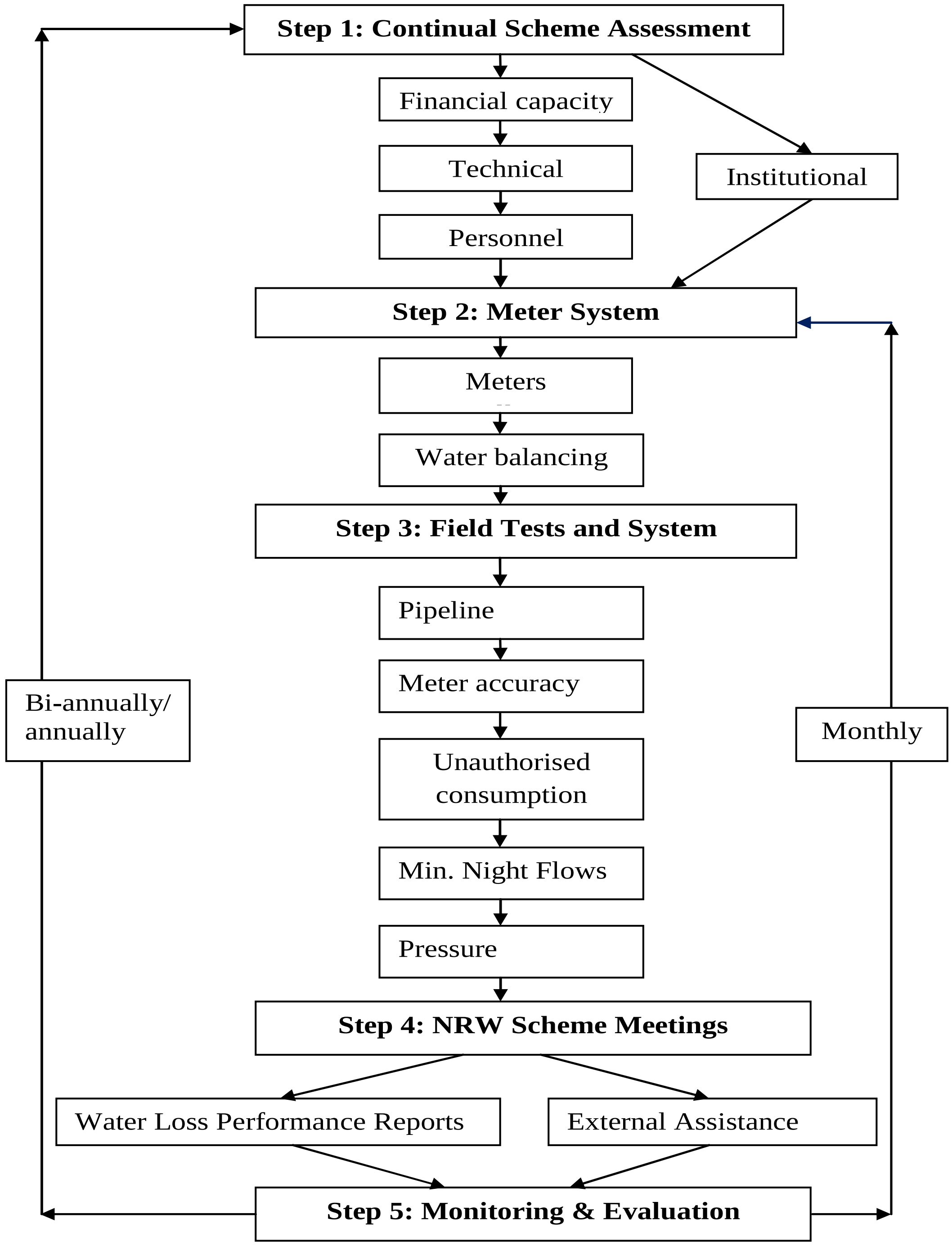


Figure: 5.11: Real Water Loss Programme for Kasungu Scheme

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

The study found out that:

1. Levels of unaccounted-for water are high in Kasungu Water Supply Scheme. The amount of water lost in Kasungu Water Supply Scheme in the year ended 2008 was 323,876 m^3 which is 28% of the amount of water produced in that year. Currently the Scheme is losing 31,620 m^3 per month. The major part of the water losses are real losses which contribute 66% of the gross UFW in the supply system.
2. High pressures in the scheme are contributing to high leakages in distribution network. Reducing pressure from 65 m to 40 m reduces leakage by more than 35%.
3. Pressures lower than 30 m in the distribution system of the scheme results in poor service level to customers located on the critical points in the area.
4. Based on payback period pressure management is a viable option for reducing leakages for Kasungu Water Supply Scheme.

6.2 Recommendations

Based on the findings of the study it is recommended that:

(1) District metered areas be formed in Kasungu Water Supply Scheme and water balance calculations for these district metered areas should be conducted regularly so as to identify areas with high water losses for urgent attention

(2) Pressure management using recommended pressure controllers such as pressure reducing valves should be implemented in the scheme to reduce and control leakages.

(3) The distribution system should be operated at a pressure range of 37 m – 40 m so as not to compromise the level of service to customers located on critical areas.

CHAPTER SEVEN

7.0 REFERENCES

Arlosoroff, S., 1998. Water Demand Management, UNHCR (Habitat) Regional Conference on Sustainable Consumption Patterns in Asian Cities, Fukuoka, Japan.

Arntzen, J., 2003. Incorporation of Water Demand Management in National and Region Water Policies and Strategies. Centre for Applied Research, Botswana. In: IUCN Water Demand Management for Southern Africa Phase II: Proceedings of the Water Demand Management Regional Workshop 2002, Johannesburg, South Africa. CD Rom.

Chavula G M S, 2002. Constraints to the Implementation of Water Demand Management in Malawi and proposed measures for overcoming them, Country Report submitted to the IUCN

CRWB (Central Region Water Board), 2006. Annual Report for 2005/06 Fiscal Year. Unpublished.

CRWB (Central Region Water Board), 2007. Strategic Business Plan (2007-2012) for Kasungu Water Supply Scheme. Unpublished.

CRWB (Central Region Water Board), 2008. Draft Annual Report for 2007/08 Fiscal Year. Unpublished.

Balkaran, C., Wyke, G., 2003. Managing Water Loss: Strategies for the Assessment, Reduction and Control of Non-Revenue Water (NRW) in Trinidad and Tobago. Available from: http://oocur.org/Proceedings/Presentations/Wyke1.pdf. Accessed December 2008.

Design Management Group (DMG), 2001. Engineers Estimate for Six Centres Project, Ministry of Irrigation and Water Development, Malawi. Unpublished.

DFID, 2003. Handbook for the Assessment of Catchment Water Demand and Use. Department for International Development, London.

Fanner, P., 2003. Assessing Real Losses, including Component Analysis and Economic Considerations: A Practical Approach. Water 21 - Article No 6. Available from: www.iwapublishing.com/template.cfm?name=w21sep03. Accessed March 2009.

Farley, M., 2001. Leakage Management and Control - A Best Practice Training Manual. World Health Organization, Geneva, Switzerland.

GOM (Government of Malawi), 2004. National Water Policy. Ministry of Water Development, Lilongwe.

Gumbo, B., 2004. The status of water demand management in selected cities of southern Africa. Physics and Chemistry of the Earth 29, 1225 – 1231.

Gumbo, B., Juizo, D., Van der Zaag, P., 2003. Information is a prerequisite for water demand management: Experiences from four cities in Southern Africa. Physics and Chemistry of the Earth 28, 827 – 837.

Hazelton, D., Nkhuwa, D., Robinson, P., Mwendera, E., Tjijenda, K., Chavula, G., 2002. Overcoming constraints to the implementation of water demand management in Southern Africa, Vol. 1, IUCN, Johannesburg.

Ismail, Z., Puad, W., 2006. Non-Revenue Water Losses: A Case Study. Asian Journal of Water, Environment and Pollution 4 (2), 113-117.

IUCN-WaterNet, 2003. Postgraduate Training Module on Water Demand Management. In: IUCN Water Demand Management for Southern Africa Phase II: Proceedings of the Water Demand Management Regional Workshop 2002, Johannesburg, South Africa. CD Rom.

Kasungu Water Supply Scheme, 2006. Monthly Performance Indicator Reports. Unpublished

Kasungu Water Supply Scheme, 2007. Monthly Performance Indicator Reports. Unpublished

Khatri, K.B., Vairavamoorthy K., 2007. Challenges for Urban Water Supply and Sanitation in Developing Countries - Discussion Paper for the session on urbanisation, UNESCO-IHE, Delft, The Netherlands. Available from: www.unesco-ihe.org/content/download/1016/11873/file/9.paper%20urbanisation%20kala%20draft.pdf.

Kingdom, B., Liemberger, R., Marin, P., 2006. The Challenge of Reducing Non-Revenue Water (NRW) in Developing Countries - How the Private Sector Can Help: A Look at Performance-Based Service Contracting, Water Supply and Sanitation Sector Board discussion paper series, Paper no. 8, The World Bank, Washington, DC.

Kovac, J., 2006. Case studies in applying the International Water Association Water Loss Task Force approach in the West Balkan region: Pressure Management. Available from: www. www.leakssuite.com/.../CasestudiesWLTFapproachWestBalkanSkopjeconference2006. Accessed 20th June 2009

Lahmeyer, JR International, 1994. Kasungu Water Supply Scheme, Operation and Maintenance Manual, Part-I: Chitete Dam. Unpublished.

Lambert, A., 2003. Assessing Non-revenue Water and its Components: a practical approach, Water 21, IWA Water Loss Task Force. Available from: www.iwapublishing.com/template.cfm?name=w21aug03. Accessed 8th December 2008.

Liemberger, R., 2002. Do You Know How Misleading the Use of Wrong Performance Indicators can be? Paper presented at the IWA Managing Leakage Conference, Cyprus, November 2002. Available from: www.liemberger.cc. Accessed 28th May 2002.

Liemberger, R., McKenzie, R., 2003. Aqualibre™ - A New Innovative Water Balance Software. Paper presented at the IWA Efficient 2003 Conference, Tenerife. Available from: www.iwahq.org.uk/bluepages. Accessed April 2009.

Liemberger R., Farley, M., 2005. Developing a Non-revenue Water Reduction Strategy Part 1: Investigating and Assessing Water Losses. Water Science and Technology: Water Supply 5 (1), 41–50.

Liemberger and Partners, 2006. WB-EasyCalc: The Free Water Balance Software, Version 1.17 (06 November 2006). Available from: www.liemberger.cc. Accessed 1st July 2009.

Marunga, A., Hoko, Z., Kaseke, E., 2006. Pressure Management as a Leakage Reduction and Water Demand Management Tool: The Case of the City of Mutare, Zimbabwe, Physics and Chemistry of the Earth 31, 763 – 770.

Metaferia, Hydroconsult, 2008. Design of rehabilitation and expansion works for Kasungu Water Supply Scheme. Consultancy report, Unpublished.

McKenzie, R., Lambert, A., 2002, Development of a Simple and Pragmatic Approach to Benchmark Real Losses in Potable Water Distribution Systems in South Africa, Water

Research Commission, Report No. TT 159/01. South Africa. Available from: www.wrc.org.za. Accessed 12th June 2009.

McKenzie, R., Mostert, H., de Jager, T., 2004. Leakage reduction through Pressure Management in Khayelitsha: Two Years down the line. Water SA Vol. 30 No. 5, p 13 – 17. Available from: www.wrc.org.za. Accessed 11th June 2009.

Mckenzie, R., Seago, C., 2004. Benchmarking of Leakage from Water Reticulation Systems in South Africa. Water Research Commission, Report No TT 244/05, South Africa. Available from: www.wrc.org.za. Accessed 12th June 2009.

McKenzie, R., Seago C., 2005, Assessment of real losses in potable water distribution systems: some recent developments. Water Science and Technology: Water Supply 5 (1), 33–40.

McKenzie, R., Wegelin W., Meyer N., Buckle H., 2002. Water Demand Management Cook-Book. Habitat/Rand Water/WRP, Johannesburg, South Africa.

Mkandawire, T., Mulwafu, W., (2006). An analysis of IWRM capacity needs in Malawi. Physics and Chemistry of the Earth 31, 738–744.

Morrison, J., 2004. Managing leakage by District Metered Areas: a practical approach. Water 21. Available from: www.water-audit.com/Water21_February_2004_-_Water_Loss.pdf. Accesed 12 June 2009.

Mulwafu, W., Chipeta, C., Chavula, G., Ferguson, A., Nkhoma, B., Chilima, G., (2003). Water demand management in Malawi: problems and prospects for its promotion, Physics and Chemistry of the Earth 28, 787–796.

Mwendera E., Hazelton D., Nkhuwa, D., Robinson, P., Tjijenda, K., Chavula, G., 2003. Overcoming constraints to the implementation of water demand management in southern Africa, Physics and Chemistry of the Earth 28, 761–778.

Ng'ong'ola D., 1999. Policies Influencing Patterns of Use of Water Resources in Malawi. Mvalo and Company, Lilongwe, Malawi.

Niras-Norconsult, Danish Hydraulic Institute, Bua Consulting Enginers, 2001. Water Resources Development Plan for Central region Water Board. Consultancy report prepared for Ministry of Irrigation and Water Development. Unpublished.

Nkhoma, B., 2004. Assessment of Leakage Control as a Tool of Infrastructure Water System Demand Management: A Case of Area 49 in the City of Lilongwe, Malawi. Unpublished Thesis, University of Zimbabwe.

Nkhoma, B., Hoko, Z., Gumbo, B., 2005. Assessment of Leakage Control as Tool of Infrastructure Water System Demand Management, A case Study of Area 49 in the City of Lilongwe, Malawi. In: Kuruvilla, M., Nhapi, I., (Eds), Water and Wastewater Management for Developing Countries, WAMDEC 2004, IWA, London. pp 175- 186.

NSO (National Statistical Office), 2008. 2008 Population and Housing Census for Malawi - Preliminary Report. Unpublished.

NSO (National Statistical Office), 2005. Malawi Second Integrated Household Surveys 2004 - 2005 (IHS-2) - Basic Information. Unpublished.

Officer, L.H., Williamson, S.H., 2009. Annual Inflation Rates in the United States, 1775 - 2008, and United Kingdom, 1265 – 2008, MeasuringWorth, 2009. Available from: http://www.measuringworth.com/inflation/. Accessed 15th June 2009.

Radivojević, D., Milićević, D., Petrović, N., 2007. Technical Performance Indicators, IWA Best Practice for Water Mains and the First Steps in Serbia. Journal of Architecture and Civil Engineering 5 (2), 115 – 124.

Ramsey, S., Mobbs, P., 2001. Performance Indicator Report. African Water and Sanitation Utilities. Water Utility Partnership, Abijan, Cote d'lvoire.

Robinson P., 2003, Water Demand Management – Economic and Financial System Lecture Notes, University of Zimbabwe. Unpublished.

Ross-Jordan, J., 2006. The Development of a Successful Unaccounted-for Water Management Programme in the Rural Water Supply Context. Water Research Commission, Report No. WRC TT 256/06, South Africa. Available from: www.wrc.org.za. Accessed 12th June 2009.

Sandström, K., Singh M., 2004. Water Demand Management in Southern Africa - Assessment of a Sida financed Water Demand Management project in Southern Africa, 1997–2004, Sida. Available from:

www.sida.se/shared/jsp/download.jsp?f=SIDA4281en_No.20+Water+web.pdf&a=3333. Accessed 10th March 2009.

Savenije, H.H.G., and P. van der Zaag, 2002, Water as an economic good and demand management, paradigms with pitfalls. Water International 27 (1): 98-104.

Seago, C., Bhagwan, J., McKenzie, R., 2004. Benchmarking leakage from water reticulation systems in South Africa. Water SA Vol. 30, No. 5, 25 – 32. Available on: www.wrc.org.za. Accessed 13th June 2009.

Sogrea, ECG, WTM Chirwa & Associates, 2002. District Centres Sanitation Study – Final Design Report for Kasungu Wastewater, Vol 3.1. Unpublished consultancy report.

Stantec, Chapita Consulting Engineers, 2002. Engineers Estimate for District Water Supply Phase III, Ministry of Irrigation and Water Development, Malawi. Unpublished.

Thornton, J., 2003. Managing Leakage By Managing Pressure: A practical approach. October Water 21, 43-44. Available from: www.iwapublishing.com/pdf/WaterLoss-Oct.pdf. Accessed 10th January 2009.

Thornton, J., Lambert, A., 2006. Managing Pressures to Reduce New Breaks. Water 21, pp 24 - 26. Available from: www.iwapublishing.com/pdf/WaterLoss-Oct.pdf. Accessed 10th January 2009.

Thornton, J., Kunkel, G., Gauley, B., Southern, D., Jackson, J., Brainard, B., Briar, R., 2002. Water Loss Control Manual, McGraw-Hill, New York.

Tsinde Development Consultants, 2002. Factors affecting the implementation of WDM strategies in Southern Africa, Theme 2 cross-cutting assessment of WDM technologies. Draft final report. In: IUCN Water Demand Management for Southern Africa Phase II: Proceedings of the Water Demand Management Regional Workshop 2002, Johannesburg, South Africa. CD Rom.

Tynan, N., Kingdom, B., 2002. A Water Scorecard – Setting Performance Targets for Water Utilities, World Bank Private Sector Note 242. Available from: www.rru.worldbank.org/documents/publicpolicyjournal/242Tynan-040802.pdf. Accessed 8th December 2008.

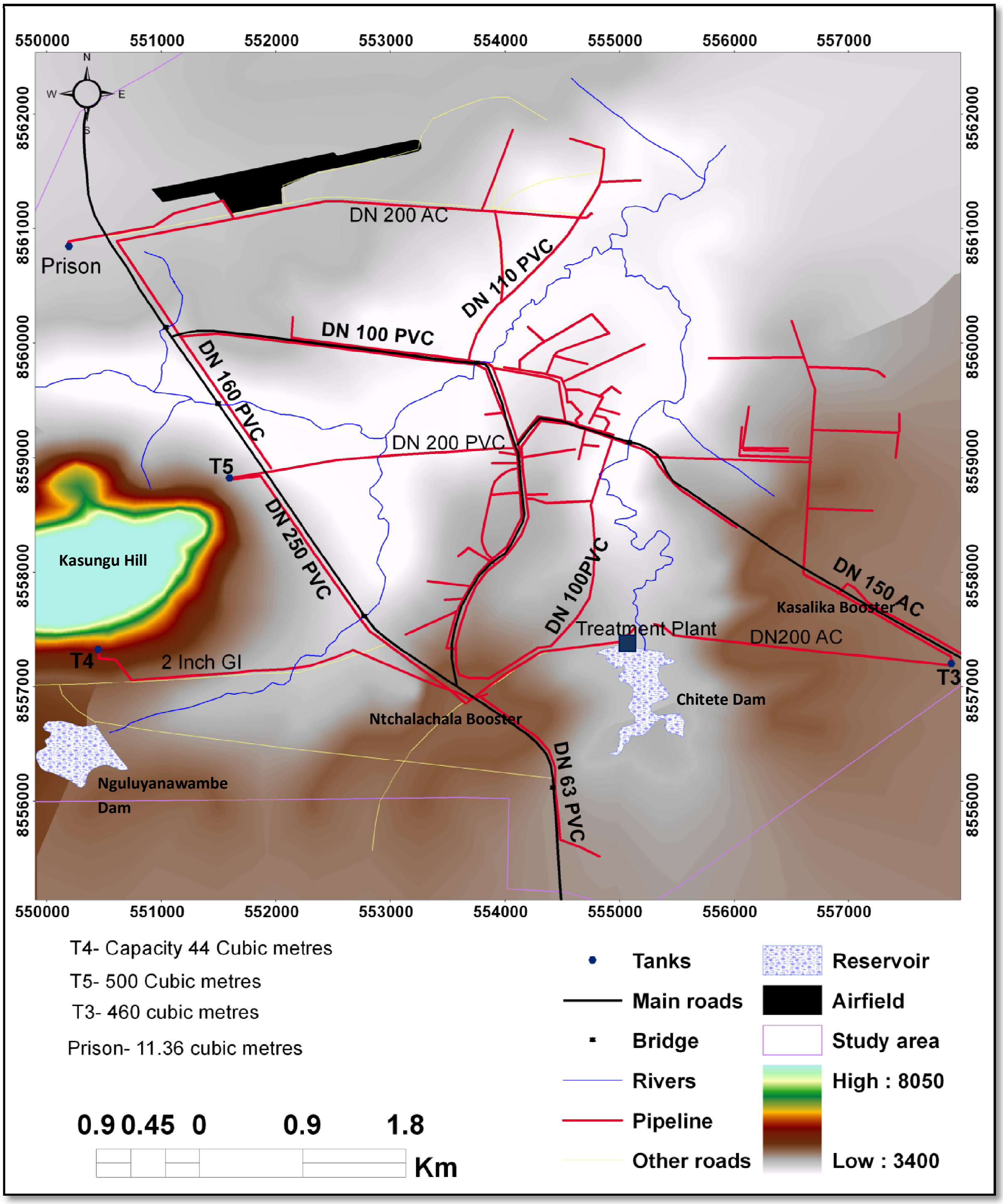
van der Zaag, P., 2003. Urban Water Demand Management, Integrated Water Resource Management (IWRM) 0.1 Lecture Notes, University of Zimbabwe. Unpublished.

Warder, G., 1994. Leakage and Demand Management, 20th WEDC Conference on Affordable Water Supply and Sanitation, Colombo, Sri Lanka.

APPENDICES

8.0 APPENDICES

Appendix A: Water supply system layout map of Kasungu Water Supply Scheme



Source: Central Region Water Board, Malawi.

Appendix B: Duration of Reported Leaks and Apparent Water Loss Parameters

Information on duration of reported bursts derived from Mackenzie et al. (2002)

Details	**Details Duration of Reported Bursts (days)**		
	Awareness and Location	**Repair Total**	**Total**
Transmission Mains	0.5	0.5	1
Distribution Mains	1.0	0.5	1.5
Connections	5.0	6.0	11
Service pipes	5.0	6.0	11

Suggested apparent loss percentages for a typical system. Adopted from Seago et al. (2004)

Illegal connections		**Meter age and accuracy**			**Data transfer**	
			Good water quality	**Poor water quality**		
Very high	10%	Poor > 10 years	8%	10%	Poor	8%
High	8%					
Average	6%	Average 5 – 10 years	4%	8%	Average	5%
Low	4%					
Very low	2%	Good < 5 years	2%	4%	Good	2%

Appendix C: Bucket test results

Date	Average Pressure (m)	Peak flow (l/s)	Time taken to fill 20 l bucket during peak demand period (s)									
			Highest points					Lowest points				
			Time reading taken	Single tap open	Tap + shower open	Elevation (m)	Place	Time reading taken (s)	Single tap open	Tap + shower open	Elevation (m)	Place
08/04/2009	65		6.09 am	54	No shower	1049	KSS 1	6.55 am	34	Tap + Shower on same pipe	1027	KADD 95
08/04/2009	65		6.12 am	67	No shower	1049	KSS 2	6.59 am	34	Tap + Shower on same pipe	1027	KADD 96
08/04/2009	65		6.16 am	55	No shower	1049	KSS 3	7.03 am	35	Tap + Shower on same pipe	1030	KADD 98
08/04/2009	65		6.30 am	64	81	1040	KADD 53	7. 13 am	33	Yard tap only	1025	Juma
08/04/2009	65		6.35 am	68	83	1040	KADD 54					
08/04/2009	65		6.39 am	63	85	1040	KADD 52					
15/04/2009	30		6.04 am	No flow	No flow	1049	KSS 1	6.26 am	94	Tap + Shower on same pipe	1027	KADD 95
15/04/2009	30		6.05 am	No flow	No flow	1049	KSS 2	6.30 am	93	Tap + Shower on same pipe	1027	KADD 96
15/04/2009	30			No flow	No flow	1049	KSS 3	6.35 am	99	Tap + Shower on same pipe	1030	KADD 98
15/04/2009	30		6.21 am	No flow	No flow	1040	KADD 53	6.41 am	70	Yard tap only	1025	Juma
15/04/2009	30			No flow	No flow	1040	KADD 54					
15/04/2009	30		6.23 am	No flow	No flow	1040	KADD 52					
28/04/2009	40		7.13 am	61	No shower	1049	KSS 1	7.38 am	54	Tap + Shower on same pipe	1027	KADD 95
28/04/2009	40		7.15 am	63	No shower	1049	KSS 2	7.40 am	53	Tap + Shower on same pipe	1027	KADD 96
28/04/2009	40		7.20 am	57	No shower	1049	KSS 3	7.45 am	52	Tap + Shower on same pipe	1030	KADD 98
28/04/2009	40		7.39 am	53	69	1040	KADD 53	7. 53 am	51	Yard tap only	1025	Juma
28/04/2009	40		7.37 am	52	67	1040	KADD 54					
28/04/2009	40		7.35 am	51	67	1040	KADD 52					
03/05/2009	50		6.02 am	61	No shower	1049	KSS 1	6.42 am	53	Tap + Shower on same pipe	1027	KADD 95
03/05/2009	50		6.06 am	69	No shower	1049	KSS 2	7.46 am	55	Tap + Shower on same pipe	1027	KADD 96
03/05/2009	50		6.09 am	58	No shower	1049	KSS 3	7.51 am	54	Tap + Shower on same pipe	1030	KADD 98
03/05/2009	50		6.25 am	67	82	1040	KADD 53	7.59 am	49	Yard tap only	1025	Juma
03/05/2009	50		6.29 am	69	79	1040	KADD 54					
03/05/2009	50		6.35 am	66	83	1040	KADD 52					

Appendix D: Calculation of Real Losses in Kasungu ADD

Loss parameters at 50 m pressure for MNF analysis adopted from McKenzie et al. (2002)

Description	Value
Background losses from mains	40 l/km/h
Background losses from connections	3 l/connection/h
Background losses from properties	1 l/connection /h
% of population active during night flow exercise	6%
Quantity of water used in toilet cistern	10 l
Average use for small non-domestic users	50 l/h
Background losses pressure exponent	1.5

Base data for night flow analysis, Kasungu ADD

Description	Value
Length of mains	5250 m
Number of connections	123
Number of properties	210
Estimated population	1 260
Average MNF at 68.2 m	4.87 m^3/h
Average MNF at 43.6 m	3.20 m^3/h

Estimation of background leakage at 50 m pressure, Kasungu ADD

Description	Calculation	Value (m^3/h)
Mains losses	5.3 km @ 40 l/km/h	0.21
Connection losses	123 @ 3 l/connection/h	0.37
Property losses	210 @ 1 l/property/h	0.21
Total background leakage at 50 m pressure	0.21+ 0.37+ 0.21	0.79

Losses at average night pressure of 68.2 m, Kasungu ADD

Description	Calculation	Value
Estimated background leakage at 50 m pressure		0.79 m^3/h
Estimated background leakage at 68 m pressure	$(68.2/50)^{1.5}$*0.79	1.26 m^3/h
Domestic night use	1260*6%*10 l/h	0.76 m^3/h
Total expected minimum night use	1.26 + 0.76	2.02 m^3/h
Measured minimum night use		4.87 m^3/15min
Correction factor for net night use per hour[5]		1.02
Adjusted minimum night use per hour	1.02*4.87	4.97 m^3/h
Water loss per hour	4.97 - 2.02	2.95 m^3/h

[5] Correction factor to change 15 minute flow to 1 hour flow equivalent adopted from Farley (2001), page 89.

Losses at average night pressure of 43.6 m, Kasungu ADD

Description	Calculation	Value
Estimated background leakage at 50 m pressure		0.79 m^3/h
Estimated background leakage at 43 m pressure	$(43.6/50)^{1.5}$*0.79	0.64 m^3/h
Domestic night use	1260*6%*10 l/h	0.76 m^3/h
Total expected minimum night use	0.64 + 0.76	1.40 m^3/h
Measured minimum night use		3.20 m^3/15 min
Correction factor for net night use per hour		1.02
Adjusted minimum night use per hour	1.02*3.2	3.26 m^3/h
Water loss per hour	3.26 - 1.40	1.86 m^3/h

Losses at average night pressure of 37.6 m, Kasungu ADD

Description	Calculation	Value
Estimated background leakage at 50 m pressure		0.79 m^3/h
Estimated background leakage at 43 m pressure	$(37.6/50)^{1.5}$*0.79	0.50 m^3/h
Domestic night use	1260*6%*10 l/h	0.76 m^3/h
Total expected minimum night use	0.50 + 0.76	1.26 m^3/h
Measured minimum night use		3.00 m^3/15 min
Correction factor for net night use per hour		1.02
Adjusted minimum night use per hour	1.02*3.00	3.06 m^3/h
Water loss per hour	3.06 - 1.26	1.80 m^3/h

Correction factors to change non one hour minimum night flows to one hour flow equivalents adopted from Farley, (2001)

Measurement period	Multiplier for net night flow
15 minutes	1.02
30 minutes	1.01
1 hour	1.0
2 hours	0.98

Appendix E : Pipe laying and pressure management investment cost data

Base data for unit costs of distribution pipes, PVC Class 10 (Covering 15% engineering design and supervision and 10% contingencies)

Pipe diameter (mm)	Design Management Group (2001)	NIRAS-Norconsult et al. (2001)	Stantec and Chapita Consulting Engineers (2002)	Norconsult and Bua Consulting Engineers (2006)
	Total unit cost incl. fittings (US$/m)	Total unit cost incl. fittings (US$/m)	Total unit cost incl. fittings (US$/m)	Total unit cost incl. fittings (US$/m)
63	7.00	8.00	7.00	10.00
90	10.00	10.00	11.00	13.00
110	15.00	14.00	15.00	16.00
200	39.00	37.00	38.00	40.00

2008 computed pipe laying cost based on annualised 2001 – 2008 inflation of 2.83% of US$ proposed by Officer and Williamson (2009)

Pipe diameter (mm)	Design Management Group	NIRAS-Norconsult et al.	Stantec and Chapita Consulting Engineers	Norconsult and Bua Consulting Engineers	Average cost incl. fittings (US$/m)
	Total unit cost incl. fittings (US$/m)	Total unit cost incl. fittings (US$/m)	Total unit cost incl. fittings (US$/m)	Total unit cost incl. fittings (US$/m)	
63	8.51	9.73	8.28	10.57	9.27
90	12.16	12.16	13.00	13.75	12.77
110	18.24	17.02	17.73	16.92	17.48
200	47.41	44.98	44.92	42.30	44.90

Total investment cost for pipe laying

Pipe diameter (mm)[a]	Length of mains (m)[b]	Average cost incl. fittings (US$/m)[c]	Total cost (US$) (b*c)
63	1850	9.27	17,149.50
90	800	12.77	10,216.00
110	1600	17.48	27,968.00
200	1000	44.90	44,900.00

Investment cost for pressure management

anderson engineering malawi ltd.

PO Box 31045
Capital City
Lilongwe 3
Malawi
Tel: 01 751 582
01 751 583
Fax: 01 751 584
Cell: 09 950 427
08 205 427
andersonltd@malawi.net

PO Box 32707
Chichiri
Blantyre 3
Malawi
Tel: 01 874 000
01 874 065
Fax: 01 874 065
Cell: 08 306 521
08 207 034
andersoneng@malawi.net

Richman Kalua
Central Region Water Board
P / Bag 59
Lilongwe.

Date: 19th June, 2009

Ref: IZK/am/CRWB/AE00875

Dear Sir,

Sub: RE: QUOTATION FOR THE SUPPLY OF PRESSURE REDUCING VALVES & WATER METERS.

We thank you for your above enquiry and we now wish to quote as follows:

QTY	ITEM DESCRIPTION	UNIT PRICE	TOTAL AMOUNT
1	100mm Pressure Reducing Valve, Cast Iron Body, synthetic	MK 1,303,974.57	MK 1,303,974.57
	trim, flanged to BS4504 Table 16, inlet 16 Bar, Outlet: 1.5 - 8 Bar		
1	200mm Pressure Reducing Valve, Cast Iron Body, synthetic	MK 6,251,242.66	MK 6,251,242.66
	trim, flanged to BS4504 Table 16, inlet 16 Bar, Outlet: 8 Bar		
1	100mm Woltex Cold Water Meter, flanged	MK 159,798.89	MK 159,798.89
		TOTAL AMOUNT	**MK 7,715,016.12**
		16.5% Govt. Vat	*MK 1,272,977.66*
		GRAND TOTAL	**MK 8,987,993.78**

Delivery: **3 - 5 weeks from the date of receipt of order.**

Validity: **15 days**

Terms of payment:
60% with official order.
30% after delivery of goods.
10% 30days after the date of invoice.

Note: **Prices quoted are based on today's rate of exchange ie ZAR1.00 = MK 21.6018. Any variation from this rate by +/- 7.5% or more, will affect the prices accordingly and be reflected on our invoices to you.**

We trust you will find our offer acceptable to you and we look forward to receiving your order soon.

We assure you of our quality products, prompt and most committed attention to all your needs.

Yours faithfully
For Anderson Engineering Ltd

Innocent Kaunda
SALES REPRESENTATIVE.

DOING WHAT WE DO WELL

BUTTERFLY VALVES

TÜV CERT ISO 9002

ENGINEERING SUPPLIERS TO THE WATERWORKS, PROCESS & MINING INDUSTRIES OF SOUTHERN & CENTRAL AFRICA.

DIRECTORS: H. JERE (Managing) F. A. OLSEN

Appendix F: Calculation of Water Losses due to Pipe Replacement

Water saving at 59 m average zone pressure (AZP) due to pipe replacement

Description	Calculation	Value
Length of Mains in Kasungu ADD		5.25 km
Number of connections		123
Length of pipe to customer meter from street edge		0.015 km
Average operating pressure		59
Unavoidable annual real losses	(18*5.25*+0.8*123*+25*0.015)*59	11.40 m^3/day
Target Loss Factor		2
Adjusted unavoidable water losses	2*11.40	22.80 m^3/day
Real Water loss from water balance (Fig. 5)	13,825/365	37.88 m^3/day
Water saving due to pipe replacement per day	37.88 – 22.8	15.08 m^3/day
Water saving due to pipe replacement per month	30*15.08	452.40 m^3/month

Appendix G: Production and Billed figures for Kasungu Water Supply Scheme

Production, consumption and UFW for 2004

Month	CRWB				Kasungu			
	Prodctn	Cons	UFW	UFW %	Prodctn	Cons	UFW	UFW %
Jan	352604	232518	120086.061	34%	86028	49276	36752	43%
Feb	371408	270144	101264.061	27%	85402	57633	27769	33%
Mar	382800	265088	117712.061	31%	90374	60467	29907	33%
Apr	390962	212356	178605.808	46%	99694	74492	25202	25%
May	320307	216780	103526.683	32%	102567	64492	38075	37%
Jun	392694	220054	172639.963	44%	87325	67935	19390	22%
Jul	380839	270579	110260.061	29%	86602	58200	28402	33%
Aug	403127	293691	109436.061	27%	83252	58254	24998	30%
Sep	421387	304539	116848.061	28%	91661	58403	33258	36%
Oct	381844	295483	86361.0606	23%	94264	68536	25728	27%
Nov	384235	306733	77502.0606	20%	91485	69407	22078	24%
Dec	387793	268303	119490.061	31%	86672	61989	24683	28%
Total	**4570000**	**3156268**	**1413732**	**31%**	**1085326**	**749084**	**336242**	**31%**

Production, consumption and UFW for 2005

Month	CRWB				Kasungu			
	Prodctn	Cons	UFW	UFW %	Prodctn	Cons	UFW	UFW %
Jan	461636	332518	129118	28%	86028	49276	36752	43%
Feb	491644	380841	110803	23%	85402	57633	27769	33%
Mar	488930	360733	128197	26%	86034	56299	29735	35%
Apr	475882	351927	123955	26%	88353	63987	24366	28%
May	520206	377950	142256	27%	98493	59806	38687	39%
Jun	480127	362035	118092	25%	89820	59026	30794	34%
Jul	498398	287607.76	210790.24	42%	97468	60430.16	37037.84	38%
Aug	511388	382469	128919	25%	96001	59754	36247	38%
Sep	502759	379820.223	122938.777	24%	98086	72488	25598	26%
Oct	557133	425942	131191	24%	101186	66163	35023	35%
Nov	508710	420720	87990	17%	94274	80807	13467	14%
Dec	468911	379638	89273	19%	85569	67009	18560	22%
Total	**5965724**	**4442200.983**	**1523523.02**	**26%**	**1106714**	**752678.16**	**354035.84**	**32%**

Production, consumption and UFW figures for 2006

Month	CRWB				Kasungu			
	Prodctn	Cons	UFW	UFW %	Prodctn	Cons	UFW	UFW %
Jan	442114	342958	99156	22%	88231	58957	29274	33%
Feb	458633	354541	104092	23%	83721	58065	25656	31%
Mar	530706	387738	142968	27%	91544	51234	40310	44%
Apr	468379	310718	157661	34%	87564	45668	41896	48%
May	453729	352468	101261	22%	77413	62177	15236	20%
Jun	498964	393455	105509	21%	90283	56060	34223	38%
Jul	522049	393177	128872	25%	96688	79383	17305	18%
Aug	540389	401718	138671	26%	85433	57190	28243	33%
Sep	522214	415428	106786	20%	98150	75337	22813	23%
Oct	558597	430448	128149	23%	101889	70594	31295	31%
Nov	466728	351935	114793	25%	93362	61844	31518	34%
Dec	457267	360160	97107	21%	86566	54114	32452	37%
Total	**5919769**	**4494744**	**1425025**	**24%**	**1080844**	**730623**	**350221**	**32%**

Production, Consumption and UFW figures for 2007

Month	CRWB				Kasungu			
	Prodctn	Cons	UFW	UFW %	Prodctn	Cons	UFW	UFW %
Jan	470283	353232	117051	25%	87325	67935	19390	22%
Feb	456181	333415	122766	27%	82870	60643	22227	27%
Mar	497831	340462	157369	32%	81708	57533	24175	30%
Apr	495583	345710	149873	30%	85433	57190	28243	33%
May	480048	360932	119116	25%	76060	52834	23226	31%
Jun	489716	371393	118323	24%	89767	66717	23050	26%
Jul	501254	359024	142230	28%	83338	60405	22933	28%
Aug	521491	381024	140467	27%	80779	57766	23013	28%
Sep	577316	440120	137196	24%	119885	85500	34385	29%
Oct	570724	414624	156100	27%	109790	81138	28652	26%
Nov	514691	401168	113523	22%	81200	64651	16549	20%
Dec	512568	387306	125262	24%	86957	64421	22536	26%
Total	**6087686**	**4488410**	**1599276**	**26%**	**1065112**	**776733**	**288379**	**27%**

Production, consumption and UFW figures for 2008

Month	CRWB				Kasungu			
	Prodctn	Cons	UFW	UFW %	Prodctn	Cons	UFW	UFW %
Jan	439872	300502	188279	39%	106180	72584	33596	32%
Feb	446198	307956	187151	38%	94292	61090	33202	35%
Mar	441089	326355	163643	33%	96808	57974	38834	40%
Apr	456783	321429	184263	36%	99694	73492	26202	26%
May	351587	223838	176658	44%	102567	63492	39075	38%
Jun	479109	352931	175087	33%	87325	66935	20390	23%
Jul	302449	216052	135307	39%	98147	71569	26578	27%
Aug	529301	391344	186866	32%	88931	70147	18784	21%
Sep	541590	371917	169673	31%	87325	66935	20390	23%
Oct	545512	404436	189986	32%	95385	70352	25033	26%
Nov	492926	355650	186185	34%	87325	66935	20390	23%
Dec	522495	389233	182171	32%	90547	69145	21402	24%
Total	**5548911**	**3961643**	**2125269**	**35%**	**1134526**	**810650**	**323876**	**29%**

Appendix H: Night Pressure and Flow Results

Night Flow and Pressure results at 65 m inlet pressure setting

Date	Time	Flow	Pressure
07/04/2009	00:00:00	10.774	68.5
07/04/2009	00:15:00	8.108	69.7
07/04/2009	00:30:00	8.774	70.1
07/04/2009	00:45:00	8.108	70.9
07/04/2009	01:00:00	8.441	70
07/04/2009	01:15:00	8.33	70
07/04/2009	01:30:00	8.663	70.1
07/04/2009	01:45:00	6.108	71.1
07/04/2009	02:00:00	5.663	71.2
07/04/2009	02:15:00	7.441	71.3
07/04/2009	02:30:00	8.441	71.3
07/04/2009	02:45:00	4.87	68.1
07/04/2009	03:00:00	6.33	71.4
07/04/2009	03:15:00	7.33	71.4
07/04/2009	03:30:00	6.441	70.5
07/04/2009	03:45:00	8.219	70.5
07/04/2009	04:00:00	8.441	70.5
08/04/2009	00:00:00	11.064	68.4
08/04/2009	00:15:00	10.287	68.4
08/04/2009	00:30:00	8.064	68.5
08/04/2009	00:45:00	8.287	68.6
08/04/2009	01:00:00	8.953	68.6
08/04/2009	01:15:00	7.731	68.7
08/04/2009	01:30:00	6.175	68.6
08/04/2009	01:45:00	7.064	68.8
08/04/2009	02:00:00	5.842	68.8
08/04/2009	02:15:00	6.842	68.9
08/04/2009	02:30:00	4.874	68.4
08/04/2009	02:45:00	8.953	69
08/04/2009	03:00:00	9.953	69.1
08/04/2009	03:15:00	8.842	69.1
08/04/2009	03:30:00	8.953	69.1
08/04/2009	03:45:00	8.175	69.2
08/04/2009	04:00:00	8.175	69.2
09/04/2009	00:00:00	9.826	68.4
09/04/2009	00:15:00	7.604	68.5
09/04/2009	00:30:00	4.872	68.4
09/04/2009	00:45:00	6.826	68.5
09/04/2009	01:00:00	6.715	68.6
09/04/2009	01:15:00	8.604	68.6
09/04/2009	01:30:00	8.715	68.7
09/04/2009	01:45:00	6.382	68.7
09/04/2009	02:00:00	4.866	68.1
09/04/2009	02:15:00	5.382	68.8
09/04/2009	02:30:00	7.493	68.8

Date	Time	Flow	Pressure
09/04/2009	02:45:00	8.382	68.9
09/04/2009	03:00:00	9.382	68.9
09/04/2009	03:15:00	9.604	68.9
09/04/2009	03:30:00	8.271	68.7
09/04/2009	03:45:00	8.271	68.2
09/04/2009	04:00:00	9.271	68.1
10/04/2009	00:00:00	9.31	67.6
10/04/2009	00:15:00	9.31	67.6
10/04/2009	00:30:00	8.31	67.6
10/04/2009	00:45:00	6.754	67.7
10/04/2009	01:00:00	5.643	67.7
10/04/2009	01:15:00	4.865	67.6
10/04/2009	01:30:00	7.532	67.7
10/04/2009	01:45:00	8.754	67.6
10/04/2009	02:00:00	9.087	67.8
10/04/2009	02:15:00	9.087	67.7
10/04/2009	02:30:00	8.199	67.7
10/04/2009	02:45:00	8.643	67.8
10/04/2009	03:00:00	8.976	67.8
10/04/2009	03:15:00	8.976	67.8
10/04/2009	03:30:00	9.754	67.8
10/04/2009	03:45:00	8.421	67.8
10/04/2009	04:00:00	9.421	67.7
11/04/2009	00:00:00	10.69	68.3
11/04/2009	00:15:00	9.13	68.5
11/04/2009	00:30:00	8.908	68.5
11/04/2009	00:45:00	9.352	68.5
11/04/2009	01:00:00	8.241	68.6
11/04/2009	01:15:00	4.865	68.6
11/04/2009	01:30:00	4.858	68.7
11/04/2009	01:45:00	6.908	68.7
11/04/2009	02:00:00	8.13	68.8
11/04/2009	02:15:00	8.908	68.8
11/04/2009	02:30:00	9.019	68.8
11/04/2009	02:45:00	8.908	68.9
11/04/2009	03:00:00	8.908	68.9
11/04/2009	03:15:00	9.13	68.9
11/04/2009	03:30:00	8.797	68.7
11/04/2009	03:45:00	8.797	68.2
11/04/2009	04:00:00	8.797	68.1
12/04/2009	00:00:00	9.31	68.4
12/04/2009	00:15:00	4.869	68.5
12/04/2009	00:30:00	4.898	70.5
12/04/2009	00:45:00	7.342	70.5
12/04/2009	01:00:00	8.231	70.6
12/04/2009	01:15:00	8.12	70.7

Date	**Time**	**Flow**	**Pressure**
12/04/2009	01:30:00	8.231	70.8
12/04/2009	01:45:00	8.898	70.8
12/04/2009	02:00:00	9.12	71.1
12/04/2009	02:15:00	8.898	71.1
12/04/2009	02:30:00	9.009	71.1
12/04/2009	02:45:00	8.898	71.2
12/04/2009	03:00:00	8.898	69.9
12/04/2009	03:15:00	9.12	69.9
12/04/2009	03:30:00	8.787	68.7
12/04/2009	03:45:00	8.787	68.2
12/04/2009	04:00:00	8.787	68.1
13/04/2009	00:00:00	7.898	67.6
13/04/2009	00:15:00	4.874	67.6
13/04/2009	00:30:00	4.874	67.6
13/04/2009	00:45:00	4.942	67.7
13/04/2009	01:00:00	4.931	69.9
13/04/2009	01:15:00	4.953	69.8
13/04/2009	01:30:00	4.92	69.9
13/04/2009	01:45:00	4.942	69.8
13/04/2009	02:00:00	5.675	68.1
13/04/2009	02:15:00	5.675	68.2
13/04/2009	02:30:00	4.87	68.8
13/04/2009	02:45:00	4.931	68.9
13/04/2009	03:00:00	4.964	67.9
13/04/2009	03:15:00	4.964	67.9
13/04/2009	03:30:00	5.342	69.8
13/04/2009	03:45:00	4.889	69.8
13/04/2009	04:00:00	4.889	69.7

Night Flow and Pressure results at 50 m inlet pressure setting

Date	Time	Flow	Pressure
04/05/2009	00:00:00	9.444	56.3
04/05/2009	00:15:00	7.778	56.4
04/05/2009	00:30:00	7.444	56.4
04/05/2009	00:45:00	7.778	56.5
04/05/2009	01:00:00	6.111	56.4
04/05/2009	01:15:00	4.147	56.5
04/05/2009	01:30:00	4.333	56.6
04/05/2009	01:45:00	4.778	56.6
04/05/2009	02:00:00	4.333	56.6
04/05/2009	02:15:00	6.111	56.6
04/05/2009	02:30:00	6.111	56.6
04/05/2009	02:45:00	6.667	56.7
04/05/2009	03:00:00	6	56.7
04/05/2009	03:15:00	5	56.7
04/05/2009	03:30:00	6.111	56.8
04/05/2009	03:45:00	6.889	56.8
04/05/2009	04:00:00	6.111	56.7
05/05/2009	00:00:00	9.333	56.4
05/05/2009	00:15:00	8.556	56.4
05/05/2009	00:30:00	8.333	56.5
05/05/2009	00:45:00	7.556	56.6
05/05/2009	01:00:00	6.222	56.6
05/05/2009	01:15:00	4.148	56.7
05/05/2009	01:30:00	4.444	56.6
05/05/2009	01:45:00	4.333	56.8
05/05/2009	02:00:00	4.151	56.8
05/05/2009	02:15:00	6.111	56.9
05/05/2009	02:30:00	6.333	56.9
05/05/2009	02:45:00	6.222	57
05/05/2009	03:00:00	6.222	57.1
05/05/2009	03:15:00	6.111	57.1
05/05/2009	03:30:00	6.222	57.1
05/05/2009	03:45:00	6.444	57.2
05/05/2009	04:00:00	6.444	57.2
05/06/2009	00:00:00	6.111	56.4
05/06/2009	00:15:00	6.889	56.5
05/06/2009	00:30:00	7.667	56.5
05/06/2009	00:45:00	7.111	56.5
05/06/2009	01:00:00	7	56.6
05/06/2009	01:15:00	4.149	56.6
05/06/2009	01:30:00	4.499	56.7
05/06/2009	01:45:00	4.667	56.7
05/06/2009	02:00:00	6.889	56.8
05/06/2009	02:15:00	7.667	56.8
05/06/2009	02:30:00	6.778	56.8
05/06/2009	02:45:00	6.667	56.9
05/06/2009	03:00:00	6.667	56.9
05/06/2009	03:15:00	6.889	56.9
05/06/2009	03:30:00	6.556	56.7
05/06/2009	03:45:00	7.556	56.2
05/06/2009	04:00:00	7.556	56.1
05/07/2009	00:00:00	6.667	55.6
05/07/2009	00:15:00	6.667	55.6
05/07/2009	00:30:00	6.667	55.6
05/07/2009	00:45:00	6.111	55.7
05/07/2009	01:00:00	6	55.7
05/07/2009	01:15:00	4.222	55.6
05/07/2009	01:30:00	4.889	55.7
05/07/2009	01:45:00	4.151	55.6
05/07/2009	02:00:00	4.444	55.8
05/07/2009	02:15:00	6.444	55.7
05/07/2009	02:30:00	6.556	55.7
05/07/2009	02:45:00	6	55.8
05/07/2009	03:00:00	6.333	55.8
05/07/2009	03:15:00	6.333	55.8
05/07/2009	03:30:00	6.111	55.8
05/07/2009	03:45:00	6.778	55.8
05/07/2009	04:00:00	6.778	55.7
05/08/2009	00:00:00	9.444	56.3
05/08/2009	00:15:00	6.889	56.5
05/08/2009	00:30:00	6.667	56.5
05/08/2009	00:45:00	7.111	56.5
05/08/2009	01:00:00	17	56.6
05/08/2009	01:15:00	6.889	56.6
05/08/2009	01:30:00	17	56.7
05/08/2009	01:45:00	6.667	56.7
05/08/2009	02:00:00	6.889	56.8
05/08/2009	02:15:00	4.15	56.1
05/08/2009	02:30:00	4.778	56.8
05/08/2009	02:45:00	4.667	56.9
05/08/2009	03:00:00	4.667	56.9
05/08/2009	03:15:00	4.889	56.9
05/08/2009	03:30:00	5.556	56.7
05/08/2009	03:45:00	6.556	56.2
05/08/2009	04:00:00	6.556	56.1
05/09/2009	00:00:00	6.111	56.4
05/09/2009	00:15:00	6.889	56.5
05/09/2009	00:30:00	6.667	56.5
05/09/2009	00:45:00	6.111	56.5
05/09/2009	01:00:00	6	56.6
05/09/2009	01:15:00	5.889	56.6

Date	Time	Flow	Pressure
05/09/2009	01:30:00	6	56.7
05/09/2009	01:45:00	4.667	56.7
05/09/2009	02:00:00	4.889	56.8
05/09/2009	02:15:00	4.164	56.2
05/09/2009	02:30:00	4.778	56.8
05/09/2009	02:45:00	6.667	56.9
05/09/2009	03:00:00	6.667	56.9
05/09/2009	03:15:00	6.889	56.9
05/09/2009	03:30:00	6.556	56.7
05/09/2009	03:45:00	6.556	56.2
05/09/2009	04:00:00	6.556	56.1
05/09/2009	00:00:00	6.467	55.6
05/09/2009	00:15:00	6.467	55.6
05/09/2009	00:30:00	6.467	55.6
05/09/2009	00:45:00	6.111	55.7
05/09/2009	01:00:00	6	55.7
05/09/2009	01:15:00	6.222	55.6
05/09/2009	01:30:00	6.889	55.7
05/09/2009	01:45:00	6.111	55.6
05/09/2009	02:00:00	6.444	55.8
05/09/2009	02:15:00	5.444	55.7
05/09/2009	02:30:00	4.556	55.7
05/09/2009	02:45:00	4.149	55.8
05/09/2009	03:00:00	4.333	55.8
05/09/2009	03:15:00	5.333	55.8
05/09/2009	03:30:00	6.111	55.8
05/09/2009	03:45:00	6.778	55.8
05/09/2009	04:00:00	6.778	55.7

Night Flow and Pressure results at 40 m inlet pressure setting

Date	Time	Flow	Pressure
16/04/2009	00:00:00	4.111	42.5
16/04/2009	00:15:00	3.111	42.8
16/04/2009	00:30:00	3.222	43
16/04/2009	00:45:00	3.444	43.7
16/04/2009	01:00:00	3.333	43
16/04/2009	01:15:00	3.222	44.5
16/04/2009	01:30:00	3.222	45.2
16/04/2009	01:45:00	3.111	44.5
16/04/2009	02:00:00	3.667	38.1
16/04/2009	02:15:00	3.778	38.6
16/04/2009	02:30:00	3.778	39.2
16/04/2009	02:45:00	3.778	39.6
16/04/2009	03:00:00	3.889	39.6
16/04/2009	03:15:00	3.778	39.2
16/04/2009	03:30:00	3.889	39.2
16/04/2009	03:45:00	3.778	39.6
16/04/2009	04:00:00	4.556	40.6
17/04/2009	00:00:00	3.112	45.5
17/04/2009	00:15:00	3.225	45.7
17/04/2009	00:30:00	3.127	45.8
17/04/2009	00:45:00	3.213	45.9
17/04/2009	01:00:00	3.112	46
17/04/2009	01:15:00	3.112	46
17/04/2009	01:30:00	3.112	46.1
17/04/2009	01:45:00	3.133	46.1
17/04/2009	02:00:00	3.133	46.2
17/04/2009	02:15:00	3	46.3
17/04/2009	02:30:00	3.211	46.3
17/04/2009	02:45:00	3.112	46.4
17/04/2009	03:00:00	3.112	46.4
17/04/2009	03:15:00	3.112	46.4
17/04/2009	03:30:00	3.333	43.1
17/04/2009	03:45:00	3.333	43.1
17/04/2009	04:00:00	3.889	46.5
18/04/2009	00:00:00	4	46
18/04/2009	00:15:00	3.333	44.1
18/04/2009	00:30:00	3.333	44.1
18/04/2009	00:45:00	3.111	46.2
18/04/2009	01:00:00	3	45.4
18/04/2009	01:15:00	3.111	40.8
18/04/2009	01:30:00	3.221	40.9
18/04/2009	01:45:00	3.223	40.8
18/04/2009	02:00:00	3.111	40.8
18/04/2009	02:15:00	3	41
18/04/2009	02:30:00	3.122	41

Date	Time	Flow	Pressure
18/04/2009	02:45:00	3.122	41
18/04/2009	03:00:00	3.222	41.1
18/04/2009	03:15:00	3.222	41.1
18/04/2009	03:30:00	3.111	41
18/04/2009	03:45:00	3.111	40.7
18/04/2009	04:00:00	3.111	40
19/04/2009	00:00:00	3.556	45.8
19/04/2009	00:15:00	3.889	45.4
19/04/2009	00:30:00	3.667	44.7
19/04/2009	00:45:00	3.667	44.1
19/04/2009	01:00:00	3.556	44.1
19/04/2009	01:15:00	3.667	44.1
19/04/2009	01:30:00	3.667	45.3
19/04/2009	01:45:00	3.778	45.3
19/04/2009	02:00:00	3.778	45.3
19/04/2009	02:15:00	3.311	44.3
19/04/2009	02:30:00	3.667	45.5
19/04/2009	02:45:00	3.778	45.5
19/04/2009	03:00:00	4.222	45.5
19/04/2009	03:15:00	5.667	45.5
19/04/2009	03:30:00	5.667	45.5
19/04/2009	03:45:00	5.667	44.7
19/04/2009	04:00:00	5.889	44.7
20/04/2009	00:00:00	5.444	44.3
20/04/2009	00:15:00	4.333	46.1
20/04/2009	00:30:00	3.333	46.1
20/04/2009	00:45:00	3.111	46.2
20/04/2009	01:00:00	3	45.4
20/04/2009	01:15:00	3.111	40.8
20/04/2009	01:30:00	3.667	40.9
20/04/2009	01:45:00	3.667	40.8
20/04/2009	02:00:00	3.778	42.8
20/04/2009	02:15:00	3.556	41
20/04/2009	02:30:00	3.667	41
20/04/2009	02:45:00	3.778	41
20/04/2009	03:00:00	3.222	41.1
20/04/2009	03:15:00	3.667	41.1
20/04/2009	03:30:00	3.667	41
20/04/2009	03:45:00	3.667	40.7
20/04/2009	04:00:00	3.322	43.4
21/04/2009	00:00:00	7.556	45.5
21/04/2009	00:15:00	5.889	45.7
21/04/2009	00:30:00	5.667	45.8
21/04/2009	00:45:00	5.667	45.9
21/04/2009	01:00:00	4.556	46
21/04/2009	01:15:00	4.667	46

Date	Time	Flow	Pressure
21/04/2009	01:30:00	4.667	46.1
21/04/2009	01:45:00	3.778	46.1
21/04/2009	02:00:00	3.778	46.2
21/04/2009	02:15:00	3	46.3
21/04/2009	02:30:00	4.778	46.3
21/04/2009	02:45:00	4.889	46.4
21/04/2009	03:00:00	5.889	46.4
21/04/2009	03:15:00	5.667	46.4
21/04/2009	03:30:00	6.333	46.5
21/04/2009	03:45:00	6.333	46.5
21/04/2009	04:00:00	5.889	46.5
22/04/2009	00:00:00	9.556	45.5
22/04/2009	00:15:00	6.889	45.7
22/04/2009	00:30:00	5.667	45.8
22/04/2009	00:45:00	4.667	45.9
22/04/2009	01:00:00	3.556	46
21/04/2009	01:15:00	3.667	46
21/04/2009	01:30:00	3.667	46.1
21/04/2009	01:45:00	3.778	46.1
21/04/2009	02:00:00	3.778	46.2
21/04/2009	02:15:00	3.333	43.3
21/04/2009	02:30:00	3.667	41
21/04/2009	02:45:00	3.778	41
21/04/2009	03:00:00	3.222	41.1
21/04/2009	03:15:00	3.667	41.1
21/04/2009	03:30:00	3.667	41
21/04/2009	03:45:00	3.667	40.7
21/04/2009	04:00:00	3.889	46.5

Night Flow and Pressure results at 30 m inlet pressure setting

Date	Time	Flow	Pressure
04/13/200	00:00:00	4.667	36.3
04/13/200	00:15:00	2.556	36.3
04/13/200	00:30:00	2.223	36.6
04/13/200	00:45:00	2.111	36.6
04/13/200	01:00:00	2.111	36.8
04/13/200	01:15:00	2.21	36.8
04/13/200	01:30:00	2.21	36.8
04/13/200	01:45:00	2.233	36.8
04/13/200	02:00:00	2.333	35.9
04/13/200	02:15:00	2.333	35.9
04/13/200	02:30:00	2.232	35.9
04/13/200	02:45:00	2.231	35
04/13/200	03:00:00	2.333	35.1
04/13/200	03:15:00	2.333	35.1
04/13/200	03:30:00	2.221	35.1
04/13/200	03:45:00	2.221	35.2
04/13/200	04:00:00	2.244	35.2
04/14/200	00:00:00	3.333	35.1
04/14/200	00:15:00	2.444	35.3
04/14/200	00:30:00	2.111	35.4
04/14/200	00:45:00	2.122	35.4
04/14/200	01:00:00	2.122	35.6
04/14/200	01:15:00	2.233	35.7
04/14/200	01:30:00	2.233	35.7
04/14/200	01:45:00	2.333	35.8
04/14/200	02:00:00	2.333	35.8
04/14/200	02:15:00	2.212	35.8
04/14/200	02:30:00	2.233	35.9
04/14/200	02:45:00	2.333	35.9
04/14/200	03:00:00	2.212	36
04/14/200	03:15:00	2.212	36
04/14/200	03:30:00	2.222	36
04/14/200	03:45:00	2.222	36
04/14/200	04:00:00	2.111	36.1
04/15/200	00:00:00	4.333	36.4
04/15/200	00:15:00	3.444	34.3
04/15/200	00:30:00	2.778	34.4
04/15/200	00:45:00	2.556	36.6
04/15/200	01:00:00	2.556	36.8
04/15/200	01:15:00	2.444	36.8
04/15/200	01:30:00	2.444	36.8
04/15/200	01:45:00	2.333	36.8
04/15/200	02:00:00	2.667	35.9
04/15/200	02:15:00	2.667	35.9
04/15/200	02:30:00	2.556	35.9

Date	Time	Flow	Pressure
04/15/200	02:45:00	2.667	35
04/15/200	03:00:00	2.667	35.1
04/15/200	03:15:00	2.111	36
04/15/200	03:30:00	2.667	36
04/15/200	03:45:00	2.667	36
04/15/200	04:00:00	3.111	36.1
04/16/200	00:00:00	2.444	35.3
04/16/200	00:15:00	2.111	35.4
04/16/200	00:30:00	2.111	35.4
04/16/200	00:45:00	2.556	35.6
04/16/200	01:00:00	2.556	35.7
04/16/200	01:15:00	2.444	35.7
04/16/200	01:30:00	2.444	35.8
04/16/200	01:45:00	2.333	35.8
04/16/200	02:00:00	2.667	35.8
04/16/200	02:15:00	2.667	35.9
04/16/200	02:30:00	2.556	35.9
04/16/200	02:45:00	2.667	36
04/16/200	03:00:00	2.667	36
04/16/200	03:15:00	2.444	36
04/16/200	03:30:00	2.778	36
04/16/200	03:45:00	2.444	36.1
04/16/200	04:00:00	4.444	36

Appendix F: Customer Survey Questionnaire

Pressure Management as a tool for control and reduction of non revenue water for Kasungu Water Supply Scheme

SURVEY QUESTIONNAIRE

Introduction

A study is being carried out to investigate the potential of reducing water losses through pressure management in Kasungu ADD by Central Region Water Board (CRWB). You are therefore being kindly asked to answer the questions below to the best of your knowledge.

Date:……………………………… Time:.…………………..………….

Respondent Name:…………………………………………………………….

Type of Settlement

(a) Low Density =1 { }
(b) Medium Density =2 { }
(c) High Density Permanent =3 { }
(d) High Density Traditional =4 { }
(e) Commercial =5 { }
(f) Institution =6 { }

HOUSEHOLD INTERVIEW

General Information

A. HOUSEHOLD CHARCTERISTICS

1. (i) Head of the household

(a) Male (18-65 yrs) =1 { }

(b) Female (18-65 yrs) =2 { }

(c) Child (10-18 yrs) =3 { }

(d) Elderly (65-above) =4 { }

(ii) Occupation of Head of household

(a) Farmer =1 { }

(b) Employed =2 { } Public [ ] , Private [ ] NGO [ ]

(c) Business =3 { }

(d) Other (Specify) =4 { }…………………………

2. What is the highest level of education of the head of the household?

(a) Primary Stds 1—3 =1 { }

(b) Primary Stds 6—8 =2 { }

(c) Secondary form 1 or 2 =3 { }

(d) Secondary form 3 or 4 =4 { }

(e) Tertiary =5 { }

(f) None = 6 { }

3. What is the marital status of the head of the Household?

a) Single { } b) Married { } c) Divorced/ Separated { } d) Widow / Widower { }

4. (i) Number of people in this household:

(a) Children: 0 – 5…….. (b) 6 – 12…… (c) 13 – 18 …….. (d) 18+……...

(Ii) total number of people in this household is: male………. Female………..

5. (i) Do you own the plot on where you are staying? Yes = **1**{ } No = **2**{ }specify ….

(ii) How long have you lived in this area?..

(ii) Before coming to this place where were you living?..

6. (i) Are any of the children going to school this year?

Boys: { } No **=2** { } Yes =**1** → Total Number: ………

Girls: { } No **=2** { } Yes =**1** → Total Number: ………

8. Does anyone in this household own:

(a). an operational radio? { } No **=2** { } Yes **=1**

(b). a bicycle? { } No **=2** { } Yes**=1**

(c). a Television { } No **=2** { } Yes**=1**

(d). a car? { } No **=2** { } Yes**=1**

9. (i) Roofing of main house (Observation by Enumerator)

(a) Grass thatched =**1** { }
(b) Corrugated iron Sheets =**2** { }
(c) Other =**3** { } Specify ………….

(ii) Walls of main house (Observation by Enumerator)

(a) Burnt brick with plaster =**1** { }
(b) Burnt brick without plaster =**2** { }
(c) Sun dried bricks with plaster =**3** { }
(d) Mud and poles =**4** { }
(e) Plastic/corrugated paper =**5** { }

(iii) Floor of main house (Observation by Enumerator)

(a) Cemented =**1** { } (b) Earth =**2** { }

B. HOUSEHOLD INCOME

10.(i) Household cash income: What is the average earning per month ?

1. Below MK 5,000.00 ( )

2. Between MK 5,000.00 and MK 10,000.00 ( )

3. Between MK 10,000.00 and MK15,000.00 ( )
4. Between MK15,000.00 and MK20,000.00 ( )
5. Over MK 20,000.00 ( )

(ii) How much did the household earn during the last 12 months?

Item	**Description of Income source**	**Amount of money earned MK**
(a)	Employment	
(b)	Agriculture	
(c)	Small Business	
(d)	Large Business	
(e)	Pensions	
(f)	Transfers	
(g)	Piece work /Ganyu	
(h)	Rents	
(i)	Others	
TOTAL		

Total cash income of this household:……..………………..…

11. What income generating assets do you have?

(a)	Business (large)	=1 { }
(b)	Business (small)	=2 { }
(c)	Livestock	=3 { }
(d)	Agricultural Produce stocks	=4 { }
(e)	Rent	=5 { }
(f)	Other	= 6 { }

C. EXPENDITURE:

12. How much money does the household spend per month on the following?

Item	**Description of Expenditure**	**Amount per Month**
(a)	Water	
(b)	Electricity	
(c)	House Rent	
(e)	Food	
(f)	School fees	
(g)	Clothing	
(h)	Medical costs	
(i)	Farming	
(j)	Groceries	
(k)	Other	

Total expenditure of this household per month…………………………….

D. Water Situation

13. What is the main source of water for your household at present for:

Usage	**Source at present** (codes provided below)	**Round trip time (min)**
(a) Drinking		
(b) Cooking		
(c) Clothes washing		
(d) Bathing		
(e)Utensil washing		
(f) Gardening/Lawns		
(g) Livestock watering		

Codes	**Source**
1	Piped individual connection own (a) Yard tap (b) In house connection
2	Piped connection Neighbour's
3	Piped Communal Water point
4	Borehole with hand pump
5	Shallow well protected
6	Shallow well unprotected
7	River/Stream

14. For your source of water supply, what's your assessment on:

	Parameter	**Code** (Provided below)
a	Taste	
b	Clarity	
c	Reliability	
d	Affordability	
e	Safety	
f	Accessibility	
g	Smell	

Code	**Level**
1	Excellent
2	Very good
3	Good
4	Poor
5	Very poor

15. Are there any immediate plans for you to change your present water source

(a) Yes **1** { } (b) No **2** { }; If yes indicate the new source…………………….

16. *If your household uses water from CRWB (codes 1- 3, under No. 13) how many hours of the day do you receive water on average?

1. 1 – 4 hours { } 4. 13 – 16 hours{ }
2. 5 – 8 hours { } 5. 17- 20 hours{ }
3. 9 – 12 hours { } 6. 21 – 24 hours{ }

17. If your household uses water from CRWB (codes 1- 3, under No. 13) what is your assessment of the water supply pressure?

1. Excellent { }
2. Very Good { }
3. Good { }
4. Poor { }
5. Very poor { }

18. If your household uses water from CRWB (codes 1- 3, under No. 13) what time(s) of the day when you experience low pressure on your tap?

1. 5.00 am – 7.00 am { } 4. 2.00 pm – 4.00 pm { }
2. 8.00 am – 10.00 am { } 5. 5.00 pm – 7.00 pm { }
3. 11.00 am – 1.00 pm { }

19. How do you rate the price of water supplied by CRWB?

1. Very expensive { }
2. Expensive { }
3. Fair { }
4. Low { }
5. Very low { }

20. (i) What is your willingness to have a different connection from the one in use?

Highly =**1** { } Average =**2** { } Lowly =**3** { }

(ii) Are you willing to pay for a new tariff? Yes =**1** { } No=**2** { }

(iii) If yes, how much money in cash would you be willing to pay?

MK…………………

Pail/day: .... l/day :.........................

21. (i) Is the water tap shared? (a) Yes **1** { } (b) No **2 {** }

(ii) How much do the other users contribute monthly?..................................

(iii) Do you struggle for people to make their contribution ? Yes =**1** { } No =**2** { }

22. Have you ever lodged a complaint to CRWB regarding the supply of water service?

Yes = 1{ } No = 2 { }

23. If yes, what is your assessment on CRWB's capacity to handle customer complaints?

1. Excellent { }
2. Very Good { }
3. Good { }
4. Poor { }
5. Very poor { }

24. What comments do you have on payment scheme for your water supply?

	Too High	High	Just Affordable	Very Affordable
Initial connection				
Regular bill payment				

The following questions should not be asked for where there is an in house connection

25. (i). What is the distance to the source of drinking water (tap or CWP)?

(estimate):

*(a) less than 100 metres=**1**{ }, (b) 100 – 500 metres=**2**{ }, (c) Over 500 metre =**3**{ }

(ii). What is the estimated time for the round trip to the water point?

*(a) Less than 30 Minutes =**1** { } (b) 30 minutes-1 hour =**2** { }

(c) more than 1 hour + =**3** { }

26. (i). How much water do you collect per day?

(estimate volume and number of containers used per day):

Volume of container:……………… Number of containers used per day……..……

(ii) How many containers of water did you draw yesterday?

Indicate total number and volume of each container: …………..……………..

Calculate:

Total volume of water: …………………….

Number of household members: ……} → volume of water per person: ………… litres

27. Do you or someone else in this household, use water for purposes other than drinking, cooking, bathing and washing clothes?

(a) Beer brewing **=1** { } (d) Watering lawns =**4** { }

(b) Brick making =**2** { } (e) Watering cattle and other animals =**5** { }

(c) Irrigation **=3** { } (f) Others specify:…………..….

28. (i) In case of water shortage, where do you get water for your domestic use?

Code	**Source**	**Response**
1	Borehole with hand pump	
2	Shallow well protected	
3	Shallow well unprotected	
4	River/Stream	
5	Other: state	

(ii) How do you assess the condition of water from this source in terms of :

	Parameter	**Code** (Provided below)
a	Taste	
b	Clarity	
c	Reliability	
d	Affordability	
e	Safety	
f	Accessibility	
g	Smell	

Code	Level
1	Excellent
2	Very good
3	Good
4	Poor
5	Very poor

29. Are there any activities you don't do now due to lack of water?

(i) No =**2**{ }

(ii) Yes =**1** { }

Name the activities……………………………….…

Give estimated volume of water needed for these activities:……………………… (l/day)

30. If you are using water from other sources, would you like to be connected to piped water?

(a) Yes = **1** { } (b) No **2 =** { }

31. **If yes on question 30**

(i) Which type of connection would you prefer?

(a) Individual Connection =**1** {In house }, { Yard tap}

(b) Communal Water Point =**2** { }

(ii) If you prefer Individual Connection, how much would you be prepared to pay per month for water use? ……………………….

(iii) If you prefer Communal Water Point, how much would you be prepared to pay per month for water use?.......................................

E. SANITATION

32. Do you have a latrine?

{a} Yes **=1** { } {b} No **=2** { }

If Yes,

33. Type of latrine:{a} Traditional pit latrine **=1** { }

{b} Improved pit latrine: **=2** { }

{c} Waterborne (septic tank) **= 3** { }

34. Which of the following sanitary facilities do you have?

(a) Dish rack =**1** { } (b) Rubbish pit **=2** { } (c) Clothes line =**3** { }

(d) Kitchen =**4** { } (e) Bath shelter =**5** { } (f) none =**6** { }

35. In your opinion, what are the most common water diseases in this area?

(a) Malaria **=1** { } (b) Cholera =**2** { } (c) Diarrhoea =**3** { }

(d) Dysentery =**4** { }

(h) Bilharzia = **5** { }

(i) Others (specify) = **6**……………………….

(ii). Do you have any ideas/suggestions on how these diseases could be prevented?

(a) Dinking safe water **=1** { } (c) Using treated mosquito nets **=3** { }
(b) Cleanliness **=2** { } (d) Others **=4** { }

END

THANK YOU FOR YOUR COOPERATION