UNIVERSITY OF ZIMBABWE

Partitioning of Unaccounted for Water for Zomba City Water Supply System in Malawi

By

Jessy Alida Chipwaila

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

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Supervisor

Eng. Z. Hoko

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DECLARATION

I, **Jessy Alida Chipwaila,** do hereby declare to the Senate of the University of Zimbabwe that this product is of my own investigation except where acknowledged.

This work has not been presented previously for any degree or similar award to this university or any other university.

Signed……………………………………………………………..

Date………………………………………………………………..

ABSTRACT

Urban water supply utilities in developing countries are faced with challenges of low service coverage and high unaccounted for water (UFW). UFW reduces the water available to customers, and results in loss of revenue for the water utility. In Southern Africa, UFW ranges from 11% to 60% and in Malawi it is between 28% and 48%. Zomba has UFW of 30%. Most studies on UFW have not focussed on its partitioning into real and apparent loss components. Crude UFW does not allow the water utility to identify appropriate priority areas and actions for UFW reduction. It is against this background that a study was carried out on the Zomba City water supply system to partition UFW. The water supply system is owned and operated by Southern Region Water Board (SRWB). The study analysed UFW, partitioned it into its components and assessed major factors affecting the components. Four water supply zones (Airwing, Malonje, Sadzi and Mtiya) were selected based on their unique characteristics. Historical data on water production and consumption were used to assess overall UFW. Bulk meter readings for each zone were taken for three months alongside the corresponding consumptions. Flow and pressure loggers were installed to obtain Minimum Night Flows (MNF) and assess pressures respectively. Water balances were carried out. Meter inaccuracy tests were also carried out to assess the impact of meter errors on apparent losses. Records of pipe bursts, faulty meters and queries on high bills were also used in the study. The average UFW from 1999 to 2008 was estimated to be 27.5% of which real losses represented 71% while apparent losses were 29%. The average UFW for the four study zones was 13% for Airwing, 62% for Malonje, 51% for Sadzi and 6% for Mtiya. Real losses in Airwing estimated at 73% of UFW, Malonje had 75%, Sadzi had 40% and Mtiya had 23% as real losses. The remaining percentages represented apparent losses for each study site. It was also established that real losses in Airwing were due to pipe bursts mainly as a result of pipe age while in Malonje and Sadzi; the real losses were affected by bursts due to pipe age and high pressures. It was found out that more than 58% of the pipe network in the whole distribution system was over 60 years old. Malonje and Sadzi areas had operational pressures above 50 m and experienced frequent pipe bursts. It was also found out that 53% of customer meters tested were over 5 years old. Meter inaccuracy tests also showed that all the meters under-registered and that 46% of the meter errors were above the allowable tolerance of -5% at low flow rates and -2% at high flow rates. It was concluded that the average unaccounted for water was above the 20% recommended for Southern African urban water supplies. Partitioning of UFW showed that different areas had different levels of real and apparent losses and gave a hint on UFW components hence is an important tool towards proper planning of priority areas in UFW control strategies. Real losses in Airwing were affected by distribution network age, while in Malonje this was affected by pressure and distribution network age. Sadzi had a high level of apparent losses as the number of connections in the zone was very high. It is recommended that routine water audits be done for the other remaining areas to come up with a comprehensive UFW control strategy. It is also recommended that feasibility of pressure management for UFW reduction be investigated in Malonje area. Distribution network replacement is recommended in Airwing. UFW control strategy for Sadzi should focus more on reducing the high levels of apparent losses.

DEDICATION

To my beloved parents: Beatwel and Margaret Chipwaila

You suffered for my JOY and I know you are proud of me!

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LIST OF ACRONYMS

AWWA	American Water Works Association
BL	Background Leakage
DMA	District Metered Area
ESIA	Environmental and Socio Impact Assessment
GI	Galvanised Iron
ICTR	Institute of Corporate Training and Research
ILI	Infrastructure Leakage Index
ISO	International Organization for Standardization
IWA	International Water Association
IWRM	Integrated Water Resources Management
MBF	Mains Break Frequency
MNF	Minimum Night Flow
MWD	Ministry of Water Development
NNF	Net Night Flow
NRW	Non Revenue Water
NSO	National Statistical Office
NWDP	National water Development Programme
OFWAT	Office of Water Services
PI	Performance Indicator
PVC	Poly Vinyl Chloride
SADC	Southern Africa Development Community
SANFLOW	South African Night Flow Analysis
SIDA	Swedish International Development Agency
SRWB	Southern Region Water Board
TIRL	Technical Indicator for Real Losses
TWL	Top Water Level
UARL	Unavoidable Annual Real Loses
UFW	Unaccounted For Water
UNEP	United Nations Environmental Programme
UNIMA	University of Malawi
WDM	Water Demand Management
ZDA	Zomba District Assembly
ZMA	Zone Metered Area

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

In the year 2000, about 1.16 billion people had no access to improved water sources and double as much (2.36 billion people) had no access to adequate sanitation worldwide (UNDP, 2003). According to UNDP (2003), Sub-Saharan Africa accounts for about 23% of the global total population without access to improved water sources. The Millennium Development Goals (MDGs) recognize that access to safe water is crucial for survival and aim to halve the proportion of people without sustainable access to safe drinking water by 2015 (UNDP, 2003). According to Baietti *et al.* (2006), the challenge to provide adequate safe drinking water and improved sanitation require well performing water utilities. For many years more than 90% of urban water supply and sanitation services in developing countries have been provided by state-owned, monolithic water organizations also known as public water utilities (Ndokosho *et al.*, 2007). As part of a general move to market oriented systems in the 1980s and 1990s, a new paradigm emerged to transform utilities into more modern service delivery organizations that emphasize operational and financial sustainability (Baietti *et al.*, 2006).

In many developing countries public water service providers have failed to provide consumers with adequate water supply and sanitation services (Baietti *et al.*, 2006). Apart from the problems of service coverage of less than 60%, other problems that are faced by water utilities in these developing countries include overstaffing and high unaccounted for water (UFW), which often averages between 40%-60% (Baietti *et al.*, 2006; Schwartz, 2008). According to Balkaran and Wyke (2002), UFW is between 15% and 30% in the developed world but elsewhere it is more likely to be in the 30% to 60% range. Moreover, the service providers in developing countries are often confronted with financial problems due to a combination of low tariffs, poor consumer records and inefficient billing and collection practices (Schwartz and van Dijk, 2007). As a result, the quality of water services that is actually delivered to the consumer, if they are connected at all, is low (Schwartz, 2006). The public water utilities, which are likely to remain responsible for service provision for many years to come do not have satisfactory performance and provide inadequate services to their customers (Schwartz, 2006).

Unaccounted for water (UFW) often constitutes a major problem in water supply, representing considerable loss in revenues, creating excessive production and reducing the available water to customers (SIDA, 2000). According to Schwartz (2008), high levels of unaccounted for water indicate inefficiency on the side of a water utility as UFW is a crude measure of the utility's performance. According to Yepes and Dianderas (1996), the level of UFW is considered a good proxy for the overall efficiency of operations of a water utility. Tynan and Kingdom (2002) indicate that a crude measure of asset maintenance is unaccounted for water. The measure captures not only physical losses but also commercial losses, due to inefficient billing or illegal connections. Thus according to Tynan and Kingdom (2002), high levels of unaccounted for water indicate poor system management and poor commercial practices as well as inadequate pipeline maintenance. This agrees with assertions by Yepes and Dianderas (1996) and Schwartz

(2008). The World Bank recommends a UFW of 23% (Tynan and Kingdom, 2002) in developing countries, while 20% was set for well performing urban water utilities in Southern African region (Gumbo, 2004).

With the increasing international trend towards sustainability, economic efficiency and protection of the environment (Savenije & Van der Zaag, 2002), the problem of losses from water supply systems is of major interest world-wide (Lambert and Hirner, 2000). Both the technical and the financial aspects are receiving increasing attention, especially during water shortage or periods of rapid development. One of the Integrated Water Resources Management (IWRM) three key policy principles is efficiency which states that water is a scarce resource hence should be used efficiently. Therefore assessment and control of UFW is a major component towards achieving efficient use of water. According to Savenije & Van der Zaag (2003), UFW control ensures sustainability of infrastructure (sustainable development), postponement of investment and availability of water to other new customers; this supports the equity principle. UFW assessment and control aims to achieve desirable consumption patterns, both in terms of distribution among sectors and quantities consumed, coupled with an increased reliability of supply (Savenije & Van der Zaag, 2003). This agrees with Lambert and Hirner (2000) who indicate that water loss control is a key to improved water demand management.

In most of the water supply systems in Southern Africa, reliable estimates of water loss components are not available (Farley, 2001). Since UFW occurs as both real and apparent losses; reporting a crude figure of UFW makes it difficult to establish areas of priority when it comes to UFW management. Southern Region Water Board presents unaccounted for water as a crude figure (SRWB, 2008a). The utility does not have the quantification of real and apparent losses. It is against this background that the study was carried out to partition UFW into real and apparent loss components in Zomba City water supply system. The water supply system is owned and operated by the SRWB.

Urban and peri-urban water services in Malawi are provided by water boards. The Regional Water Boards inherited very old and inefficient water supply facilities from the District Water Supply Fund which was formerly responsible for supplying water in small urban areas in Malawi (Mulwafu *et al.*, 2002). In Zomba City, the old facilities are responsible for high losses of water through leakage. The poor conditions of the old pipelines result in frequent pipe bursts (SRWB, 2009). There are also issues of faulty meters and problems of uneven pressure in the water supply systems that can cause pipe bursts. Management of unaccounted for water in the distribution system will improve service delivery, as some of the areas in the city are currently experiencing water shortages (SRWB, 2009).

The study was carried out in the four specific zones which were Airwing, Malonje, Mtiya and Sadzi. All these zones have individual water connections but very few connections in Mtiya and Sadzi are communal water points (CWPs). The entire Zomba City has a total of 79 CWPs (SRWB, 2009). Approximately 70% of the study areas are traditional and high density areas whereby those connected to SRWB water supply have single taps. The other percentage has multiple in-house taps. Malonje is reported to have high level of reported problems which include pipe bursts and water shortages (SRWB, 2009) and 40% of the population relies on boreholes, indicating low coverage and water supply inefficiencies by SRWB. From the socio-economic survey done by SRWB (2009) it was reviewed that Malonje, Mtiya and Sadzi had low coverage of piped water supply of 65%.

1.2 Problem statement

Many water utilities have managed to quantify their total unaccounted for water (UFW). Urban water supply systems in Southern Africa have UFW ranging from 11 to 60% and in Malawi, the unaccounted for water ranges between 28% and 48% (World Bank, 2007). Unaccounted for water for Zomba City is at 30% (SRWB, 2008a). In most of the water supply systems in Southern Africa, reliable estimates of water loss components are not available (Farley, 2001). A crude figure of UFW which is reported by many water utilities does not give the water utility clues to prioritise and schedule on the operations and management of the system (Kingdom *et al.*, 2006). It is for this reason that a study was carried out in Zomba City water supply area, to partition unaccounted for water, into real and apparent losses; and to establish the major contributing factors to the current water losses in the system.

1.3 Justification

The UFW for Zomba city is currently high at around 30% (SRWB, 2009), and the SRWB aim to reduce this to 20% by 2020. Almost 58% of the distribution mains are old network and the poor conditions of the old pipelines result in frequent pipe bursts as reported by SRWB (2009). Management of unaccounted for water in the distribution system will improve on water demand management, as some of the areas in the city such as some parts of Malonje and Mtiya are currently experiencing water shortages (SRWB, 2009). Identification of priority areas and effectiveness on the UFW reduction can be achieved if water audits and UFW partitioning are carried out.

According to Liemberger (2002), real and apparent losses have to be quantified. No proper unaccounted for water reduction strategy can be planned without the quantification of physical and apparent (commercial) losses (Kingdom et al., 2006). When the magnitude of all components is known it is possible to forecast potential savings (real losses) and potential revenue increase (apparent losses), develop real and apparent loss reduction strategies and set realistic targets (Liemberger, 2002). Thus breaking down unaccounted for water may assist the water utility to improve knowledge and documentation of the distribution system including problem and risk areas. The breakdown and hence the water audit also becomes a valuable tool to manage resources, by getting a better understanding of what is happening to the water after it leaves the treatment plant. Thornton (2002) indicates that water loss reduction programmes lead to reduced water losses, financial improvement, increased knowledge of the distribution system, more efficient use of existing supplies, safeguarding public health and property, improved public relations, reduced legal liability, and reduced disruption of water supply to customers.

1.4 Objectives

1.4.1 Main objective

- The main objective of the study was to assess and partition unaccounted for water into real and apparent losses for Zomba City water supply system and to analyse system characteristics in order to predict UFW trends for better operation and management of the water system.

1.4.2 Specific Objectives

The specific objectives of the study were:

- To establish the trends of unaccounted for water for Zomba city from 1999 to 2008.
- To establish unaccounted for water in selected parts of the Zomba City water supply area, partition it into real and apparent losses and further assess the revenue loss due to the unaccounted for water in the system
- To analyse system characteristics such as pressure, pipe age, bursts, meter inaccuracy, tank overflows; and identify the most significant ones with respect to UFW in the area.
- To develop relationships that will describe and predict the unaccounted for water with respect to system characteristics for better operation and management of the water system.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

Most of the water on the earth, some 97%, is contained in the world's oceans and is therefore not for essential agriculture, drinking, or most industrial uses (Butts, 1997). Moreover only 0.36% of the world's water in rivers, lakes, and swamps is sufficiently accessible to be considered a renewable fresh water resource (Butts, 1997). The supplies of useful fresh water are finite, and most of the forms in which it is used have no substitute. In 2000 a global population of 1.16 billion people lacked adequate potable water supply (UNDP, 2003). Water constitutes a worldwide challenge for the 21st century, both in terms of the management of available water resources and the provision of access to drinking water and sanitation for the world's population (UNDP, 2003; SADC, 2005). Projections of population, water demand, and water development indicate that by 2025 some countries in the Southern African region will experience water quality and quantity problems in the dry season and others will experience "water stress" (SADC, 2005). Malawi and South Africa will experience "absolute scarcity" where the fresh water resources distribution will be less than 1000 l/capita/yr (UNEP, 1999; SADC, 2005). It can be deduced that water shortage and scarcity has now become a global concern and poor management of water resources can exacerbates its unavailability.

An essential component of water demand for public water supply may be the losses in transport, treatment and distribution systems normally known as unaccounted for water (ICTR, 2005). ICTR (2005) suggests that UFW may reach levels of 60% in old and deteriorated systems. According to Balkaran and Wyke (2002) unaccounted for water (UFW) also known as water losses, is between 15% and 30% in the developed world but elsewhere it is more likely to be in the range of 30% to 60%. UFW in the range of 40% to 60 % is far often the case in urban distribution systems in the developing world (SIDA, 2000; Baietti *et al.,* 2006; Schwartz, 2008). In Malawi unaccounted for water ranges between 28% and 48% (World Bank, 2007). UFW in most developing urban water utilities is very high compared to the international standards set. Van der Zaag (2003) states that the normal percentages for unaccounted for water in the system are from 15% to 25%, including a 5% 'loss' in the treatment plants and SIDA (2000) reports that UFW in the range of up to 15% to 20% of the produced quantity is often a realistic and sustainable level for developing countries. Public water utilities have a duty to ensure UFW control in order to achieve sustainable and efficient water supply systems.

According to SIDA (2000) unaccounted for water through leaking pipes, overflows from tanks, illegal connections, metering errors and non-metered uses in the water production, poor plumbing and other faults in the system very often constitutes a major problem in water supply resulting in considerable loss in revenues and excessive production. SIDA (2000) states that comprehensive water loss control programmes are often priority issues in urban water supply rehabilitation and improvement projects. Contrary to this, Schwartz (2008) indicated that operation and maintenance in water supply has a low, and usually an inferior profile as compared to new construction and system extension. According to Schwartz (2008), while water utilities get funding for new construction; little money and attention is given for operations and asset maintenance. The challenge is that unaccounted for water may exceed one quarter of the water put into supply, and according to Balkaran and Wyke (2002) this can represent a substantial financial loss to any water undertaking. It is suggested therefore that water demand management (WDM) with improvements to the existing water supply systems should be pursued before construction of new and costly systems are undertaken. UFW assessment and control in a water utility is important as there are considerable reduction in water shortages, improvement in revenue and postponement of major infrastructure investment on water supply system. Thus as one of the major WDM tools UFW control needs to be pursued.

2.2 Unaccounted for Water

Unaccounted for water is the difference between the amount of water produced, or purchased, and the amount of water sold to all customers (Johnson, 1996). UFW includes underground leakage; unauthorized use; unavoidable leakage, inaccurate master, industrial, commercial and domestic meters and unusual causes (Johnson, 1996). According to Johnson (1996), unusual causes include one of the following: recirculating water, that is, water pumped into a pressure zone with an open valve which allows the water to recirculate without being consumed; not accounting for treatment plant use; estimated pumping rate due to inaccurate or non-existent meters; leakage in reservoirs, ground storage tanks or elevated storage tanks; and unintentional inter-system connections where water passing through is unrecorded or there are emergency connections to other distribution systems. There are different definitions and words to describe unaccounted for water which mostly confuse the readers. According to Thornton (2002) the problems of water and revenue losses are divided into three. There are technical problems where not all water supplied by a water utility reaches the customer; financial problems where not all of the water that reaches the end user is properly measured or paid for and terminological problems where standardized definitions of water and revenue loses are lacking (Thornton, 2002). Johnson's definition of unaccounted for water did not break it down into its categories. Based on the International Water Association (IWA), there are two major categories under which all types of supplier loss occurrences fall (Lambert and Hirner, 2000). These are real and apparent losses. Real losses are physical escape of water from the distribution system, and include leakage and overflows prior to the point of end use (Lambert and Hirner, 2000). This can be synonymous with technical problems of water and revenue losses as presented by Thornton (2002). Apparent losses are essentially losses consisting of customer use which is not recorded due to metering error, incorrect assumptions of unmeasured consumption and water theft (Fanner, 2004) and this definition is similar to the financial problems of water and revenue losses as described by Thornton (2002). Unaccounted for water should be broken down into its components to ease their assessment and reduction.

According to KWA (2002) a high percentage of unaccounted for water in a public water utility may arise when the utility has:

- ❖ Inaccurately estimated the amount of water pumped or purchased due to no metering of all water at the intake source or by using raw water or finished water meters that are inaccurate or improperly installed;

- Inaccurate customer meters;
- Bookkeeping errors;
- Non-metered uses such as water used in the treatment process, city buildings, churches, watering a golf course;
- Water leaks.

Table 2-1 gives the IWA standard water balance which just like in financial cash balance analysis and auditing, is where the amount of water put into distribution is compared with the sum of the components of water consumed or used (Farley, 2001). Further to this table are the steps used to calculate the components of the water balance and are presented after Table 2-1.

Table 2-1: The IWA 'best practice' standard water balance

1	2	3	4	5	6	7
Own Sources	Corrected System Input Volume	Water Export	Authorized Consumption	Billed Authorized Consumption	Billed Water Exported	Revenue Water
		Water Supply			Billed Metered Consumption	
					Billed Un-metered Consumption	
				Unbilled Authorized Consumption	Unbilled Metered Consumption	Non-Revenue Water (NRW)
Water Imported					Unbilled Un-metered Consumption	
			Water Losses (UFW)	Apparent Losses	Unauthorized Consumption	
					Customer Metering Inaccuracies and Data Handling Errors	
				Real Losses	Leakage on Transmission and/or Distribution Mains	
					Leakage and Overflows at Utility's Storage Tanks	
					Leakage on Service Connections up to point of Customer metering	

(Adopted from Fanner, 2004)

- Steps for calculating non-revenue water and water losses *(adopted from Lambert and Hirner, 2000).*

The following steps are used to obtain components of the water balance, which at the end enable the water utility to calculate its water losses and non-revenue water. The steps refer to Table 2-1 above which has seven (7) columns.

- Step 1: Define sources of water and enter in Col. 1.

- Step 2: Define corrected *System Input Volume* as sum of Col 1 and enter in Col. 2. Col. 3 represents total water diverted by the water utility and this can either be exported to other water utility or can be supplied to the utility's customers.

- Step 3: Define *Billed Metered Consumption, Billed Unmetered Consumption and Billed water exported* in Col. 6; enter total in *Billed Authorised Consumption* (Col. 5) and *Revenue Water* (Col. 7).

- Step 4: Calculate the volume of *Non-Revenue Water* (Col. 7) as corrected *System Input Volume* (Col. 2) minus *Revenue Water* (Col. 7).

- Step 5: Define *Unbilled Metered Consumption* and *Unbilled Unmetered Consumption* in Col. 6*;* transfer total to *Unbilled Authorised Consumption* in Col. 5.

- Step 6: Add volumes of *Billed Authorised Consumption* and *Unbilled Authorised Consumption* in Col. C; enter sum as *Authorised Consumption* (top of Col. 4).

- Step 7: Calculate *Water Losses* (Col. 4) as the difference between corrected *System Input Volume* (Col. 2) and *Authorised Consumption* (Col. 4).

- Step 8: Assess components of *Unauthorised Consumption* and *Metering Inaccuracies and data handling errors* (Col. 6) by best means available, add these and enter sum in *Apparent Losses* (Col. 5).

- Step 9: Calculate *Real Losses* (Col. 5) as *Water Losses* (Col. 4) minus *Apparent Losses* (Col. 5).

- Step 10: Assess components of real losses (Col. 6) by best means available (night flow analysis, burst frequency/flow rate/duration calculations, modelling etc), add these and cross-check with volume of *Real Losses* in Col. 5 which was derived from Step 9.

From Table 2-1, the difference between non-revenue water and water losses can be seen in that non-revenue water represents unbilled authorized consumption, apparent losses and real losses while water loss or unaccounted for water represents apparent and real losses. The UFW can be considered as a total volume for the whole system, or for partial systems such as raw water mains, transmission or distribution (Lambert and Hirner, 2000). And where UFW analysis is carried out for the distribution network or zone, it is referred to distribution losses (Lambert and Hirner, 2000). In each case the components of the calculation would be adjusted accordingly. There are many causes of UFW in the water supply system and each cause may contribute differently to UFW. For successful control of UFW, all the technical, financial and terminological aspects of UFW need to be understood by the water utility. This includes assessment of UFW using the IWA standard water balance.

2.3 Components of Unaccounted for Water

UFW is broken down into two main components which are real (physical) losses and apparent (commercial) losses (Yepes and Dianderas, 1996). A few methodologies have been developed to assess the unaccounted for water in water distribution systems, however most of them just concentrate on the real losses concept, and have no emphasis on the apparent losses, which is so important in most undeveloped and developing countries (Tabesh and Asadiani Yekta, 2005). In most cases, unaccounted for water is presented as a crude figure that is, it is not broken down into its components. For instance, for well performing water utilities, the World Bank set 23% as unaccounted for water in developing countries (Tynan and Kingdom, 2002). Baietti *et al.*, (2006) listed levels of unaccounted for water and circumstances which give rise to such losses without stating how much constitutes real or apparent loss components. This indicates that most of the studies done do not further on to partition UFW. Contrary to this, some water utilities like those in South Africa have calculated components of non-revenue water, apparent losses and real losses using the standard annual water balance and have further developed software tools to enable reduction of UFW (Mckenzie *et al.*, 2002b). Unaccounted for water is a problem for all water utilities (Balkaran and Wyke, 2002) and the need to know the causes and quantities of the various components of UFW is obvious and has to be emphasized (Kingdom *et al.,* 2006). Table 2-2 presents the composition of UFW for some selected cities as reported by Yepes and Dianderas (1996).

Table 2-2: Composition of UFW

Country/City	Year	Physical (%)	Commercial (%)	Total (%)
Singapore	1989	4	7	11
Spain, Barcelona	1988	11	12	23
Colombia, Bogota	1991	14	26	40
Costa Rica, San Jose	1990	21	25	46

(Source: Yepes and Dianderas, 1996)

The table suggests that the issue of UFW partitioning, although has been taken up by few water utilities, is not new; for example, the table shows that Singapore partitioned UFW in 1989. Therefore UFW partitioning should not be taken as a new subject. Yepes and Dianderas (1996) presented unaccounted for water in terms of its two components. From Table 2-2, it can be seen that each of the two components contribute significantly to UFW, contrary to the common assumption that real losses are always greater than apparent losses. Farley (2001) indicates that the studies of Vietnamese water companies established that around two-thirds of losses are due to non-physical losses (apparent losses) and one-third are due to physical losses. Real losses in the system may dominate if that system has old distribution pipelines which can no longer withstand high pressures and experience a lot of bursts and leaks. Unavailability of customer cadastre, reluctance on meter repairs and poor accountability to customers may lead to high levels of apparent losses. Thus presenting unaccounted for water as a crude figure may not enable the water utility visualise how each component is contributing to total UFW and hence may not be able to narrow down to areas of priority during unaccounted for water control programmes.

2.4 Apparent losses

Apparent losses (AL) consist of unauthorized consumption (theft or illegal use), and all types of inaccuracies associated with production metering and customer metering (Lambert and Hirner, 2000; Tabesh and Asadiani Yekta, 2005). Apparent water losses can be perceived as occurring in three primary ways (Lambert and Hirner, 2000). According to Lambert and Hirner (2000) these losses occur as a result of errors in water flow measurement, errors in water accounting and unauthorised usage or theft. They are related to management losses resulting in a shortfall of revenue for water supplied (Farley, 2001). Because this water was available for sale, these losses are incurred at retail rate (Tabesh and Asadiani Yekta, 2005). Under-registration of production meters and over-registration of customer meters lead to under-estimation of real losses; and over-registration of production meters and under-registration of customer meters, lead to over-estimation of real losses (Lambert and Hirner, 2000). Hence an inappropriate assessment of apparent losses often results in real losses being overstated in the water audit, potentially misguiding water loss optimisation planning by placing inordinate emphasis on leakage while potential revenue recovery goes unattended (Thornton, 2002). This reveals that assessment of apparent losses has a direct impact of real losses and therefore it is important to pay attention to both components of unaccounted for water.

Further to the IWA standard water balance in Table 2-1, apparent losses are broken down into four component errors (IWA, 2008). There are losses due to under-metering which refers to the errors generated by the water meters themselves or by the management of the water meters where the meter does not completely register the volume passing through them (Rizzo *et al.,* 2004). For unmetered customers, estimation of unmetered consumption also generates errors. This is a very important component for systems that are not fully metered (Rizzo *et al.,* 2004; IWA, 2008). Unauthorised consumption is another component of apparent losses which refers to unregistered water connection and any kind of frauds or malpractice (Tabesh and Asadiani Yekta, 2005). According to Rizzo *et al. (*2004), unauthorised consumption comprises theft and any form of illegal consumption. The fourth error component of apparent losses is linked to data acquisition system which, according to IWA (2008), refers to the errors that may be generated at the various stages of the data acquisition process such as data capture (meter readings and computer system data entry), transmittal, processing, manipulation etc. According to Rizzo *et al*., (2004) data acquisition errors are data transfer errors between meter and billing system and data analysis between archived. Assessment of apparent losses is therefore supposed to target these four components. Consequent to the four categories of apparent losses, there are four categories of actions, as presented in Fig. 2-1 that can be implemented to get the apparent losses under control (Thornton, 2005).

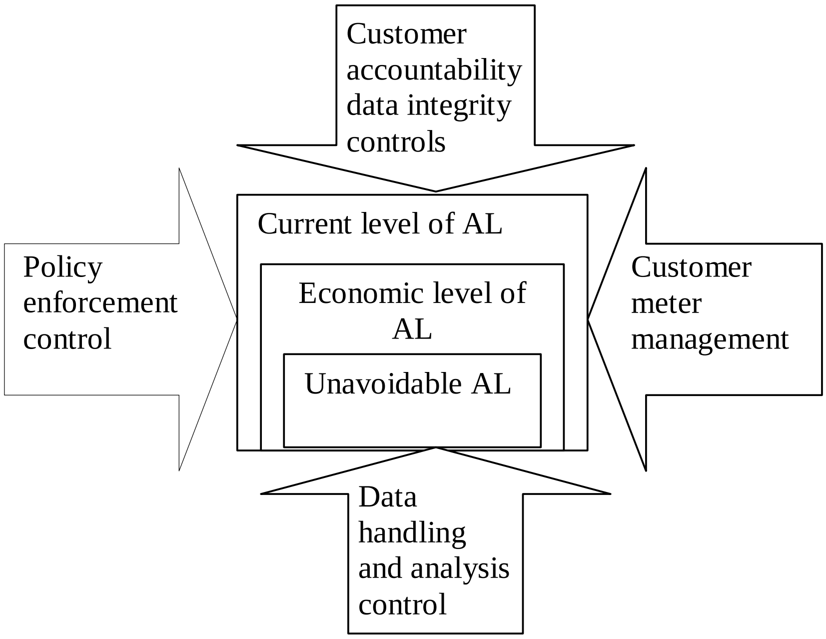


Fig. 2-1: Components of a proactive apparent loss management program

(Adopted from Rizzo et al., 2004)

The level of apparent loss may increase or decrease depending on the level of control of each category of loss. One of the major characteristic of the apparent losses is that they can be positive or negative (IWA, 2008). For instance a water meter may over-register in some specific conditions; and a non-metered consumption can be overestimated (IWA, 2008). Working on the four reduction strategies presented in Fig. 2-1 is a key to reduced apparent losses.

2.4.1 Assessment of Apparent Losses

There are various factors affecting apparent losses as discussed in the previous section and these can be assessed in different ways. The proceeding discussion looks at ways of determining their quantities which can later be used in the water balance analysis.

- Under-registration by customers' meters

This concept reflects the fact that the water metering devices do not actually display an exact readout of the water volume that passes through them (Sánchez, 2007). This is influenced by several factors. Customer meters tend to under-register as a result of meter aging, inappropriate meter installation, inappropriate sizing and impacts of customers' in-house installation. Meter mismanagement also result in meter under-registering or errors. This includes errors in meter reading, invented meter reading and when the meter is out of operation (IWA, 2008).

Meters that under-register can be estimated from a sample survey (Sánchez, 2007). Accurate ‘C’ or ‘D’ class meters, may be temporarily installed in line with the customer’s meter, as check meters to compare the volume flows. A meter test bench which has an inbuilt calibrated meter can also be used if available (IWA, 2008). Other organizations have used a 200 l calibrated drum and checked the accuracy of the meter under test by filling the drum to a mark of 200 l, and reading the volume that has passed through the meter. The volume which is lost due to under-registration in the surveyed area is calculated and extrapolated. According to Sánchez (2007) calculation of metering errors is solely executed in accordance to the age of the metering device. Inaccuracy is determined for each metering device in a % over its readout, based on the age of the device counted since the date of its installation. The error percentage, which is then multiplied by the recorded amount (metered billed and/or metered unbilled in the period of analysis), is assigned to the meters per linear distribution (Sánchez, 2007).

- Meter Error Curve

Meter inaccuracy depends on the flow rate at which the meter is being used (IWA, 2008). Studies have reviewed that residential consumption typically occurs at 5, 15, and 80 percent for low, medium, and high flows, respectively. A study carried out in Detroit Water and Sewage Department (DWSD, 2004) concluded that 15- to 20-year-old all-brass meters (no longer manufactured) have an overall accuracy of 98.5 to 99% while 15-year-old meters with plastic drives have tested out at 95% accuracy. In another study, in Australia, DWSD (2004) indicated that 6% of the water delivered to 11,000 residential properties was not measured due to inaccuracy in the flow meters, but nothing is mentioned in regarding the age and calibration of meters.

The meter has to be tested at different flow rates to give different errors from which a meter error curve is established (Sánchez, 2007; IWA, 2008). For better use of the results from the meter survey, the water utility has to know its customers and their consumption patterns, that is, the category in which the customer falls; how much the customer uses and at what flow rates. When the meters have been tested, the water utility can have a picture on what kind of the meter a customer requires so that the utility does not lose a lot of revenue through meter under registering or errors.

Fig. 2-2 shows the meter error curve. The 2% and 5% values for new meters are suggested by international standard (ISO) (IWA, 2008). The curve of the meter should always be located inside what is called the “tunnel” (IWA, 2008). This indicates a normal operating meter which is under-registering to acceptable levels. Fig. 2-2 shows that even with a new meter, the error (under-metering) may be very high when the consumption flow rate is small. The error is 100% under the start-up flow rate. The meter should not be used for flow rates lower than the minimum flow rate (IWA, 2008). But the customer’s consumption is what it is: this is the reason why, even with new meters, there is always a volume of water consumed that is not metered that is apparent loss.

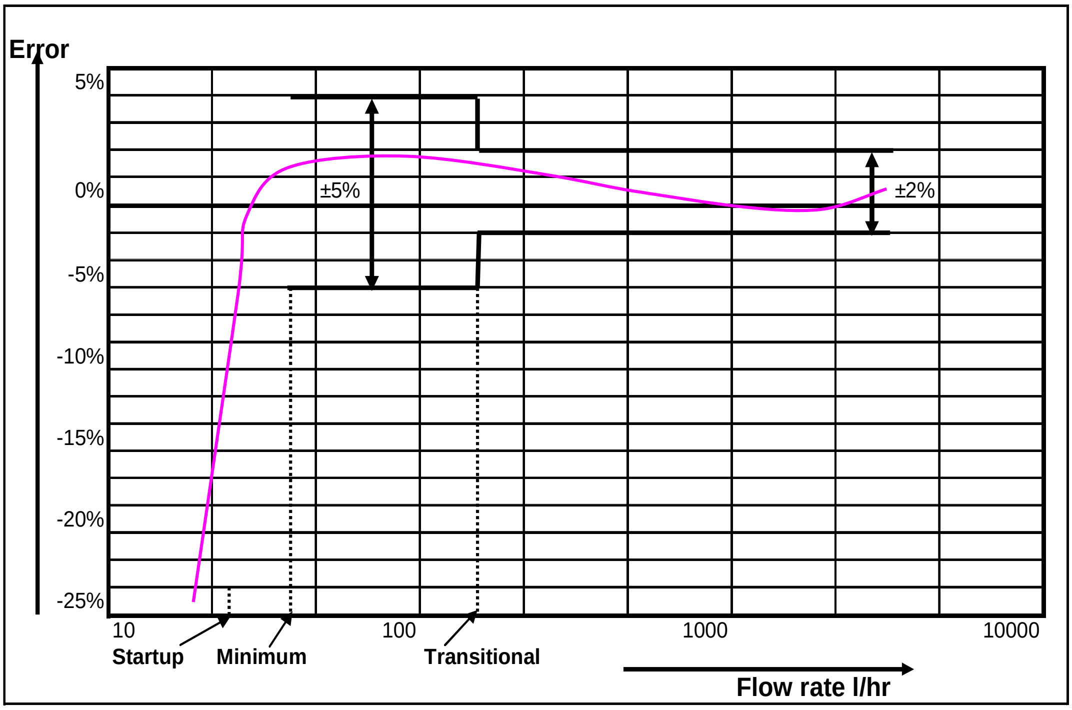


Fig. 2-2: Customer meter error curve

(Adopted from Actaris Meter Systems, 2004)

- Stopped or broken meters

Stopped or broken meters record zero flow when the customer is actually using the water (IWA, 2008). Average consumption on the other hand does not represent the true consumption of the customer and usually under-estimates the consumption. The number of these can be estimated from meter records or a sample survey (Farley, 2001). During meter readings, meter readers take records of all meters which are stuck and are not recording at all. Volume lost due to stuck meters can be calculated from meter records or from estimates of per capita consumption (Farley, 2001). Meter records give an average consumption of the customer based on the past consumption patterns.

- Unauthorised use

Unauthorized use is an area often overlooked in trying to reduce unaccounted for water. Unauthorized use can consist of unmetered use by contractors; unauthorized or unmetered connections; and theft by bypassing meters. Unauthorized use, especially in older systems, can be one of the most difficult areas to eliminate in trying to reduce unaccounted for water (Johnson, 1996).

As in real losses, the most important first step that must be taken with regard to apparent losses is in their quantification, or measurement. Unless some idea is known about the volume of water that is being consumed but not being paid for, little support will be provided by the organization concerned to reduce this apparent loss (Rizzo *et al.*, 2004). It can also not be concluded that the apparent losses are low in a water utility by just looking at a large number of new meters installed, as meter errors are not the only factor influencing apparent losses and literature has also revealed that even a new meter under-registers to some degree; quantification is the only way to confirm that the apparent losses are indeed low.

2.5 Real Losses

Real losses (RL) are physical water losses from the pressurised system, up to the point of customer metering (Farley, 2001). According to Tabesh and Asadiani Yekta (2005), real losses are categorised as water losses from reported and unreported bursts, background losses, reservoir leakage and overflow and leakage from valves and pumps. Because this water did not have the opportunity to pass through a customer's meter, Tabesh and Asadiani Yekta (2005) indicate that these losses are incurred at the production rate. Further to this, Farley (2001) argues that since real losses comprise physical water losses from the water supply system, real losses lead to reduced supply to customers. The IWA recommended definition for real losses is 'the annual volumes lost from transmission and distribution systems through all types of leaks, bursts and overflows on mains, service reservoirs and service connections, up to the point of customer metering' (Thornton and Lambert, 2005).

Leaking systems may present substantial threats to public health, because of possibilities for infiltration of contaminated groundwater under low pressure conditions in the distribution network (Tabesh and Asadiani Yekta, 2005). Leak detection programs are effective ways to minimize leakage and to fix small problems before they become major ones (Water Audit Guidance, 2008). Thus real loss control through leak management is essential not only to avail water to customers but to protect the public health as well. Fig. 2-3 presents the components of real losses.

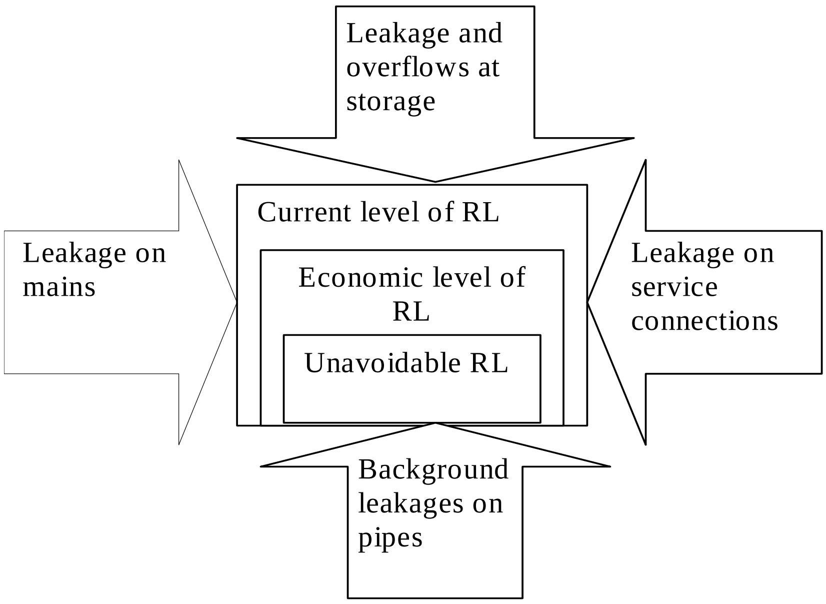


Fig. 2-3: Components of real losses

(Adopted from Thornton, 2005)

Measures to control real losses should be applied simultaneously on the four components in Fig. 2-3. Initial efforts can reduce real losses from current level to economic level of real losses. Further reduction of these components will reduce real losses to unavoidable real losses where further reduction will not be economical (Thornton, 2005). Fig. 2-4 provides the proactive real loss control program.

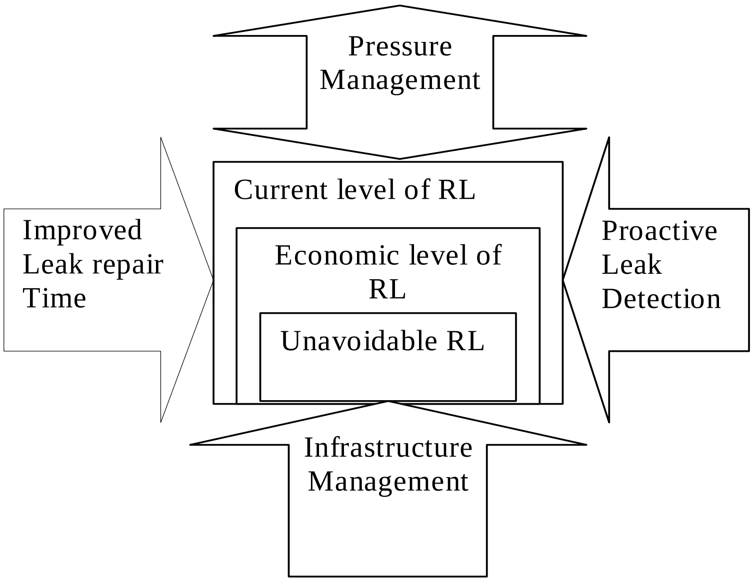


Fig. 2-4: Components of a proactive real loss management program

(Source: Thornton, 2005)

There are four major components to real loss control which aim to reduce the four real loss components presented in Fig. 2-3. The number of new leaks arising each year is influenced primarily by long-term infrastructure or pipeline and asset management which includes selection, installation, maintenance, renewal and replacement. Pressure Management can influence the frequency of new leaks, and the flow rates of all leaks and bursts (Lambert, 2002). The average duration of the leaks is limited by the speed and quality of repairs, that is, improved leak repair time, and the proactive leakage control strategy controls how long unreported leaks run for before they are located (Thornton, 2005). The extent to which each of these four activities is carried out will determine whether the volume of annual Real Losses increases, decreases or remains constant (Lambert, 2002). To keep real losses at minimum, that is, to squeeze the real loss box, the four measures in Fig. 2-4 have to be employed effectively.

2.5.1 Assessment of Real Losses

There are various components of real losses and these can be assessed in different ways (Farley, 2001). The proceeding discussion looks at the components and ways of determining their quantities which can later be used in the water balance analysis.

- Reservoir Leaks

Leakage from reservoirs can be measured by the reservoir drop test. The inlet and outlet valves of the reservoir are closed and the drop in water level over a period of time is measured. For reservoirs which have compartments, each can be monitored in turn. According to Farley (2001), drop tests are usually carried out at night to minimize disruption to the supply.

- Reservoir overflows

Overflows from reservoirs are assessed by inspecting the float valves when the reservoir is at top water level (TWL). The volume passing for the period when the reservoir is at TWL is estimated or measured (Lambert and Hirner, 2000).

- Leakage from trunk mains

Assessment of leakage from trunk mains can be done by inserting meters or clamp-on ultrasonic meters at each end of the main to calculate the change in volume flow rate. An alternative way is to include the trunk mains in the distribution system measurement as suggested by Farley (2001).

- Leakage in distribution system

According to Farley (2001), leakage in the distribution system is assessed using two main classes of measurements. These are the supply zone measurement and the district metered areas (DMAs) measurement. These classes are as discussed below.

  - Supply zone measurement: use of minimum night flows (MNF)

The urban water distribution system is often subdivided into sub-districts containing 200 to 3000 properties (Gumbo *et al.*, 2003). These areas are isolated and fed through a single meter, capable of measuring and recording the low rate of flow that occur during the early hours of the morning, also known as Minimum Night Flow (MNF). This is a method for measuring the night flow into a supply zone and includes trunk main leakage.

The MNF, usually occurring between 12 am and 4 a.m., is one of the most meaningful pieces of data for measuring leakage (Thornton, 2005). According to Farley (2001), authorized consumption between 12 am and 4 am is at a minimum and, therefore, leakage is at its maximum percentage of the total flow. It is assumed that the night flows closely represent the water loss and particularly real losses in the supply zone. This is because little legitimate consumption is expected to take place during the period of measurement.

The measured night use by large customers and the estimated night use by households are subtracted from the measured night flow to give the loss in the distribution system (Farley, 2001). According to Thornton (2005), the estimation of the leakage component at minimum night flow is carried out by subtracting an assessed amount of legitimate night-time consumption for each of the customers connected to the mains in the zone being studied. Mckenzie (1999) indicates that the result obtained from subtracting the assessed night use and exceptional night use from the minimum night-time flow is known as the Net Night-time Flow (NNF) and this consists predominantly of real or physical losses from the distribution system.

Typically, in urban situations, about 6% of the population will be active during the minimum night-time flow period (Mckenzie, 1999). If it is known that there is significant or non-normal night use, otherwise known also as exceptional night use, within the zone, then this must also be estimated or measured by carrying out meter reading tests during the minimum night period. NNF can be further subdivided into background leaks and breaks using component analysis methodology (Farley, 2001; Thornton 2005).

In cases where there are no bulk meters, another form of reservoir drop test can be used to obtain the MNF, where the inlet valve to the reservoir is closed and the drop in level over the same period is measured, after subtracting the same values for customer use (Farley 2001). As it makes use of the reservoir, this calculation will also include reservoir leakage and trunk main leakage.

- District Meter Areas (DMAs**)**

According to Farley (2001), DMAs are small zones of 500 to 3000 households within a supply zone. Gumbo *et al.* (2003), state that DMAs typically contain 2000 to 5000 properties. Each DMA is a discrete zone, with a defined boundary. The boundary may either be permanent or temporary. Flows into (and out of) each DMA are monitored by a flow meter. The meters are read regularly and if supply is inexplicably high, inspectors are sent into that district to locate leaks (Gumbo *et al.,* 2003). When monitoring shows that leakage has increased in a DMA, sub-division of DMAs into smaller areas by temporarily closing valves can be carried out (Farley, 2001). This enables the DMA team to narrow down to the areas of highest real losses. In DMAs where sub-dividing would cause too much disruption, consideration can be given to installing a meter or meters on an internal boundary. In effect this creates two DMAs, one cascading into another (Thornton, 2002). These meters would not normally be read, until DMA monitoring shows an increase in night flow. Internal valve closure may be carried out in conjunction with metering for further sub-division.

Night flow measurements are used to calculate leakage in the distribution system (distribution mains, service connections and fittings), after subtracting customer night use as recommended by Farley (2001). This method has the advantage that the water utility personnel can concentrate their efforts in those districts where the highest levels of leakage occur. It also has the added advantage that information regarding flows and use of water within the network is obtained that can be useful for the day to day running of the network and for the planning and design of future extensions. However, the method is not sensitive to changes in leakage and does not determine the position of leaks. Mckenzie *et al. (*2002b) state that although district metering allows the detection and estimation of water losses within the district it is highly dependent on the range of measurement, accuracy and sensitivity of the water meter.

2.5.2 Ways to minimize Real losses

In a water utility, a number of factors might contribute to the low level of leakage. These include low operating pressure, when the system is very new and burst rates in the system are low (Farley, 2001). Location of the mains influences detection of leaks. Farley (2001) indicates that when the mains are located in footpaths under paving blocks, which are usually characterized by sand soils with a high water table, virtually all leaks are visible. The poor quality of water usually exacerbates corrosion of the network thereby increasing leaks; hence water quality control is very important in leak reduction. Rapid response to reported leaks also reduces leaks.

- Pressure management

Sudden drops in pressure may reduce the leak flow rate from a defect in a pipe (Gumbo *et al.,* 2003). Thus reduction in pressure leads to reduced rate of escape through each leak and may also affect the number of leaks occurring. Effective management of pressures is the essential foundation for an effective leakage management strategy (Lambert, 2002). Pressure reduction is relatively cheap and can be quickly effected, but Mckenzie *et al. (*2002a); and Thornton and Lambert (2007), caution that lower pressure may also increase the leak population by making them less detectable.

Pressure reduction can be achieved in a number of ways such as reducing pumping heads, installing break pressure tanks and using pressure-reducing valves. The control of pressure surges and cycling is likely to reduce the numbers of bursts and leaks that occur, especially in plastic pipes. The South African Code of Practice SABS 0306 “Code of Practice for the Management of Potable Water in Distribution Systems” recommends that for water distribution networks, the static pressure should be limited to between 30 m and 60 m (Gumbo *et al.,* 2003). ICTR (2005) recommends that water pressures should not exceed 50 m at service connections, unless the service is provided with a pressure-reducing device. Pressure control is a necessary tool for the technical management of the system. When combined with any other method of water loss estimation, pressure control could give very useful information in order to identify the causes of water lost through leakage.

2.6 Performance Indicators

Performance indicators are a means of measuring and comparing progress in operations (Rizzo, 2007). Unaccounted for water is usually expressed in a number of ways. The most common one is the difference between water supplied and water sold expressed as a percentage of net water supplied (Balkaran and Wyke, 2002). Use of percentage values in expressing unaccounted for water, although frequent (Farley, 2001), is not usually recommended for comparing leakage rates from one system to another. According to Farley (2001), this indicator fails to take account of any of the main local influences. On the other hand, Balkaran and Wyke (2002) indicate that percentages are useful for comparing the leakage rates for the same system from one year to another. Since by using percentages comparisons can be drawn from one year to the other within the same utility, OFWAT (2002) describes that percentages can be used for ‘internal benchmarking’. It is not feasible and helpful to use percentages for ‘external benchmarking’, in other ways, where there is an international comparison.

OFWAT (2002) further states that expressing leakage figures in terms of percentage of distribution input can be misleading. For example, an increase in consumption will appear to lead to a leakage level reduction when in actual fact, the volume of water lost has not reduced. Likewise, a successful campaign on efficient use of water will reduce the amount of water put into supply and leakage will appear to increase. The recently developed IWA performance indicators also suggest that leakage should not be presented in percentage form (OFWAT, 2002). It can therefore be concluded that percentages should be used when comparing unaccounted for water from one year to the other in the same water utility.

Balkaran and Wyke (2002) indicate that the other ways of expressing unaccounted for water are as the difference between water supplied and water sold expressed as a volume of water 'lost' per km of water distribution network per year (m^3/km/yr) and as the difference between water supplied and water sold expressed as volume of water 'lost' per water connection (m^3/connection/yr). These two volumetric indicators can easily be used to baseline and track performance of an individual water supplier's loss management efforts. It is also easy to turn the volumes into values for simple and more complex economic calculations (Thornton and Lambert, 2005). Accounting for the losses in terms of percentage of the volume produced is significant to the efficiency of the system but does not allow conclusions about the profit possibly obtained with their detection and depends on the water utility characteristics under analysis. The implementation of leakage surveys is related with the lost volume, the pipe length and the customer number of each water utility (more precisely with the number of connections) Marques and Monteiro (2001). According to Marques and Monteiro (2001), expressing losses as volume per pipe length per time from the economical, water quality and environmental points of view, is extremely important to decision making when conducting a leak survey.

Network efficiency which is defined as the relationship between the daily average water volume produced and the total network length is also an important performance indicator. This indicator characterises the population dispersion within the water utility and as this indicator increases, the higher is the population concentration and, as a consequence, the higher will be the consumption and more profitable will be the water utility (Marques and Monteiro, 2001). This discussion suggests that percentage should not be used when comparing performance of different water utilities. It is an important tool to check the utility's asset maintenance efforts from one year to the other. UFW of different water utilities should be compared using volumetric indicators as it implies comparing entities with common parameters and hence assists the water utility in coming up with profitability and water loss control strategies.

A better interpretation of the actual real losses in any distribution network is obtained by comparing technical indicator for real losses (TIRL) also known as current annual real losses (CARL) with a best assessment of unavoidable annual real losses (UARL) for local conditions (Farley, 2001). Based on a statistical analysis of international data, including 27 diverse water supply systems in 19 countries, a method of predicting UARL has been developed and tested for application to systems with average operating pressure of between 20 and 100 m, density of service connections between 10 and 120 per km of mains and customer meters located between 0 and 30 m from the edge of the street.

$$UARL = (18 \times L_m + 0.80 \times N_c + 25 \times L_p) \times P \quad \text{………………………….Equation 2-1}$$

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

L_m = Length of mains (km);
N_c = Number of service connections (main to meter);
L_p = Length of unmetered underground pipe from street edge to customer meters (km);
P = Average operating pressure at average zone point (m).

(Source: Mckenzie et al., 2002a).

As reported in Farley (2001), UARL can vary between 20 and 142 litres/service connection/day for specific combinations of average operating pressure between 20 and 60 m, density of service connections between 20 and 100 service connections per km of mains and customer meters located between 0 and 20 m, from the edge of the street and the delivery point (length of connections). The ratio of the actual CARL to UARL related to the local system is a useful non-dimensional index of the system performance (Thornton, 2005). This is known as infrastructure leakage index (ILI) and it is worked out as:

ILI = CARL / UARL……………………………………………………Equation 2-2

(Source: Liemberger et al., 2007).

ILI is recommended as an additional step for the interpretation of the actual value of CARL and should hence be used for comparison of the utility's total real loss management efforts and performance.

CHAPTER THREE

3.0 STUDY AREA

3.1 Location

Zomba District is located in the Southern Region of Malawi and its geographical coordinates are 15° 23' 0" South, 35° 20' 0" East (Wikipedia, 2009). It is bordered by Chiradzulu to the South West, Mulanje and Phalombe Districts to the South, Machinga District to the North, Balaka District to the North West and Mozambique to the East (NWDP II, 2007; ESIA, 2009). The City of Zomba is the district headquarters, and according to NWDP II (2007), it is 64 km north of Blantyre City, the country's main commercial centre; and 288 km south of Lilongwe City, the Capital of Malawi. Zomba City is the second largest town in the Southern Region after Blantyre and the fourth largest in the country. Appendix XI shows map of Zomba.

3.2 Topography, Geology and Climate

The topography of Zomba district varies from mountainous and hilly regions that comprise the ridge dividing the Upper Shire Valley in the Western part of the district to the broad, flat plains of Lake Chilwa (a sensitive wetland ecosystem) in the East (ESIA, 2008). The district elevation varies from 627 masl at Lake Chilwa to 2,130 masl on Zomba Plateau. The diverse topographical characteristics generate a variety of climatic zones between different areas of the district (NWDP II, 2007; ESIA, 2008). The geology of Zomba district is varied with a base complex composed of metamorphic rocks derived from sedimentary and igneous rocks of Precambrian origin. There are different types of minerals and these include limestone currently being mined commercially in the district. The climate of Zomba district is cool to hot with annual average temperatures ranging from 15 °C to 25 °C. Zomba experiences a tropical climate with three main seasons: cold-dry, hot-dry and hot-wet, ranging respectively from April to July, August to October and November to March. Zomba receives an annual rainfall of between 600 mm and 1500 mm.

3.3 Vegetation and Environment

The vegetation of Zomba is primarily Savannah and it can be classified into two distinct biotic communities (ESIA, 2008; ZDA, 2008a). Part of the plateau is semi evergreen forest while the other part is made up of wetlands. Miombo woodlands comprise forestlands in the plateaux hills and escarpments that have medium to high rainfall. Mopane woodlands which are largely dominated by *Colophospermum mopane* with open glades cover the fringes of the district. The district has high species diversity particularly on the Zomba Mountain. In addition to the various tree species, the district has the Zomba Forest Reserve. However, most of the natural vegetation has been greatly reduced and has been replaced by exotic bluegum, pine, gmelina and other tree species.

The environmental situation in Zomba is fast deteriorating due to the rapid loss of forest cover (ZDA, 2008a). Deforestation is occurring at a very fast pace as a result of human encroachment in protected forests, for purposes of agricultural expansion, increasing demand for fuelwood (charcoal and firewood), and higher timber requirement. The rate of forest destruction is further aggravated by infrastructure development, such as the construction of Mulunguzi Dam and expansion of the district road network.

3.4 Land Use

With regard to land use, Zomba district has a total area of 2,541 km^2 (ESIA, 2009). According to NWDP II (2007) this land area is 3% of the total land area of Malawi. Most of the land in the district is under customary land tenure system. The City of Zomba covers a total land area of 22,800 ha of which 10,242 ha (44.9%) is taken by urban development, while forest reserves and plantations cover 5406 ha (23.7%) and 7152 ha (31.4%) respectively (ZDA, 2008b).

3.5 Socio-economics

According to the SRWB (2008b), Zomba City had the lowest unemployment rate of 15.9% compared to the other cities where Lilongwe had 18.6%, Blantyre had 21.3% and Mzuzu had 18.8% unemployment rate. Most of the people in the City were civil servants (49.6%), 33.9% were self employed, 11.1% were farmers and 5.4% were family business workers. Most formally employed individuals (97%) were service personnel, professional and technical personnel, production and clerical; and 3% were in managerial and administrative positions.

3.6 Population Size and Growth

From the 2008 Population and Housing Census conducted by National Statistical Office (NSO, 2008), Zomba District had a total population of 670, 533 which is about 5.2% of the national population. The average population growth rate per annum is estimated at 2 % in the rural and 2.9% in the Zomba City. Zomba City had a population of 87, 366 (NSO, 2008; ZDA, 2008b).

3.7 Water resources

Zomba District has many rivers that include Mulunguzi, Thondwe, Domasi, Naisi, Namadzi, Phalombe and Likangala (NWDP II, 2007). In addition to several rivers of importance, the District has Lake Chilwa into which some of these rivers drain. The new dam on Mulunguzi River is the main water supply source for the City of Zomba and its peri-urban areas

3.8 Water Supply

3.8.1 Urban and peri-urban areas in Malawi

The existing urban and rural water supply schemes and systems in Malawi provide access to potable water facilities for up to 54 % of the country’s population, which reduces to 32 % with access to potable water at any one time due to breakdowns, drying up of sources and other operational and maintenance problems (MWD, 1994; Mvalo and Company, 2002). Before 1996, urban water supply schemes, except those for Blantyre and Lilongwe were run by Government under the district water supply fund. The Water Resources Management Policy and Strategy launched in 1994 focused on improving water supply and sanitation services that had deteriorated and were facing major challenges of sustainability, with emphasis on decentralisation and commercialisation (Mvalo &

Company, 2002). This was achieved through the establishment of three regional water boards to take over the water supply schemes which were centrally run by Government through District Water Supply Fund of the Ministry of Water Development. Five water boards are now established and operate under the Water Works Act of 1995 which is the legal framework of the water resources management policy of 1994 (MWD, 1994; Water Works Act, 1995).

Water services in urban and peri-urban areas in Malawi are provided by public water utilities, also known as water boards. The Regional Water Boards inherited very old and inefficient water supply facilities from the District Water Supply Fund which was formerly responsible for supplying water in small urban areas in Malawi (Mulwafu *et al.,* 2002). These old facilities are responsible for high losses of water through leakage. There are also issues of faulty meters and problems of uneven pressure in the water supply systems that can cause pipe bursts. Despite these challenges, urban water supply coverage has improved (WHO, 2000). Fig. 3-1 shows the increase in service coverage for urban water supply which are managed by water boards.

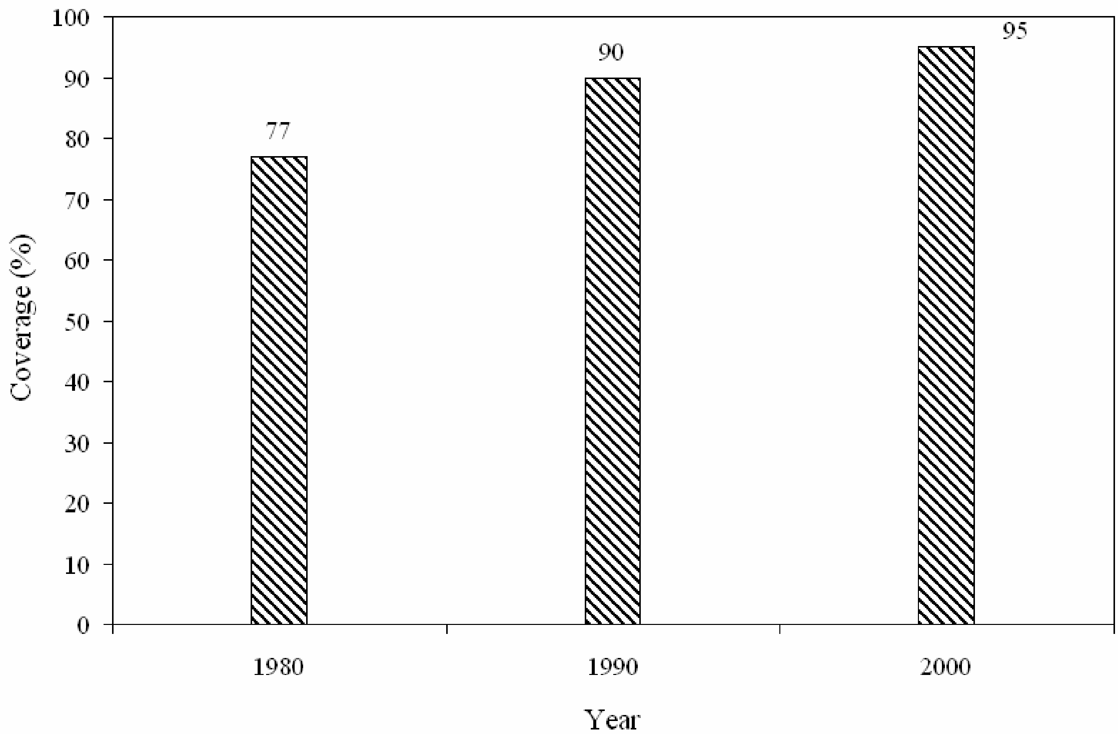


Fig. 3-1: Urban water supply coverage in Malawi

(Source: WHO, 2000)

Fig. 3-1 shows that there was a general increase in urban water service coverage from 1980 to 2000. In 2000 the coverage was 95%. Effort is required to get to 100% coverage and since unaccounted for water reduces water availability, UFW control can avail some water and hence it can increase service coverage to include some new customers who are not connected to the urban water supply.

3.8.2 Zomba City

Southern Region Water Board is the supplier of potable water to the City of Zomba and some parts of the Zomba district. The Water Board abstracts water from a new dam on Mulunguzi River on Zomba plateau. Zomba City water supply system has service coverage of 89% by population (SRWB, 2008a).

The Zomba Water Supply system originally consisted of an intake on the Mulunguzi River, a conventional treatment plant with a capacity of 6,000 m^3/day, 17 storage tanks with capacities ranging from 25 m^3 to 455 m^3 and 90 km of distribution pipelines with pipe diameters ranging from 25 mm to 200 mm made of various types of materials. This system was built in the early 1950s and could not suffice the demand starting from the 1980s. Due to acute shortage of water within the Zomba City the Government of Malawi with financing from the World Bank under the National Water Development Project initiated a project aimed at augmenting and extending the water supply including construction of a more reliable water supply source. This project resulted in the construction and commissioning of a 3.4 Mm^3 Mulunguzi Dam designed for the year 2015, an additional 12,200 m^3/d capacity treatment plant, storage tanks with a total storage capacity of 9,750 m^3; and a total of 41.3 km of pipeline of PVC, GI and ductile iron with diameters ranging from 80 to 350 mm (Lahmeyer International, 2000).

- Operational challenges

According to the SRWB brief outline of Zomba scheme[1] (2008a), the city water supply faced a lot of challenges. Some of the problems include:

- ❖ Old Water Supply Infrastructure

Zomba City has some water supply networks which were constructed in the early 1950s hence they are very old. Almost 58% of the distribution mains are at their serviceability limit state (SRWB, 2009). The Zomba City water supply is hence pumping a lot of money on the maintenance of the infrastructure such as AC and steel pipes. The infrastructure is also not adequate for the current population since the infrastructure was constructed some 60 years ago when the population was still small and huge investments were not feasible.

- ❖ Meters are operating beyond their design life

The number of meters of over 10 years of age is estimated to be in excess of 4000 out of the 9,249 meters (43%) in the Zomba scheme. It is felt that the scheme is losing a lot of revenue through meter errors, as water meters tend to under-register when they are getting old (SRWB, 2008a).

[1] Zomba scheme has six sub-schemes; one of them which is also the largest is Zomba City water supply system.

❖ High Unaccounted for Water

Zomba City has high unaccounted for water in the range of 30%. The reason for the high unaccounted for water is mostly pipe bursts which are as a result of old pipelines that can no longer withstand high pressures in the water supply network. The high unaccounted for water is also as a result of old meters that usually under-register consumptions. Apart from the challenges above, there are no devices in the system installed to monitor unaccounted for water at different stages and partitioning of UFW has also not been done.

- Efforts to reduce high unaccounted for water

The SRWB uses improved leak repair time strategy (speed and quality of repairs) and infrastructure management strategy to control real losses and customer meter management to control apparent losses. The Water Board has increased the number of maintenance teams and vehicles to facilitate quick repair of bursts, and whenever the burst cannot be repaired immediately, valves are closed to minimise water losses. In an effort to reduce apparent losses, the SRWB started the replacement of faulty meters in March 2009.

3.9 Specific Study Areas

The study was done in the Zomba City distribution system with a specific focus on four distribution areas or zones. The areas are distinct zones supplied by an individual tank each and have operational measuring devices (bulk tank outlet meters). Fig. 3-2 and Fig. 3-3 show the schematic and distribution network of Zomba City water supply system respectively with the specific study areas highlighted, and Table 3-1 presents the base data for the specific study areas.

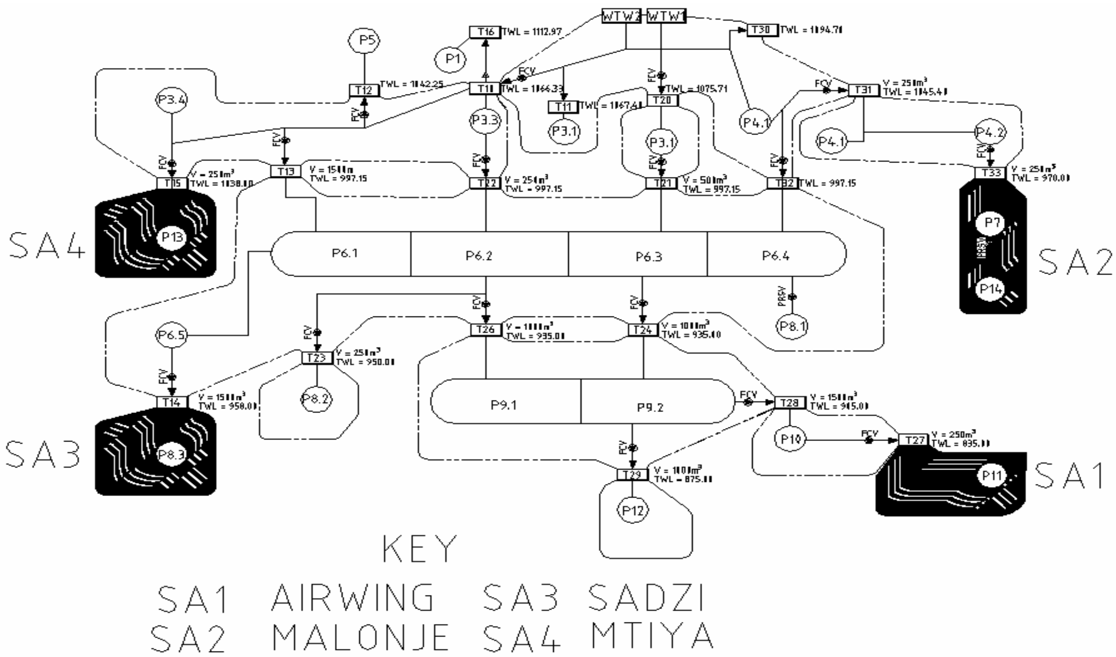


Fig. 3-2: Schematic of Zomba City water supply showing specific study areas.

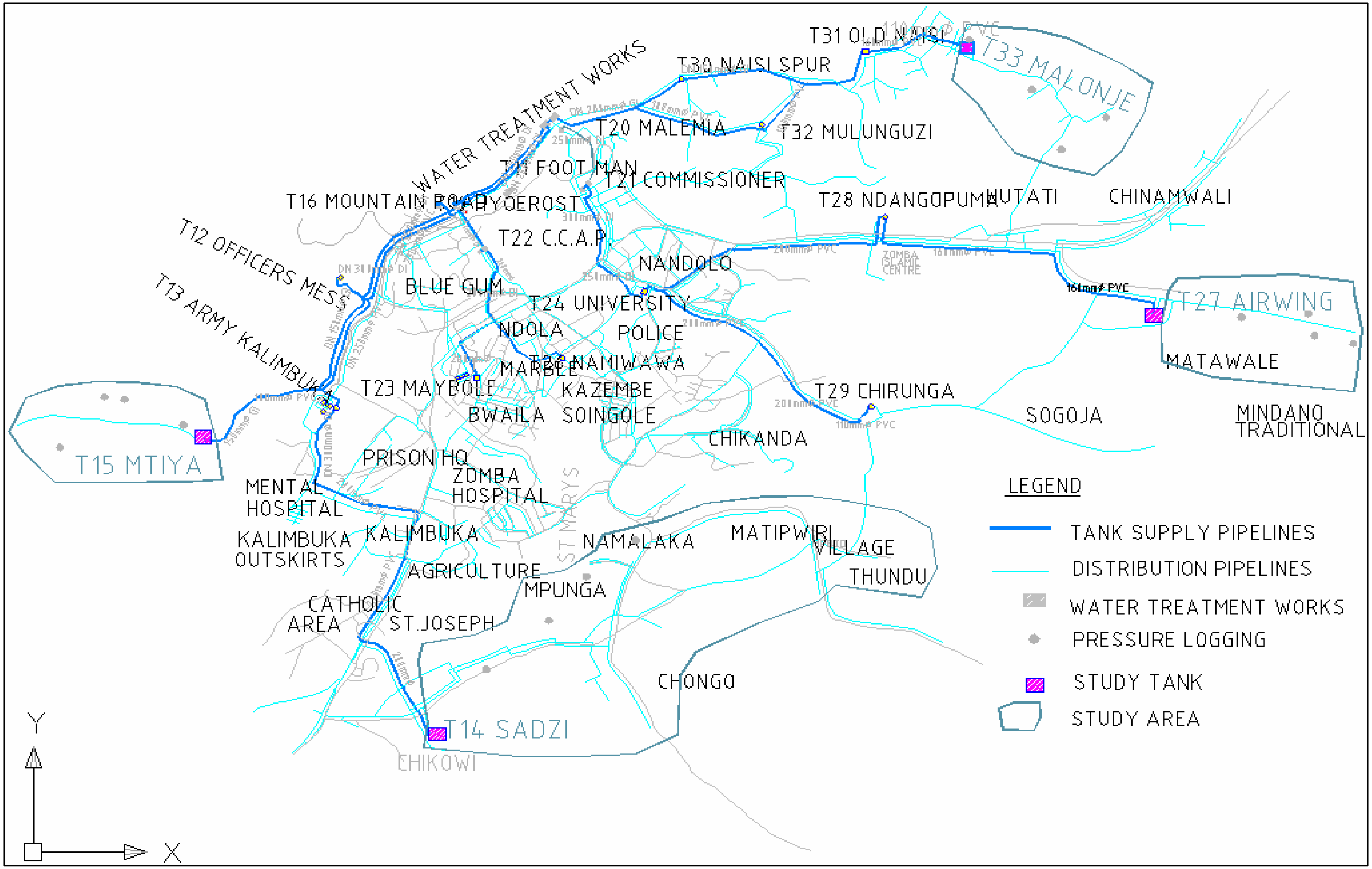


Fig. 3-3: Zomba City water distribution system showing study areas

The specific study areas were Airwing, Malonje, Sadzi and Mtiya. Schematic of the distribution system in Appendix XII also show the pressure zones of Zomba City water supply system.

Table 3-1: Details of Study Areas

Area/Tank	Tank size (m3)	Tank elevation (masl)	No. of connections supplied	Mains length (km)
Airwing	250	840	52	1.2
Malonje	250	962	179	2.4
Sadzi	1500	960	965	12.1
Mtiya	250	1027	42	1.4

CHAPTER FOUR

4.0 MATERIALS AND METHODS

4.1 Study Design

The study used documentation review and field data collection, and both qualitative and quantitative data were collected. This study was carried out on Zomba City water distribution system from January to April 2009, and components studied included overall unaccounted for water, real losses and apparent losses, system pressure variations and age of the distribution network.

The main monitoring points were on water production meters at the treatment works, tank bulk meters, customer meters and customer taps. Apart from the whole distribution system, four specific supply areas were studied. These areas were selected based on their unique characteristics in the sense that they were distinct zones, each being supplied by a single tank which additionally did not supply any other area. All the specific study areas had residential or individual customers, and the tanks had bulk meters in good condition as recommended by Farley (2001). Table 4-1 summarises the data collected and frequency of monitoring.

Table 4-1: Data collection: Monitoring and Frequency

Objective	Type of data	Nature of data	Monitoring	Frequency	Purpose of data
Trends of UFW (1999-2008)	-Water production -Total billed consumption	Historical	Production meter readings	monthly	To evaluate UFW
UFW of specific study area	-Tank water supply -Consumption for specific areas	Current	-Bulk meter readings -Consumption from billing	-Weekly for three months -Monthly consumption	To obtain UFW for specific areas
Partitioning of UFW	-Minimum Night flow	current	Bulk meter flow logging	4 days on each of the 4 tanks	-To determine real losses then partition UFW
System characteristics	Pressure	Current	Logging on customer taps	24hr- 4 days in each area	-Assess pressures for real losses
	Meter errors	Current	Meter inaccuracy tests	Each meter tested at 3-4 different flow rates	-Assess meter errors for apparent losses

4.2 Data Collection

This section presents the data collected based on the specific objectives of the study.

4.2.1 Trends of unaccounted for water

To establish trends of unaccounted for water for Zomba City, two important data sets were required. These were water produced by the utility intended to supply the City of Zomba and water consumption billed for the City of Zomba as recommended by Lambert (2003). Thus historical data on the water production were collected from the Zomba City water treatment works. Water production readings before the treatment plant were not used as they also included the water used for backwashing of the filters which was a 'useful loss'. Hence water production readings after the treatment works (the net system input) were taken for the period between the years 1999 and 2009. Data on monthly water consumption billed was taken from the billing section.

Further to the above data, corresponding number of customers served in terms of number of connections which were active were also taken from the billing summaries. Lengths of the distribution mains (network) were also calculated from the distribution drawings.

4.2.2 UFW for specific study areas

Tank bulk meter readings (outflow) for specific study area were taken once every week for a period of three months. Customers supplied by such tanks were also identified and consumption billed for these customers over a period of three months was taken from the billing section.

4.2.3 Partitioning of UFW

- Flow logging

Data logging exercise for the four study distribution areas was carried out. A flow logger was installed at the tank bulk meter which was at the inlet to the zone as suggested by Farley (2001). While the flow logger was on a particular bulk meter, the pressure logger was changed every 24 hours within the zone at different elevations in order to have an appreciation of pressure variations in the zone. The results from the flow logging were used to assess the minimum night flows from which real losses were calculated. The apparent losses were worked out from the difference of total UFW and real losses

4.2.4 System characteristics influencing UFW

- Pressure logging

Pressure logger was installed on different points in the study distribution areas, for 24hrs at each point. There were only two data loggers available, one for the tank outflow assessment and the other one for zone pressure assessment. It was therefore not possible to have several pressure loggers at various elevations (or locations) at the same time. The pressure results were assessed with the flow patterns from the tanks.

Pressure at various points of the distribution zones was also recorded using a pressure recording gauge and bucket tests were carried out where estimated average time to fill a 20 litre standard bucket was recorded.

- Meter inaccuracies

A meter testing bench was used to verify the accuracy of customer meters as suggested by Sánchez (2007) and IWA (2008). The testing bench was installed in line with the customer meter under test (see Appendix XIII). Meters were tested at flow rates of 150, 300, 500, 800 and 1000 *l*/hr in order to obtain the meter error curve.

- Secondary data

Secondary data were gathered through interviews, reviews of operations reports, distribution drawings and customer care documents. Such data included records on pipe burst, type and sizes of pipes, the age of the distribution system, tank over flows and their frequencies and data on errors due to data acquisition.

4.3 Data analysis

4.3.1 Trends of unaccounted for water

Unaccounted for water was analysed based on the water balance method, where the difference of water production and water billed was obtained as recommended by Farley (2001) and Lambert (2003). Historical monthly water production meter readings and water billed were used in the water balance method. According to Motiee *et al.* (2007), the water balance in a water network system can be defined as:

$$Q_p = Q_c + Q_L \quad \text{......................................Equation 4-1}$$

Where:
Q_p = Produced or supplied volume per time;
Q_c = Consumption volume per time;
Q_L = Total water losses volume per time.

Number of connections and length of distribution mains were also obtained in order to express unaccounted for water not only as a percentage of production but also as the function of number of connections and length of the pipeline as suggested by Balkaran and Wyke (2002). Trends of UFW from 1999 to 2008 were established.

4.3.2 UFW for specific study areas

Based on the same water balance method in equation 4-1, the difference between the tank supply (bulk meter readings) and the customer consumption (from billing) was taken as unaccounted for water also known as distribution loss in the specific distribution areas or zones. The unaccounted for water for these study areas was expressed as a percentage of volume supplied; volume per connection per time period; and as volume per length of pipe mains per time period.

4.3.3 Partitioning of UFW

- Real Loss Assessment: Minimum Night Flow Analysis

Real losses were assessed from data logging results which had evidence of pipe bursts and the Minimum Night Flows. For each day, the minimum flow occurring between 12 am and 4 am was used as minimum night flow in the analysis as proposed by Thornton

(2005). MNF were analysed using the South African Night Flow Analysis (SANFLOW) Model version 1.6. The model was developed by the South African Water Research Commission in order to help water suppliers to determine the level of unexplained burst leakage in a particular zone metered area (ZMA) from the analysis of recorded minimum night flows (McKenzie, 1999). Apart from the MNF data, the SANFLOW model also requires basic infrastructure variables such as length of mains, number of connections; number of properties, estimated population, average zone night pressure and major water users. Where there was no data such as leakage coefficients and pressure correction factors, some assumptions were made and SANFLOW default values which were recommended by Mckenzie (1999) were used. Tables 4-2 and 4-3 provide the base information and assumed parameters which were used in the SANFLOW model for each of the study area. Detailed outputs of the SANFLOW model are provided in Appendix VI.

Table 4-2: Infrastructure variables used in SANFLOW Model

Description	Value			
	Airwing	Malonje	Sadzi	Mtiya
Length of mains (km)	1.2	2.4	12.1	1.4
Number of connections	101[2]	179	965	42
Number of properties	120	220	1300	70
Estimated population	800	800	6500	600

Table 4-3: Leakage Parameters Used in SANFLOW Model

Description	Value				
	Default[3]	Airwing	Malonje	Sadzi	Mtiya
Background losses from mains (*l*/km.hr)	40	40	40	40	40
Background losses from connections (*l*/conn.hr)	3	3	3	3	3
Background losses from properties (*l*/conn.hr)	1	1	1	1	1
% of population active during night	6	6	6	6	1[4]
Quantity of water used in a cistern (*l*)	10	10	10	10	10
Background losses pressure exponent	1.5	1.5	1.5	1.5	1.5
Burst/leaks pressure exponent	0.5	0.5	0.5	0.5	0.5
exceptional use m^3/hr	-	6[5]	0	0	0

[2] There were 52 connections in Airwing, one of which is the Airwing (Army) institution bulk meter. An equivalent of 50 connections has been used to represent the bulk meter.
[3] SANFLOW default value
[4] Almost all the houses in Mtiya had single outside taps and normal night use was expected to be very low.
[5] In Airwing exceptional use of 6 m^3/hr was assumed to represent the night use for customers served from one bulk meter. High water usage is common in households where service is through a bulk meter and water bills are covered by the institution.

In the SANFLOW model the excess night flows (ENF) from which the real losses (RL) are worked out are calculated as follows:

Expected night use = background losses + normal night use………………..Equation 4-2

ENF=Measured MNF-Expected night use………………………………..Equation 4-3

RL ($m^{3/}$month) =ENF (m^3/hr) × (hour/day factor) × 30 days/month……..…Equation 4-4

(*Adopted from Fanner, 2004*).

The maximum ENF value was used hence the hour/day factor was taken as 24 as recommended by Lambert (2002). The real losses determined represent the current annual real losses (CARL).

- Apparent loss Assessment

Apparent losses (AL) were obtained as the difference between the average zone UFW (distribution losses) and the real losses. Based on water balance, apparent losses were calculated as:

AL (m^3/month) =Average UFW- RL………………………...…………….Equation 4-5

- Meter Inaccuracy Tests

A meter testing bench was used to investigate the accuracy of customer meters as suggested by Sánchez (2007) and IWA (2008). The testing bench was temporarily installed in line with the customer's meter, as a check meter to compare the volume flows. The meters were tested at different flow rates to obtain the meter error curve.

The meters were also categorised with respect to their age; to assess the effect of age on meter inaccuracy. For residential consumption (C_R) and meter error (E) or meter accuracy (A), the volume lost (L) due to meter inaccuracy was estimated as:

$L=\{C_R / (1-E)\}-C_R$……………………………………….………………….Equation 4-6

Or

$L = (C_R/A)-C$…………………………………………….…………….Equation 4-7

(*Adopted from DWSD, 2004)*

CHAPTER FIVE

5.0 RESULTS AND DISCUSSION

5.1 Trend of unaccounted for water for Zomba City

Data on water production collected from the water treatment works, and water consumption collected from the billing section were used to determine trend of unaccounted for water. The number of service connections obtained from the billing system and distribution mains length determined from the distribution drawings and operations reports enabled expressing UFW in volumetric terms in addition to percentage as recommended by Balkaran and Wyke (2002). Table 5-1 summarises the water produced, water billed, and unaccounted for water for 1999 to 2008. Monthly details are presented in Appendix I.

Table 5-1: Yearly unaccounted for water for Zomba City water supply system

Year	Water Prod (m^3/yr)	Water billed (m^3/yr)	Apx mains (km)	conns	UFW			
					Vol (m^3/yr)	Vol % of Prod	m^3/km/yr	m^3/conn/yr
1999	2,635,066	2,045,291	90	2,775	589,775	22.4	6,553	213
2000	3,219,040	2,141,569	90	3,135	1,077,471	33.5	11,972	344
2001	4,431,450	2,828,998	132	3,495	1,602,452	36.2	12,140	459
2002	4,768,010	3,180,000	132	4,000	1,588,010	33.3	12,030	397
2003	4,693,888	3,663,063	132	4,343	1,030,825	22.0	7,809	237
2004	4,781,266	3,564,494	132	4,278	1,216,772	25.5	9,218	284
2005	4,749,074	3,717,818	156	4,512	1,031,256	21.7	6,611	229
2006	5,132,983	3,586,128	156	4,708	1,546,855	30.1	9,916	329
2007	4,698,937	3,778,632	156	5,579	920,305	19.6	5,899	165
2008	5,369,925	3,738,002	156	5,966	1,631,923	30.4	10,461	274
Average					1,223,564	27.5	9,261	293

Fig. 5-1 presents plots of the total annual water produced and billed and UFW from 1999 to 2008.

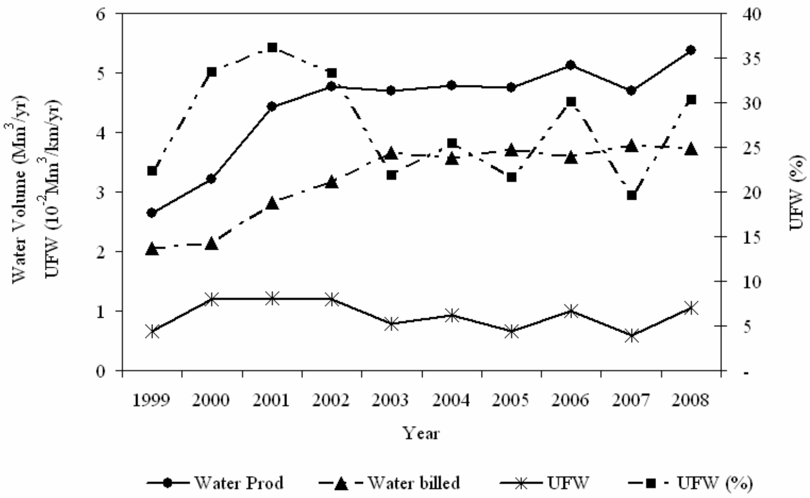


Fig. 5-1: Total water produced, billed and UFW for Zomba City from 1999 to 2008

From Fig. 5-1, there is a general increase in water production and consumption over the 10-year period but UFW does not show a defined pattern. The average unaccounted for water for the 10-year period was established as 27.5% (293 m^3/conn/yr) with the lowest occurring in 2007 at 19.6% (165 m^3/conn/yr) and the highest occurring in 2001 at 36.2% (459 m^3/conn/yr). The high UFW of 36.2% in 2001 may be as a result of frequent bursts occurring due to pressure testing of the new network and within the old water supply boundaries which were joined to the new distribution network. It may also be because the number of new customers increased but they were not immediately updated in the customer database, hence the water used by such customers was unaccounted for.

From a study by Gumbo (2004) it can be concluded that the average UFW for Zomba City was higher than the UFW for the City of Bulawayo which was 20%. Marunga *et al.* (2006) found out that UFW for the City of Mutare was 57% in 2006 which is more than double the UFW of Zomba City. In a similar water supply system, Nkhoma *et al*. (2005) established the UFW for Lilongwe City in Malawi as 38%, which is higher than that of Zomba City. The average unaccounted for water for Zomba City was above 20% which is recommended for well performing urban water utilities in the Southern African region (Gumbo, 2004). It can be concluded that the UFW for Zomba was within the range reported in literature (20% to 57%) but higher than the level recommended for Southern Africa.

5.2 Unaccounted for Water and its partitioning for the specific study areas

5.2.1 Unaccounted for water for study areas

The UFW for the specific study areas represents the distribution loss in the study areas and it was determined based on the difference of the bulk meter readings and consumption billed for the areas, that is, the water balance as recommended by Farley (2001).

- Water Consumption

The billed consumptions and number of connections for each specific study area were established and are summarized in Table 5-2. Airwing Tank supplies 8% of the connections in Matawale, an area known as Airwing. Malonje Tank supplies parts of Chinamwali and Malonje and the whole of Habitat area. Sadzi Tank supplies 87% of Sadzi and 82% of Thundu in addition to all connections in Mpunga and Chizalo areas. Mtiya Tank supplies the whole of Mtiya area. More details of these percentages are presented in Appendix II.

Table 5-2: Consumption billed for the four study areas

Area	No. of connections	Consumption billed (m^3)			
		Dec 2008	Jan 2009	Feb 2009	Average
Airwing	101	8,293	8,194	7,642	8,043
Malonje	179	3,385	3,315	3,463	3,388
Mtiya	42	414	405	407	409
Sadzi	965	12,412	11,768	11,589	11,923

Consumption for Airwing area appears to be very high with respect to the number of connections supplied by the Airwing Tank. This was the case as one of the connections in Airwing area was the Airwing institution. This institution had different houses but it was served from one bulk meter. Where government institutions are responsible for water bills, there is usually high usage of water by consumers paid for (Schwartz, 2008). Sadzi zone had the highest number of connections and consumption of all the areas.

- Tank Supply

There were no records of tank bulk meter readings kept before and hence the data used was obtained during the study period. Bulk meter readings recorded are also shown in Appendix II. The water supplied to the distribution area was determined as the monthly difference in meter readings. The results are presented in Table 5-3.

Table 5-3: Water supply to the four study areas

Area	**Tank Supply (m^3)**			
	Month 1	**Month 2**	**Month 3**	**Average**
Airwing	8,650	10,270	8,910	9,277
Malonje	9,021	9,243	8,411	8,716
Mtiya	440	460	410	437
Sadzi	26,538	19,620	26,310	24,153

Sadzi, which is supplied by a 1500 m^3 tank, had the highest tank outflow or supply. The other three areas are supplied by 250 m^3 tank each, but the water consumption for Mtiya area was far much lower than that for Airwing and Malonje areas. This indicates to the low number of connections and the type of housing in Mtiya where most of the properties have single taps.

- UFW

The UFW for the specific study areas was determined as the difference between the water supplied to the distribution area and the consumption billed for that area (Farley, 2001). This was considered as the total volume for partial systems as discussed by Lambert and Hirner (2000). Based on the average supply and consumption for the three month period, the UFW for the four supply areas were determined and the results are as presented in Table 5-4.

Table 5-4: Average UFW[6] for the four supply areas

Area	**Average Tank Supply (m^3/month)**	**Average Consumption (m^3/month)**	**Conns**	**Approx Mains (km)**	**UFW**			
					m^3/month	**%**	**m^3/conn/yr**	**m^3/km/yr**
Airwing	9,277	8,043	101	1.2	1,234	13	147	11,942
Malonje	8,892	3,388	179	2.4	5,504	62	369	27,751
Mtiya	437	409	42	1.4	28	6	8	246
Sadzi	24,153	11,923	965	12.1	12,230	51	152	12,125

[6] The UFW for the specific areas is actually the distribution losses in these distribution areas.

As a percentage of tank supply or outflow; distribution losses in Airwing were low but the distribution losses per connection were high. Malonje had the highest distribution loss of all the specific study areas. Sadzi had distribution losses of 51% which was also very high. Sadzi is the biggest zone in all aspects, that is, it is supplied by a 1500 m^3 tank, there were 965 customers and the total distribution mains of 12.1 km. Mtiya had the low unaccounted for water of 6%. The factors which influence unaccounted for water such in the four areas included pressure, pipe age, meter mismanagement and each area was influenced differently.

The UFW for the month of February 2009 was also determined since the data on meter readings (water supply) and corresponding consumption billed for this month for all the specific study areas were available. Table 5-5 gives a summary of the UFW calculated.

Table 5-5: Unaccounted for water for February 2009

Area	**Supply**	**Consumption**	**UFW**			
			(m^3)	**(%)**	**m^3/conn/yr**	**m^3/km/yr**
Airwing	8,650	7,642	1,008	11.7	120	10,080
Malonje	9,021	3,463	5,558	61.6	373	27,790
Mtiya	440	407	33	7.5	9	283
Sadzi	26,530	11,589	14,941	56.3	186	14,817

Tables 5-4 and 5-5 show that in Airwing, the UFW of 11.7% (120 m^3/conn/yr) in February was lower than the average UFW of 13.3% (147 m^3/conn/yr). The average UFW for Malonje was slightly higher than its UFW in February. Mtiya also had an average unaccounted for water which was closer to its unaccounted for water for February. There was a clear difference on the unaccounted for water for Sadzi for the month of February (186 m^3/conn/yr) and the average UFW (152 m^3/conn/yr) obtained. In all the four specific areas, the average unaccounted for water was used for further partitioning.

5.2.2 Partitioning of unaccounted for water

- Assessment of Flow logging results

Detailed results of the flow logging are provided in Appendix IV. The results were also plotted and Figs 5-2 to 5-4 present the patterns of flow for Airwing, Malonje and Sadzi.

  - Airwing Tank Outflow

Fig. 5-2 shows the results of outflow pattern for Airwing Tank from 26 March to 31 March 2009.

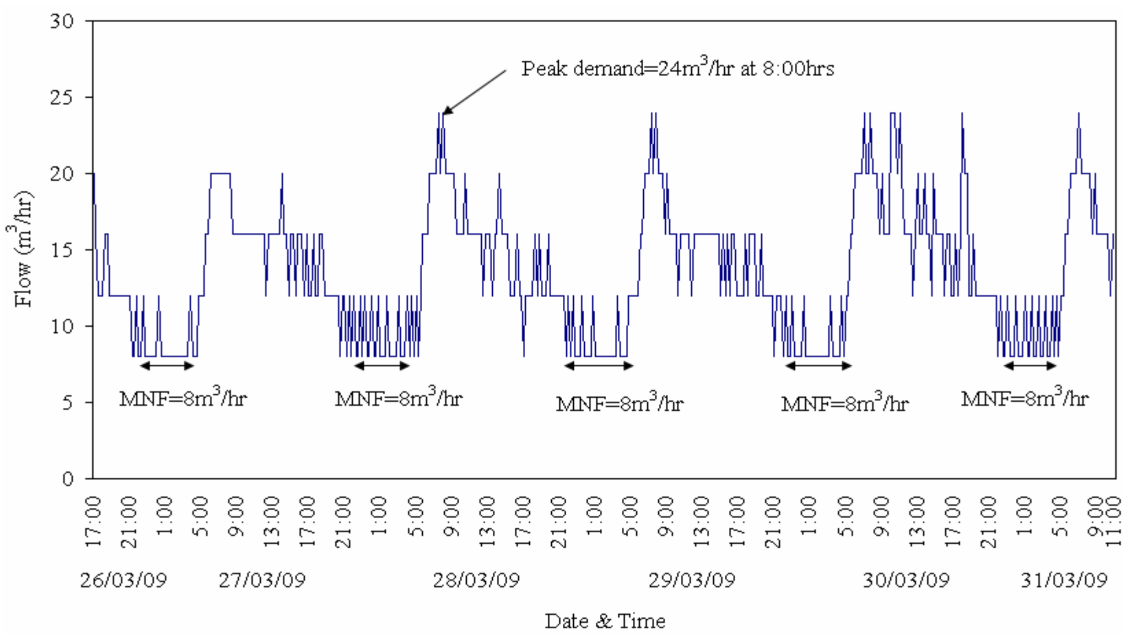


Fig. 5-2: Airwing Tank outflow pattern

From Fig. 5-2 it can be seen that the minimum night flow, which according to Thornton (2005) usually occurs between 12 am and 04 am, was 8 m^3/hr throughout the logging period. The highest peak flow for the zone was 24 m^3/hr and this occurred around 8 am. The average flow of Airwing Tank was 12 m^3/hr. Hence the peak factor for the distribution zone was 2.

- Malonje Tank

Fig. 5-3 shows the outflow pattern for Malonje Tank for the period 31 March 2009 to 6 April 2009

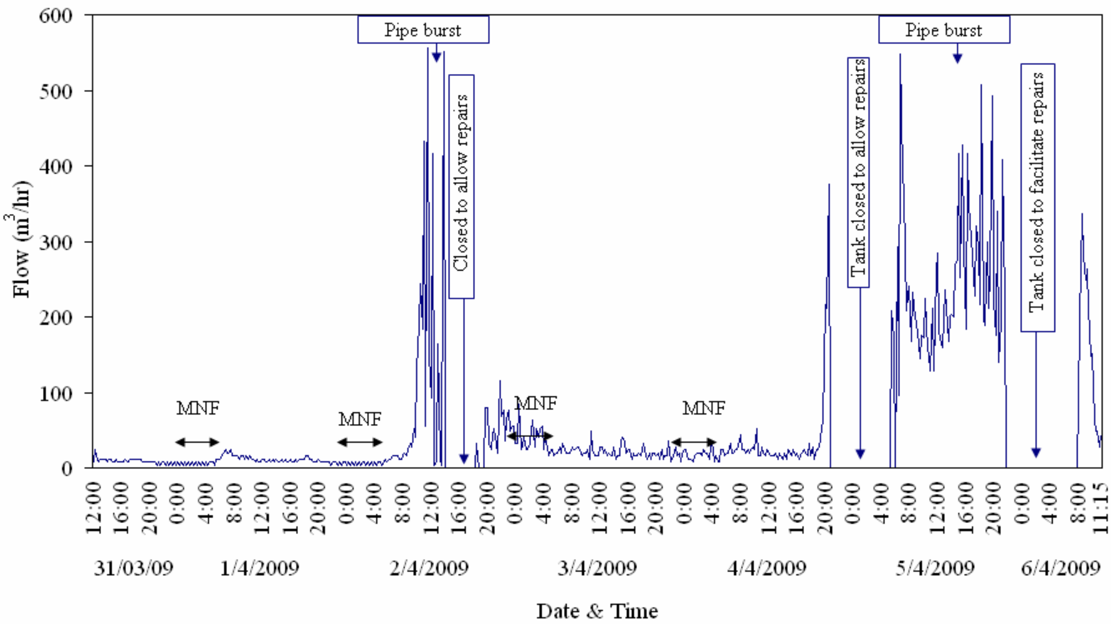


Fig. 5-3: Malonje Tank outflow pattern

The flow logging results in Fig. 5-3 indicate that pipe bursts were a major problem in the zone. There was a burst on the 2nd of April 2009 which lasted for 2-3 hrs and the other one on the 5th of April 2009 which lasted for some 15 hrs, just within a space of 3 days. These major bursts occurred on a 90 mm PVC pipe as shown in the bursts records in Appendix VIII. From the average flows which occurred during the burst period, it was established that 380 m^3 of water was lost in the first burst which lasted for two hours. This volume was three times the average daily consumption of Malonje. From the second burst which lasted for 15 hours, 3000 m^3 of water was lost.

The outflow pattern from Fig. 5-3 also indicates that at some times during the logging period the tank was empty. Whenever there were huge pipe bursts like those which occurred during the time of outflow logging, the tank outlet valve was closed to allow repairs.

Malonje Tank had a problem of overflowing and during data collection this was occurring at least once in a week. The automatic flow control devices were not functioning. Control of overflow was done manually by monitoring the water level and closing the inlet valve when the tank was about to get full. It usually took time to reopen the valve and this made the tank empty at times.

The MNF for this zone were varying, with the lowest as 4 m^3/hr and the highest as 24 m^3/hr which could have been affected by a major leak or burst.

- Sadzi Tank

Fig. 5-3 shows the outflow pattern for Sadzi Tank for the period 6 April 2009 to 9 April 2009

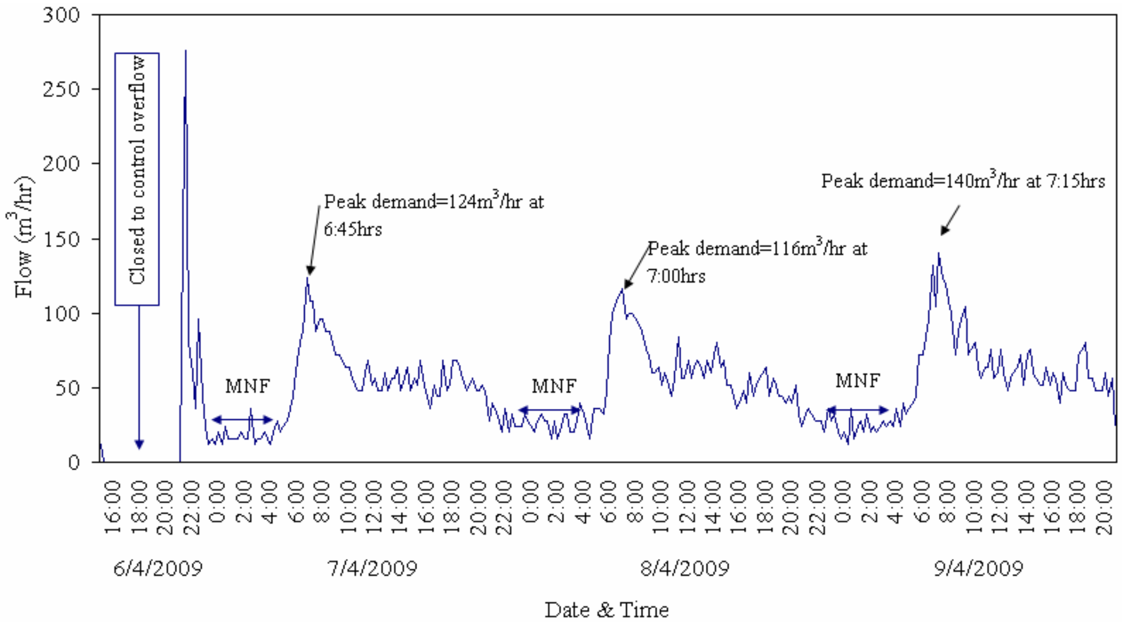


Fig. 5-4: Sadzi Tank outflow pattern

Sadzi Tank was empty during some time of the first day of data logging. In Fig. 5-4, the zero flow registered from 15:30 hrs to 21:30 hrs on the 6th April 2009 confirms this. The tank experienced overflow and this occurred two times during the data collection period. Control of overflow was done manually by monitoring the water levels in the two compartments of the tank and closing the inlet valves when the tank was about to get full. Just like in Malonje, it usually took time to reopen the valves and this made the tank empty. There was a sharp rise in flow at 21:45 hrs on the 6th April 2009. This may be due to the rise in consumption since the tank was initially empty. The 24-hr pattern from 7th April to 9th April was uniform. The MNF ranged from 12 m^3/hr to 16 m^3/hr.

Data logging to obtain flows was an important source of Minimum Night Flow data which were used to obtain real losses. The outflow patterns for a longer period of time say one month can also help the distribution network engineer or in-charge to establish consumption patterns for the particular zone and hence come up with variations in real losses (and unaccounted for water) with respect to consumption patterns. Table 5-6 summarises the MNF for the three study areas. Mtiya did not produce feasible results on the MNF possibly because the flow rates were too low to be sensed and captured by a data logger.

Table 5-6: MNF for the period 27 March to 9 April 2009

Area	**Date**	**MNF [7] (m^3/hr)**	**ENF (m^3/hr)**	**RL (m^3/day)**
Airwing	27/03/09	8	1.2	30
Airwing	28/03/09	8	1.2	30
Airwing	29/03/09	8	1.2	30
Airwing	30/03/09	8	1.2	30
Airwing	31/03/09	8	1.2	30
Malonje	01/04/09	4	1.7	40.8
Malonje	02/04/09	4	1.7	40.8
Malonje	03/04/09	24	21.7	520.8
Malonje	04/04/09	8	5.7	136.8
Malonje	05/04/09	-[8]	-	-
Malonje	06/04/09	-	-	-
Sadzi	07/04/09	12	2.6	62.4
Sadzi	08/04/09	16	6.6	158.4
Sadzi	09/04/09	12	2.6	62.4

- Real Loss Assessment using MNF Analysis

From the flow logging results, the minimum flow occurring between 12 am and 04:00 was taken as the MNF (Table 5-6) as indicated by Farley (2001) and Thornton (2005). Mckenzie (1999) indicates that the measured MNF is composed of background losses, normal night use and excess night flow (ENF) and the SANFLOW model, which was used, breaks down the MNF into these components. Detailed outputs of the SANFLOW model are presented in Appendix VI. Table 5-6 also presents the ENF obtained from the SANFLOW model. The SANFLOW model calculates the ENF as follows:

[7] The minimum flow occurring between 12:00 am and 04:00 am (Farley, 2001)
[8] The tank was closed to facilitate repairs, hence there was no record for MNF.

Expected night use = background losses + normal night use……………...…Equation 5-1

ENF = Measured MNF-Expected night use…………......……………………Equation 5-2

ENF on the night when there was no pipe burst was used to evaluate real losses (RL) using equation 5-3 below.

RL (m^3/month) =ENF (m^3/hr) × (hour/day factor) × 30 days/month…......….Equation 5-3

(*Adopted from Fanner, 2004*).

The maximum ENF value was used hence the hour/day factor of 24 was applied recommended by Lambert (2002). Real losses for the three areas except Mtiya were calculated using the equation 5-3 above. Table 5-7 gives the real losses for the three study areas.

Table 5-7: Real losses obtained from MNF analysis

Area	**ENF (m^3/hr)**	**Real losses (m^3/month)**	**m^3/conn/yr**	**m^3/km/yr**
Airwing	1.2	900	107	9,000
Malonje	5.7	4104	275	20,520
Sadzi	6.6	4752	59	4,713

Hence the apparent losses (AL) for the three areas were calculated as:

AL (m^3/month) =Average UFW- RL…………………………...…………….Equation 5-4

(Adopted from Rizzo, 2007)

The real losses for Mtiya were not calculated directly from the excess night flows as the flow logging results were not used. Therefore since there were few connections an estimate of apparent losses for this area was done. An assumption was made that errors causing apparent losses were contributing a 5% loss on consumption. This was mainly based on the meter errors which will be discussed later. Therefore for Mtiya which had an average monthly consumption of 409 m^3, the actual consumption was:

Actual consumption = (Consumption/Accuracy)
= 409/0.95
= 430.5 m^3/month

Hence
Apparent losses = 430.5-409
= 21.5 m^3/month

And
Real losses = UFW- Apparent loss
= 28-21.5
=6.5 m^3/month

- Partitioning of Unaccounted for Water for specific study areas

The average UFW and real losses for the zones have already been presented in Tables 5-4 and 5-7 respectively. The apparent losses were obtained from the difference of the average UFW and real losses in each of the three zones as per equation 5-4, and real losses for Mtiya were obtained as the difference of UFW and apparent losses as recommended by Mckenzie *et al.* (2002b). Table 5-8 gives the partitioning of UFW into real and apparent losses for the study areas.

Table 5-8: Partitioning of UFW

Zone	**UFW (m^3)**	**Real losses**				**Apparent losses**	
		m^3/month	**%**	**m^3/conn/yr**	**m^3/km/yr**	**m^3/month**	**%**
Airwing	1,234	900	73	107	9,000	334	27
Malonje	5,504	4,104	75	275	20,520	1,400	25
Sadzi	12,230	4,752	39	59	4,713	7,478	61
Mtiya	28	6.5	23	1.9	55.7	21.5	77
Total	18,996	9,762.5	51	91	6,850	9,233.5	49

Table 5-8 shows that the real losses in the specific study areas were 51% and apparent losses were 49% of the total losses in the four study areas. This indicates that the apparent losses in the distribution system can be as high as real losses contrary to the default value of 20% assumed in most water utilities in South Africa (Seago *et al.*, 2004). Apparent losses are valued at retail billing rates whereas the real losses are valued at the variable cost of water production and distribution as indicated by Charalambous (2005) and Tabesh and Asadiani Yekta (2005), hence the SRWB should consider that the reduction of apparent losses is as important as the reduction of real losses. It is through partitioning that the water utility could be able to know the levels of both real and apparent losses and effectively plan the UFW control strategies.

- Airwing Zone

Airwing zone had 73% of unaccounted for water occurring as real losses. There were few connections in the zone (52) and management of these connections might not be a problem hence apparent losses were much lower than the real losses. Losses occurring beyond the Airwing institution bulk meter were not part of the utility's losses and this can also be one of the reasons why there was low overall unaccounted for water for Airwing. Control of real losses in this zone should be a priority area as they were much higher than apparent losses.

- Malonje Zone

This zone had real losses of up to 75% of the unaccounted for water. The high level of real losses was mainly due to the frequent pipe bursts as suggested by Thornton and Lambert (2007), occurring in the area as evidenced by the results of outflow logging in Fig. 5-3 and records on the faults. There was a high level of real losses than apparent losses hence UFW control strategies should focus more on real losses than apparent losses.

- Mtiya

There was low level of real losses of 23% in Mtiya zone. The distribution system was not very old as it was commissioned in the year 2001 hence the real losses were low. The number of connections (customers) was small (42) hence the level of apparent losses were due to meter under-registering and meter reading errors as suggested by Sánchez (2007).

- Sadzi

Sadzi zone had apparent losses as high as 61%. There were a lot of customers/connections in the zone (965) and management of such customers in terms of meter readings, data entry, illegal connections may be a problem (Marques and Monteiro, 2001; Kingdom *et al.,* 2006). Apparent losses in Sadzi were a major problem and according to Kingdom *et al.* (2001), UFW control strategies should give priority to this component of unaccounted for water. From the faults records, it also showed that illegal connections were more suspected in Mpunga, Sadzi and Chizalo areas. These areas are fed by Sadzi Tank.

- Infrastructure leakage index (ILI) of the study areas

The ILI provides an indication of how serious the leakage occurring in a particular area is compared to the theoretical minimum level of leakage that can be achieved (Seago *et al.,* 2004). Table 5-9 gives the ILI for the study areas which was determined from the equation:

$$ILI = CARL / UARL \quad \text{......Equation 5-5}$$

Where:
CARL = Current annual real losses obtained from the MNF analysis

$$UARL = (18 \times L_m + 0.80 \times N_c + 25 \times L_p) \times P \quad \text{......Equation 5-6}$$

UARL = Unavoidable annual real losses (l/d)
L_m = Length of mains (km)
N_c = Number of service connections (main to meter)
L_p = Length of unmetered underground pipe from street edge to customer meters (km)
P = Average operating pressure at average zone point (m)

(*source: Mckenzie et al., 2002a)*

Table 5-9: ILI for study areas

Area	CARL (m^3/month)	UARL (m^3/month)	ILI
Airwing	900	155	6
Malonje	4,104	279	15
Sadzi	4,752	1485	3.2
Mtiya	6.5	87	0.07

According to Mckenzie *et al.* (2002a), for most African water supply systems it would be unusual to achieve an ILI value of below 2.0 and values in the order of 5.0 to 10.0 are relatively common and represent systems in a reasonable condition. The ILI values for the 30 South African water suppliers ranged from 0.08 to 15.96 (Seago *et al.,* 2004). Therefore, although the study areas are not full water utilities, it can be concluded that ILI for Airwing and Sadzi were within the acceptable range and the ILI for Mtiya was even much lower than the minimum suggested by Mckenzie *et al.* (2002a). This suggests that real losses in Mtiya were not a problem. The ILI for Malonje of 15 implied that the condition of the distribution system was deteriorating and real losses were therefore a very serious problem.

- Partitioning of unaccounted for water for Zomba City

Based on the factors influencing UFW, estimated levels of UFW and results from meter testing in the specific study areas, components of UFW for the entire Zomba City water supply system were estimated.

The estimations were based on two assumptions. The first assumption was based on apparent losses due to meter errors. The meter error of 6.5% was used which incorporated other errors such as data acquisition, and estimation errors based on similar study conducted by DWSD (2004). Table 5-10 gives a breakdown of the UFW in Zomba City based on meter errors.

Table 5-10: Zomba City UFW partitioning based on meter errors

Total UFW (m^3/month)	**Real Losses**				**Apparent Losses**	
	M^3/month	**%**	**m^3/conn/yr**	**m^3/km/yr**	**m^3/month**	**%**
102132	78562	77	157	6,040	23570	23

Based on meter errors, the UFW for Zomba was estimated as composed of 77% real and 23% apparent losses.

The second estimation composed of grouping the other distribution tanks/areas based on their similar characteristics in terms of size, age with the specific study areas. Table 5-11 below gives a summary of breakdown of UFW based on the second assumption. The specific study areas covered only 20% of the service connections and/or 11% of the distribution mains, thus the assumptions made may not be true for the whole system but can give a picture of the UFW partitioning in the whole system. Further assessment of real and apparent losses will assist to come up with an accurate partitioning of UFW for the whole Zomba City water supply system.

The total distribution losses were estimated to be 91,318 m^3/month and for the average UFW of 102,132 m^3/month, the transmission losses were calculated as 10,814 m^3/month, that is, average UFW minus distribution loss. Therefore estimated total real losses were 72,716 m^3/month.

Table 5-11: Distribution losses for Zomba based on results from study areas

Tank	Tank Name	Tank Size (m^3)	Distribution loss (m^3/month)	Real loss (m^3/month)
T10	Hydrostat	341	28	7
T11	Footman	25	28	7
T12	Officers Mess	227	28	7
T13	Kalimbuka	2,718	12,230	8560
T14	Sadzi	1,500	12,230	4752
T15	Mtiya	250	28	7
T16	Mountain	25	28	7
T20	Malemia	455	1,234	900
T21	Commissioner	591	1,234	900
T22	CCAP	705	5,504	4104
T23	Maybole	705	5,504	4104
T24	University	1,000	5,504	4104
T26	Namiwawa	1,000	12,230	8560
T27	Air Wing	250	1,234	900
T28	Ndangopuma	1,500	12,230	8560
T29	Chirunga	1,000	5,504	4104
T30	Naisi Spur	26	28	7
T31	Old naisi	250	5,504	4104
T32	Mulunguzi	455	5,504	4104
T33	Malonje	250	5,504	4104
Total losses			91,318	61902

Table 5-12 gives a breakdown of the UFW in Zomba City based on estimated distribution losses.

Table 5-12: Zomba City UFW partitioning based on distribution losses

Total UFW (m^3/month)	Real Losses				Apparent Losses	
	m^3/month	%	m^3/conn/yr	m^3/km/yr	m^3/month	%
102,132	72,716	71	145	5,595	29,416	29

Real loss from Table 5-10 is higher than that presented in Table 5-12. UFW partitioning in Table 5-10 is based on one element of meter error, which cannot be a good proxy of the total apparent losses. Table 5-12 gives a closer estimate of UFW components as it has been derived based on a number of factors on the ground such as size of zones, and condition of the system. Therefore UFW components of 71% real losses and 29% apparent losses are considered reasonable.

Based on the results established by Seago *et al.* (2004), the estimated apparent loss for Zomba City compares well with the apparent losses for a water supply system in South Africa having most of its meters over 10 years old, the water quality of the area being fairly good (8 %), charging non flat rate tariff with high occurrence of illegal connections (8 %), and its data transfer/acquisition being poor (8 %).

The average real loss of Zomba City at 404 *l*/connection/day is higher than the average annual real loss of 340 *l*/connection/day for the 30 South African water supply systems which was established by Seago *et al.* (2004). Seago *et al.* (2004) also reported that the average real losses for the international data set which included 27 diverse water supply systems in 19 countries was 276 *l*/connection/day which is much lower than that of Zomba City. It can be concluded therefore that the real losses in Zomba City were above the average real losses reported in literature.

- Revenue Loss from Unaccounted for Water

The entire Zomba City water supply system had an average UFW of 102,132 m^3/month. The average water tariff of US$[9] 0.64/$m^3$; which is currently charged by Southern Region Water Board was used to estimate the revenue loss due to apparent losses as literature states that apparent losses are incurred at retail rate (Charalambous, 2005; Tabesh and Asadiani Yekta, 2005). Water production costs obtained from SRWB included costs of chemicals and power used, and treatment plant staff costs only. Charalambous (2005) indicates that real losses should be valued at the variable cost of water production and distribution which implies that the production costs presented by SRWB were underestimated. Therefore the total production cost of water was assumed to be US$ 0.25/m^3 which was the average urban water production cost according to WHO (2000). Table 5-13 presents the revenue loss due to UFW for Zomba City.

Table 5-13: Revenue loss due to UFW in Zomba City

Area	Real losses (m^3/month)	Equivalent revenue loss (US$)	Apparent losses (m^3/month)	Equivalent revenue loss (US$)	Total revenue loss (US$)
Zomba City	72,716	18,180	29,416	18,820	37,000
Specific study areas	9,763	2,440	9,233	5,910	8,350

From the 2007-2008 SRWB annual operations report (SRWB, 2008c) the monthly operation costs (which included cost of chemicals, water treatment works staff costs and cost of power) for Zomba City were at an average of US$ 7,000/month. The current loss of revenue from UFW for the entire Zomba City is very high at an equivalent of 5-month operations costs. The reduction of UFW in Zomba City will increase revenue to SRWB. The revenue if recovered can be used for the operations and maintenance activities of the water supply system thereby improving the efficiency of the water supply system. Lower UFW also decreases production costs and especially capita investments since less production capacity is required (Nwasco, 2005).

5.3 System characteristics influencing UFW

5.3.1 Pressure and Real Losses

Since the distribution system had no network model, the logging points included boundaries of the pipe network, high spots, and known areas of low and high pressures as suggested by Farley (2001). Elevations of the pressure monitoring points in the study

[9] US$ 1= MK 139.99 on 20th March 2009 (source: National Bank of Malawi)

distribution areas were taken using a GPS. Appendix III presents a summary of the logging points attributes.

From the pressure patterns, the maximum night pressures were taken for each logging point and Table 5-14 provides these pressures and associated elevations.

Table 5-14: Maximum Night Pressures for logged points in the study areas

Area	**Elevation (masl)**	**Night Pressure (m)**	**Area**	**Elevation (masl)**	**Night Pressure (m)**
Airwing (Mkangala)	836	7	Sadzi (Sayenda)	958	32
Airwing (Muhommad)	810	30	Sadzi (Kapalamula)	8 92	56
Airwing (Mdoka	800	36	Sadzi (Mboga)	884	0.4
Airwing (Khalidi)	799	40	Sadzi (Mulima)	883	66
Malonje (Pemba)	959	58.5	Mtiya (Madula)	1025	8.3
Malonje (Pute)	930	81.6	Mtiya (Kupempha)	1005	16
Malonje (Jobe)	910	99	Mtiya (Mkulumba)	990	32.6
Malonje (Dzimbiri)	880	114	Mtiya (Juma)	980	34.7

The maximum night pressures at the center of each zone were roughly taken as average zone night pressures (AZNP) as suggested by Farley (2001) and were used in the analysis of Minimum Night Flows (MNF) using the SANFLOW model. The detailed pressure logging results are presented in Appendix V. Pressure patterns for the four study areas were determined and presented in Figs 5-6 to 5-9. Further to real loss assessment, various types and sizes of pipes in the entire Zomba City distribution system for the mains commissioned in 2001 were obtained and are presented in Appendix VII. Results from the bucket tests are also provided in Appendix VII. Records of pipe bursts for 2008 and 2009 were also obtained and assessed for a common period of 4 months from January to April; summary of assessment is presented in Appendix VIII.

Fig. 5-5 shows the relationship between real losses and pressure for the study areas.

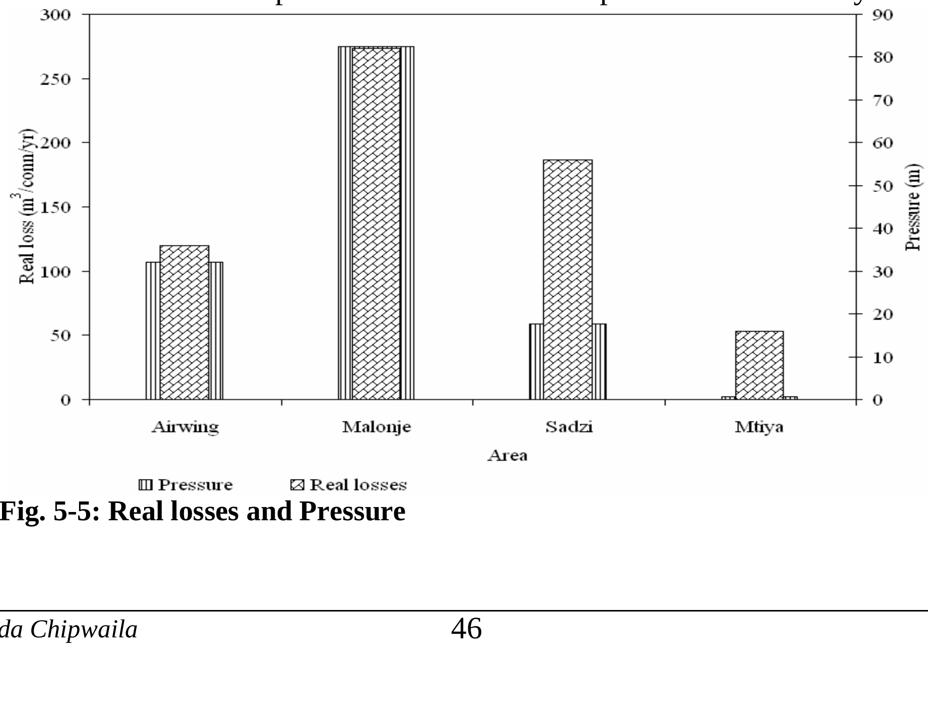


Fig. 5-5: Real losses and Pressure

There was a general relationship between pressure and real losses, except for Airwing area. This indicates that real losses were directly affected by pressure in Malonje and Sadzi, but the high real loss level in Airwing was affected by other factors apart from pressure. Further discussion on pressure and real losses is done in the following sections.

- Airwing Zone

Fig. 5-6 shows the pressure and flow patterns for Airwing area plotted on the same graph.

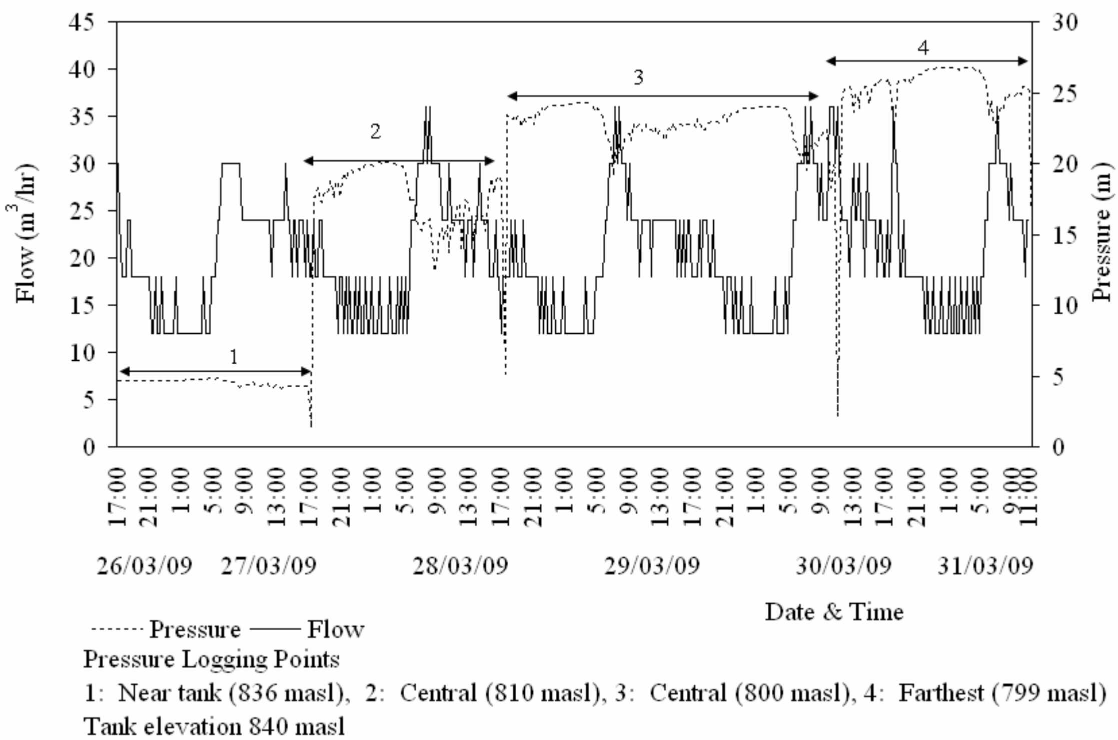
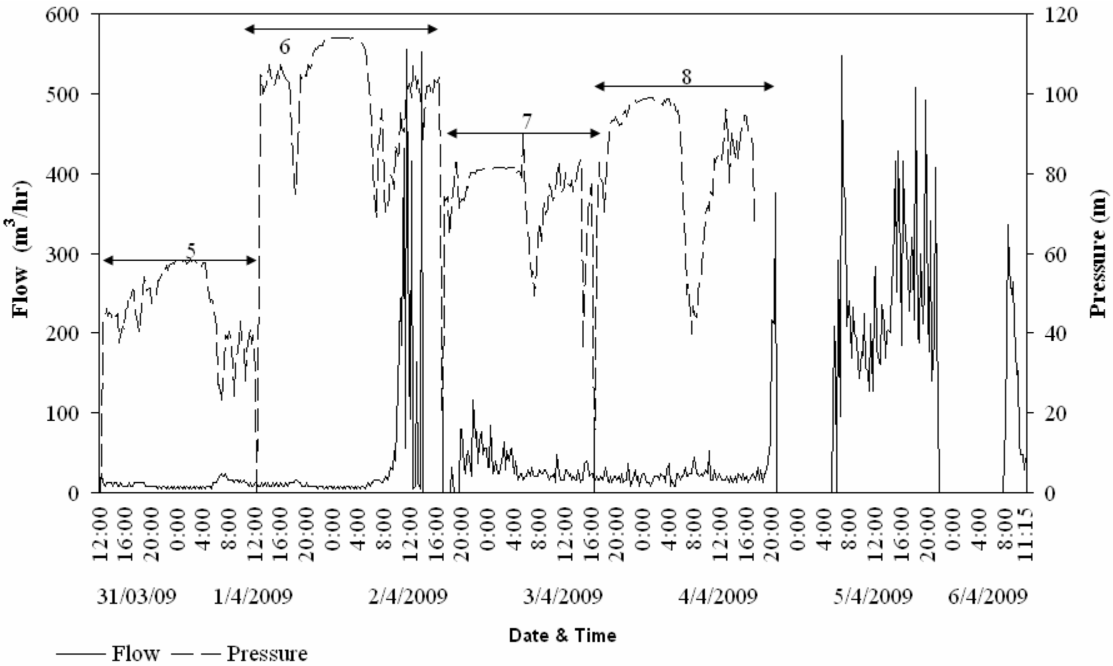


Fig. 5-6: Airwing outflow and pressure patterns

From Fig. 5-6, the pressures were high at low elevations and farthest point. For example Airwing Tank was at 840 masl; points in the distribution area with elevations of 836 masl and 799 masl had pressures around 7 m and 40 m respectively. Fig. 5-6 also indicates that at minimum night flows, pressures were high. Since pressure logging covered all the critical points in the zone, the pattern in Fig. 5-6 can be taken as the general pressure pattern for Airwing. Hence in Airwing pressures at the tap generally ranged from 7 m to 40 m. Pressures in the zone were below 50 m; the threshold to induce major pipe bursts as suggested by Farley (2001). From the faults records, there were also few pipe bursts recorded in the area which confirmed the low levels of pressure. Despite low pressures and few pipe bursts, real losses were high in Airwing. The high level of real losses suggests that there were other leaks caused by age of the mains. This can also suggest a high night water usage in the Airwing institution.

- Malonje Zone

Malonje pressure and flow patterns plotted on the same graph are presented in Fig.5-7.



Pressure Logging Points:
5: Near tank (959 masl), 6: Farthest (880 masl), 7: Central (930 masl), 8: Central (910 masl)
Tank elevation 962 masl

Fig. 5-7: Malonje outflow and pressure patterns

Fig. 5-7 shows that pressures were high at low elevations and farthest point. For instance, Malonje Tank was at an elevation of 962 masl; points 959 masl and 880 masl in the distribution area had maximum pressures around 58.6 m and 114 m respectively. Since pressure logging covered all the critical points in the zone, the pattern in Fig. 5-7 can be taken as the general pressure pattern for Malonje. Hence in Malonje pressures at the tap generally ranged from 40 m to 114 m.

Pressures in Fig. 5-7 were all above 50 m at point 6. There was a 90 mm PVC pipe burst as shown on the flow pattern of the same Fig. 5-7. The burst records presented in Appendix VIII also confirmed that there was a 90 mm PVC pipe burst on this day. The bursts were influenced by the high pressures in this zone. On 75% of the logged time in Malonje, the pressures were above 50 m. Pressures in the area were high enough to induce pipe bursts. The frequent pipe bursts therefore indicates the effect of pressures in the area. It can be concluded therefore that the high level of real losses of 275 m^3/conn/yr was as a result of pipe bursts due to the high pressures and distribution mains age.

- Mtiya Zone

Fig. 5-8 is a plot of pressures in Mtiya distribution system.

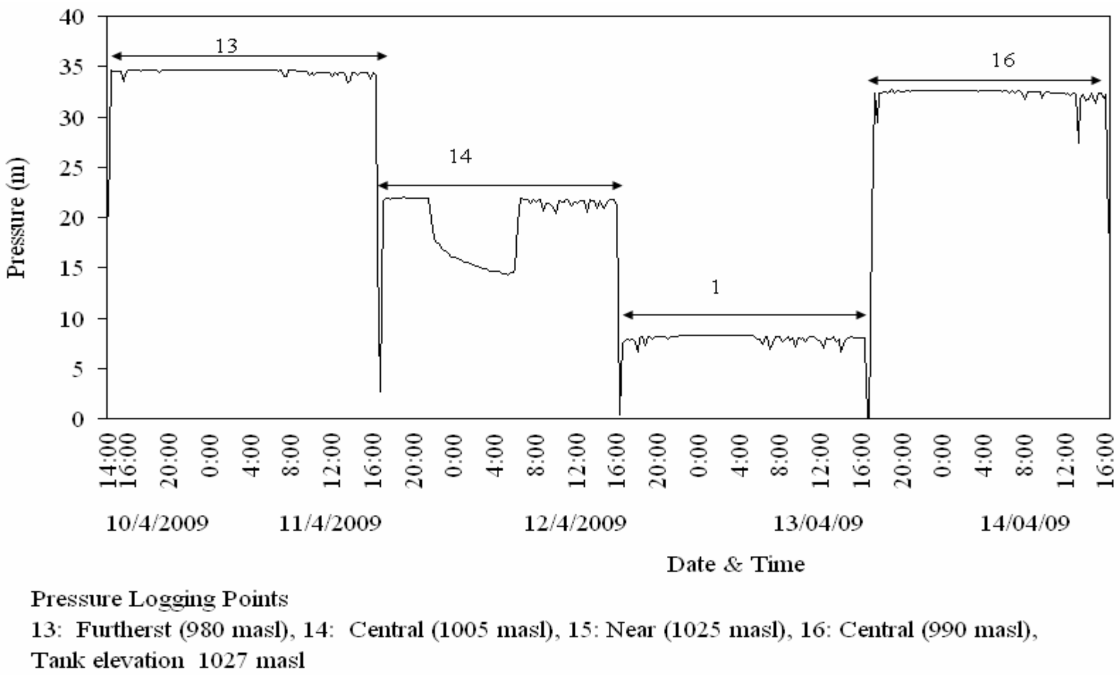


Fig. 5-8: Mtiya pressure pattern

The maximum night pressure obtained in this zone was 34.7 m which occurred between 12 am and 04:00 am of 11th April 2009. The night pressures were as low as 8.3 m at some locations. Since pressure logging covered all the critical points in the zone, the pattern in Fig. 5-8 can be taken as the general pressure pattern for Mtiya. Hence in Mtiya pressures at the tap generally ranged from 8 m to 34 m. Although there was no flow pattern for this area, the pressures were very low to induce pipe bursts in the system which was also quite new hence the real losses in this area were very low. Records of pipe bursts also indicated that Mtiya zone had no problems with pipe bursts.

- Sadzi Zone

Fig. 5-9 shows the Sadzi pressure and flow patterns plotted on the same graph.

At minimum night flows the pressures were high as it is shown in Fig. 5-9 except for one point from18 hrs of 8th April 2009 to 6 hrs of 9th April 2009, where the pressure was almost zero throughout the period. It is possible that the customer's meter valve was closed. This was one of the measures customers in Zomba City took to control theft and vandalism of their service connection materials such as meters, taps, stop corks etc (SRWB, 2008a). Since pressure logging covered all the critical points in the zone, the pattern in Fig. 5-9 can be taken as the general pressure pattern for Sadzi. Hence in Sadzi pressures at the tap generally ranged from 32 m to 74 m. Real losses in Sadzi were at 59 m^3/conn/yr. The real losses were moderately high. From the burst records, Sadzi area had a high frequency of bursts as shown in Appendix VIII. Bursts which were contributing to the 39% real losses were due to the relative high pressures exerted on the old distribution system.

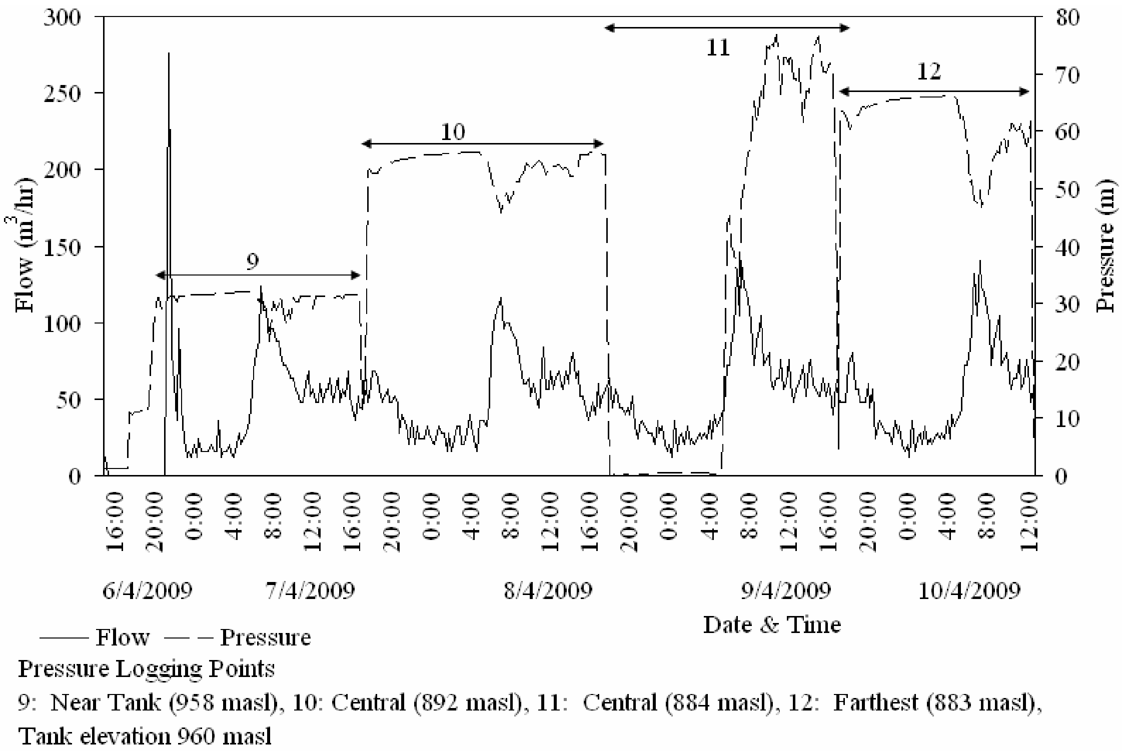


Fig. 5-9: Sadzi outflow and pressure patterns

From the pressure patterns and the level of real losses in the study areas, it can be concluded that real losses in Airwing and Mtiya were not influenced by the pressures in the system while in Malonje and Sadzi real losses were affected by the high pressures in the system.

Pressure is not an independent factor which affects real losses, its effects can be very clear when the distribution system is also very old. The following section discusses the effect of distribution network age on real losses.

5.3.2 Age of distribution mains and Real losses

From the assessment of the distribution drawings, projects and operations reports and from interviews of key staff, it was established that 42% of the distribution mains was laid within the past 10 years and that 58% of the pipe network was laid over 60 years ago. These include cast iron, asbestos cement and galvanised wrought iron (GI). All these materials suffer from degradation over time due to operational measures, environmental conditions and general wear and tear and result in increased leakage in the network (Balkaran and Wyke, 2002). Table 5-15 is a summary of distribution mains, their age and water losses occurring in the study areas. Old mains were laid prior to 2001 and new mains were laid in the year 2001.

Table 5-15: Mains age and unaccounted for water

Area	Total Mains (km)	Old Mains (km)	New Mains (km)	Old Mains (%)	UFW (%)	Real losses		
						(%)	m^3/conn/yr	m^3/km/yr
Airwing	1.2	1.2	0	100	13	73	107	9,000
Malonje	2.4	2.3	0.12	95	62	75	275	20,520
Sadzi	12.1	9.3	2.8	77	51	39	59	4,713
Mtiya	1.4	0	1.4	0	6	23	1.9	55.7

All the pipe mains for Airwing were categorized as old and most of the network in Malonje and Sadzi were classified as old network as well. There was no pipe network in Mtiya prior to 2001 hence the system was categorized as ‘new’.

- Airwing

All the distribution mains in Airwing were old pipes. This zone had 73 % of the UFW as real losses (107 m^3/conn/yr). This was a substantial figure indicating that age of the distribution mains had a significant contribution to real losses. All losses occurring after the Airwing institutional meter did not contribute to revenue loss to the water utility but would be of concern to the utility in cases of low availability of water resource. Pipe bursts were not frequent in the area hence the real losses in the area were likely affected by leaks from the old mains and an increased night usage in Airwing institution.

- Malonje

Malonje area had 95% of its distribution mains as old pipes and approximately 75% of the UFW in the area (275 m^3/conn/yr) were real losses. This signifies first that age of the mains had a significant contribution to real losses and second that age was a major factor on the overall unaccounted for water in this zone. Mains age couple with high pressures in Malonje were influencing on pipe bursts and hence real losses in the area.

- Mtiya

Mtiya distribution mains was laid and commissioned in the year 2001. The system can therefore be categorized as ‘new’. The overall UFW was low at 6% and the real losses were also low compared to the other study areas. For a ‘new’ system like this one the major challenge is on the apparent losses which can be as a result of meter inaccuracies, or data acquisition etc.

- Sadzi

Although 77% of the mains were old network, real losses were only 39% of the total UFW (59 m^3/conn/yr) in this area. There were moderately high pressures exerted on the old pipes and fittings.

Areas which had high pressures and most of the distribution network being very old had high levels of real losses. One such area was Malonje. Airwing had old distribution network but the pressures were relatively low and in Mtiya pressures were low and the network was relatively new hence low level of real losses. It can therefore be concluded that when the system had high pressure and old mains the effect on real losses became very high. New system can withstand high pressures only up to some level.

5.3.3 Meter inaccuracies and Apparent Losses

The field customer meters were tested at various flow rates and errors studied. Most of the meters (about 90%) in the Zomba City and hence the study areas were Kent type with some newer Aquadis and Actaris types. Most of the meters had brass drives, only few had plastic drives hence assessing the effect of drives on meter accuracy was not carried out as it was deemed unnecessary.

New meters were not tested and calibrated prior to installation as recommended by IWA (2008). Furthermore, old meters that were removed for repairs were not tested after repair. Tables 5-16 and 5-17 summarise the meter tests details for the four study areas.

Table 5-16: Distribution of meters tested in study areas

Area	Total meters	No. Tested	%Tested of total	Tested meters above 5 yrs	No. of total meters above 5 yrs (by deduction)	% meters above 5 yrs
Airwing	52	9	17	6	35	67
Malonje	179	15	8	10	119	66
Sadzi	965	22	2	11	4483	50
Mtiya	42	6	14	2	14	33
Total	1238	52	4	29	651	53

From Table 5-16, it can be seen that 53% of the total meters in the study areas were above 5 years of age. Meters which were tested were of various ages. Age was calculated as a period from when the meter was installed as suggested by Sánchez (2007), and Table 5-17 provides the age range of these meters.

Table 5-17: Results of Meter Inaccuracy Tests

Area	Age (yrs)			Meters with Unaccepted	% unaccepted	Estimated Losses (m^3/month)	Loss as % of AL	Loss as % of UFW
	0-5	6-10	11-20					
Airwing	3	5	1	5	55.6	23	8	1.9
Malonje	5	7	3	8	53.3	127	9	2.3
Sadzi	11	7	4	10	45.5	418	6	3.4
Mtiya	4	2	0	1	16.7	1	5	4

All meters tested during the data collection period under-registered, reference of this can be made to Appendix X which gives results of the tested meters in each study area. From the meter inaccuracy results an average under-registering of 5% for unacceptable meters and 2% for acceptable meters were established and adopted for Airwing, Malonje and Sadzi areas and an average under-registering of 2% for unacceptable meters was adopted for Mtiya. The volumetric water loss (apparent loss) as a result of meter inaccuracy was determined and is also presented in the same Table 5-17. Estimated volume lost in a month was worked out as:

Loss = (Residential metered consumption/Accuracy)-residential metered consumption

For Malonje for example this was calculated as:

Loss = $((3388 \times 0.533/0.95)-(3388 \times 0.533))+(3388 \times 0.467/0.98-3388 \times 0.467)$
= $127 m^3$/month

From the sample meters, 55.6 % of meters tested in Airwing had an unacceptable error, Malonje had 53.3% and Sadzi had 45.5% of meters with an unacceptable error. Mtiya had the least number of meters that had unacceptable error (16.7%). The unacceptable error is when the meter error curve is outside the 'tunnel' as shown by some meters in Fig. 5-10.

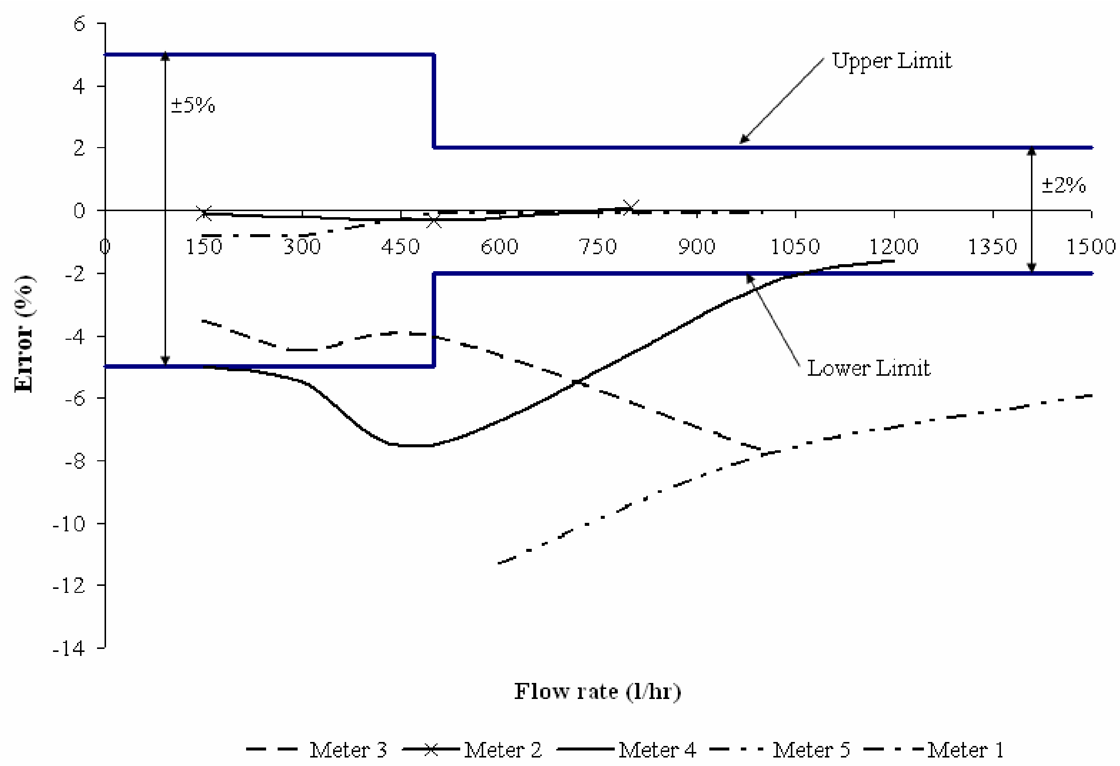


Fig. 5-10: Meter curves for selected meters

Selected meter error curves plotted in Fig. 5-10 above indicate that the error curve may be acceptable when it is within the upper and lower limits or unacceptable when it is outside the lower and upper limit as recommended by IWA (2008). Meter error curves 1 and 2 were within the acceptable limits. Meter error curve 5 was outside the acceptable lower and upper limits hence it was regarded as unacceptable. Meter error curve 3 was within the acceptable limits at low flow rates only and meter curve 4 was within the acceptable limits at high flow rates. The meter needs to be selected in order to fit the customer's consumption pattern as recommended by IWA (2008). Meter 3 may be given to the customer who uses water at low flow rates such as those with one tap only and meter 4 may be give to the customer who uses water at high flow rates such as those with showers and multiple taps. Hence it is important to study consumption patterns of customers to enable proper selection of meters. Meter inaccuracy testing and hence proper meter sizing could actually be an important tool in apparent loss reduction as suggested by Rizzo (2007).

According to Johnson (1996), as much as 2% of unaccounted for water in a zone can be due to under-registration of low flows on domestic meters. Losses due to meter errors in Sadzi and Mtiya were higher than 2% of the total UFW (distribution losses) in the respective areas.

Meter errors contributed to less than 10% of apparent losses in all the study areas. It can be concluded that apparent losses in these areas were also caused by other factors such as data acquisition errors, illegal consumption or estimations of stuck meters consumption. For instance, based on the meter readers' assessment, 13% of the meters in Zomba City were stuck in December 2008; Airwing had 67%, Malonje had 19%, Sadzi had 11% and Mtiya had 7% stuck meters. Errors on estimation of consumption for such meters may contribute to apparent losses as indicated by Rizzo *et al.* (2004). Errors on data acquisition were also a component of apparent losses in Zomba City water supply system. Based on the customer service records, over 90% of customer queries on high bills were related to errors in meter readings and data entry. Such queries were usually resolved by passing credit adjustment on the customer which was a loss of revenue to the utility. Appendix IX presents some queries resulting to the loss of revenue in Zomba City water supply system.

The age of the meters was plotted against the error unacceptability and the results show that there was a direct relationship between these two as shown in Fig. 5-11. The linear trend line was used.

The linear relationship between age of meters and unacceptability is very important. For a known number of meters above 5 years, number of meters with unacceptable errors can be obtained as:

$$M_u = 1.078M_5 - 15.636 \qquad \text{Equation 5-7}$$

Where M_u = number of meters with unacceptable errors
M_5 = percentage of meters above 5 years.

This relationship (equation 5-7) can be used to assess number of meters which under-register to an unacceptable level when the records of meter age are available. For example when 70% of the meters are above 5 yrs old, 60% of all the meters will have an unacceptable error.

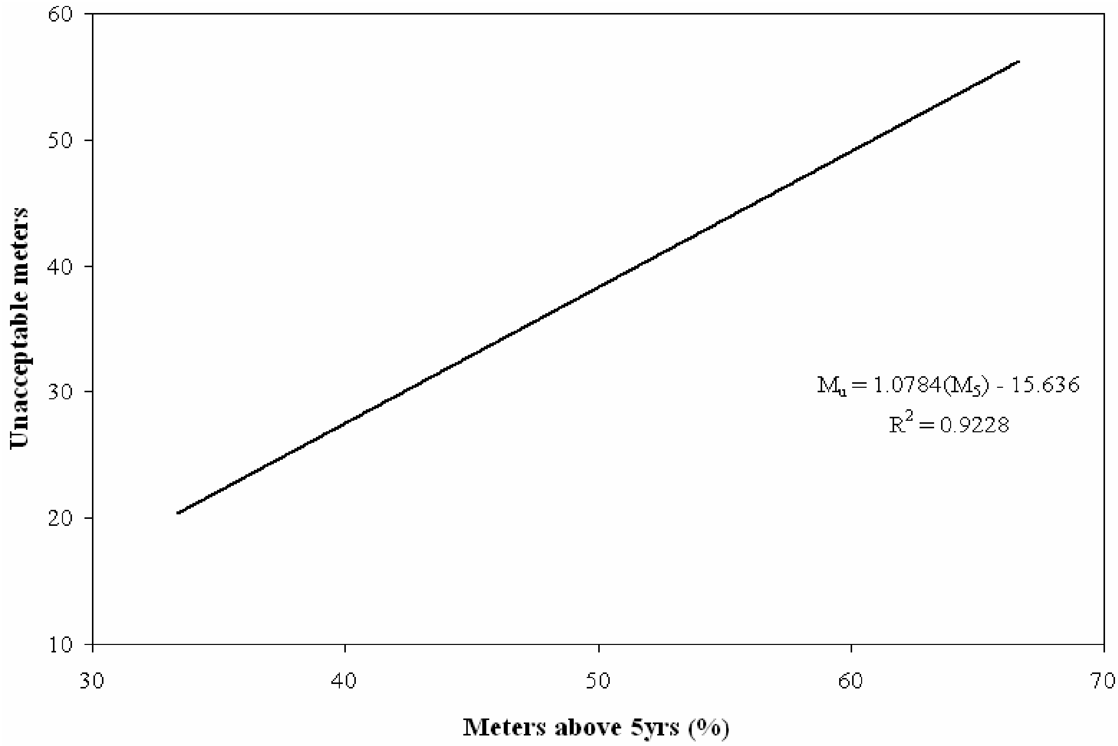


Fig. 5-11: Age of meters and error unacceptability

5.3.4. Tank overflows

Tank overflows were a major problem in the Zomba City water supply system. Malonje Tank (250 m^3) was overflowing at least once in a week and Sadzi Tank (1500m^3) had a 24 hr overflow before valves were closed in one of the days during data collection. These tanks no longer have automatic flow control valves as they were stolen or vandalised Quantification of volume lost through overflows was not done but observations confirm that a huge amount of water was lost due to tank overflows. Lack of functioning level control valves in the reservoirs resulted in real losses and failure to supply (when the inlet valves were left closed).

- Summary of system characteristics affecting UFW

❖ Real losses were affected by leaks and bursts due to mains age and high pressures. Real losses in Airwing area were mainly affected by age of the mains as pressures were low to induce pipe bursts. In Malonje both pressure and mains age contributed significantly to the high level of real losses. Real losses in Sadzi were affected by distribution mains age and moderately high pressures. Pressure and mains age had low impact on real losses and hence unaccounted for water for Mtiya area.

❖ Meter errors contributed less than 10% of apparent losses in each of the areas studied Airwing was the only zone which reported a high level of stuck meters. It is believed that most of its apparent losses were coming from the estimation of consumption from these stuck meters. Meter errors and stuck meters contributed moderately to apparent losses in Malonje and Sadzi zones and in Mtiya zone, these errors were low. Apparent losses in Sadzi were very high at 61%, thus factors such as illegal connections and errors on meter readings should be high. This therefore needs further investigation.

The chart on the next page (Fig. 5-12) gives a summary of factors that affected unaccounted for water in the four study zones. Table 5-18 below gives the key as used in the chart in Fig. 5-12.

Table 5-18: Key for summary of factors affecting UFW

Key	Interpretation
H	The impact of the system characteristic was high
L	The impact of the system characteristic was low
M	The impact of the system characteristic was moderate
AL	Apparent losses
RL	Real losses

1

Area	UFW (%)	Real (%)	Apparent (%)	System Characteristic					
				Mains age	Pressure	Bursts	Over flows	Meter Errors	Stuck meters
Airwing	13	73	27	H	L	L	L	M	H
Malonje	62	75	25	H	H	H	H	M	M
Sadzi	51	39	61	H	M	H	H	M	M
Mtiya	6	23	77	L	L	L	L	L	L

2

Area	Mains age (%)
Airwing	100.0
Malonje	95.0
Sadzi	77.0
Mtiya	0.0

3

Area	Pressure (m)
Airwing	36
Malonje	81.6
Sadzi	56
Mtiya	16

4

Area	Bursts (No.) (Jan-Apr 09)
Airwing	4
Malonje	40
Sadzi	90
Mtiya	1

5

Area	Meter Error (%)
Airwing	8
Malonje	9
Sadzi	6
Mtiya	4

6

Area	Stuck Meters (%)
Airwing	67
Malonje	19
Sadzi	11
Mtiya	7

7

Area	Unknown RL
Airwing	H
Malonje	L
Sadzi	L
Mtiya	L

8

Area	Unknown AL
Airwing	L
Malonje	H
Sadzi	H
Mtiya	H

Fig. 5-12: Influence of system characteristics on UFW

❖ Unknown Real Losses

In Airwing all the distribution mains were old and real losses were high (73%), but the area did not have a lot of pipe bursts. It can be concluded therefore that leaks in the old pipe joints were high causing the high level of real losses. Most of the distribution mains in Malonje were old pipes and there were high pressures in the system which caused frequent pipe bursts. It can hence be deduced that the level of real losses which was unknown was very low. Real losses in Mtiya were low: distribution mains were new, and pressure and pipe bursts were low in the zone. A high percentage of Sadzi distribution mains were old (77%). The area also had moderately high pressures. These two characteristics caused frequent pipe bursts. It can be concluded that the level of real losses which was unknown was very low.

To combat the real losses in Airwing, Malonje and Sadzi, the main focus would be on the age of mains as the three areas had a high percentage of old distribution mains. Pressures in Sadzi and Airwing were not very high such that mains replacement alone can contribute significantly to the real loss reduction. As stated earlier on that significant effect of pressure becomes very clear when the distribution network is very old. Malonje requires the attention on both mains and pressures.

❖ Unknown Apparent Losses

The major causes of apparent losses in Airwing zone were stuck meters and meter errors hence the level of unknown apparent losses was low. Meter errors and stuck meters in Malonje did not contribute significantly on the apparent losses in the zone. This indicates that the level of unknown apparent losses in this area was very high. With 179 connections it is important to further investigate the other causes of apparent losses such as meter reading errors and illegal connections in the zone.

In Sadzi, meter errors and stuck meters were contributing low to apparent losses. This indicates that the level of unknown apparent losses was high. This zone had 965 connections. Errors in data acquisition and illegal connections may be very common in this zone. Further assessment on the same was very important as this zone had a high level of UFW as apparent losses (61%). Mtiya had a high level of apparent losses, although overall the UFW was only at 6%. Meter errors and stuck meters had low effect on apparent losses, implying that the level of unknown apparent losses was high. Being a small zone, further investigation would be required on the other possible causes of apparent losses especially meter readings or data acquisition errors.

5.4 Relationships between system characteristics and unaccounted for water

Based on the findings on effect of system characteristics on real and apparent losses, some mathematical relationships were developed to predict the losses as a result of the system characteristics. The following section discusses these relationships.

- Apparent losses and age of meters

One of the factors which influence meter errors is the age of meters. Apparent losses as a result of meter age based on the results from the four study areas were assessed and a relationship was developed which can describe the effect of number of meters which were more than five years on the apparent losses. Table 5-19 shows the parameters used to develop this relationship.

Table 5-19: Parameters for meter age and apparent losses

No of meters above 5 yrs	Apparent loses due to meter errors (m^3/month)
35	23.0
119	95.0
483	285.5
14	1.0
651	404.6

Fig. 5-13 plots the relationship between meters above 5 years and apparent loss due to meter errors.

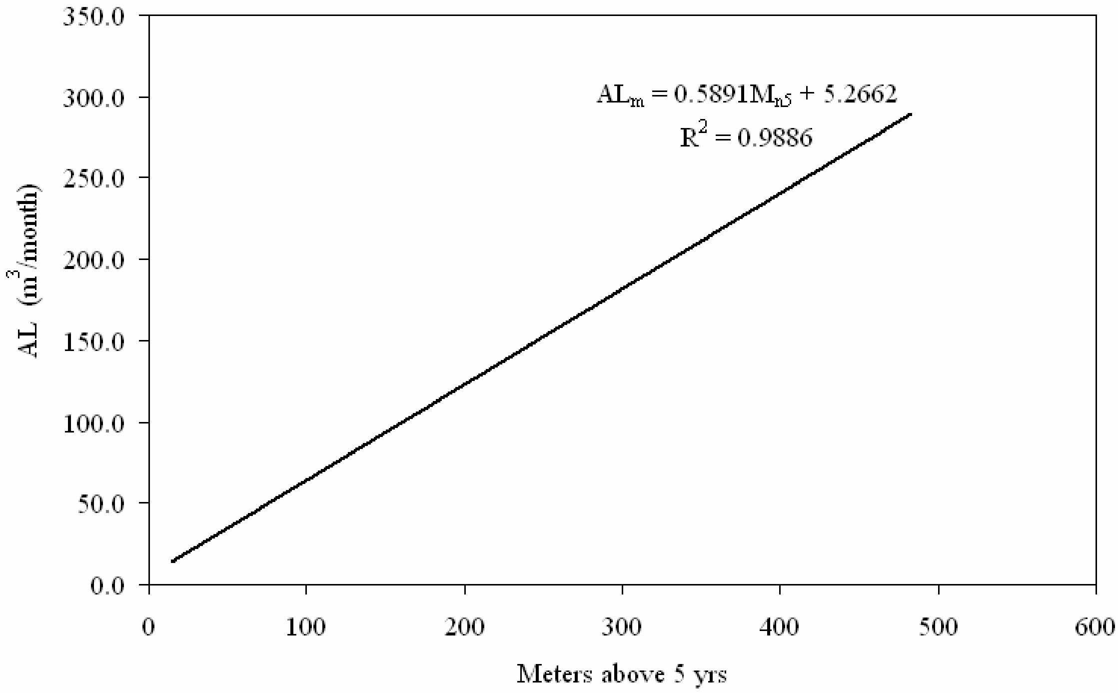


Fig. 5-13: Relationship between apparent losses and meter age

Fig. 5-13 indicates that apparent losses due to meter errors were directly proportional to number of old meters. In this case the maximum age for a well performing meter was taken as five (5) years. The relationship obtained was

AL_m = $0.5891M_{n5} + 5.2662$ ……………………………………..…..Equation 5-8

Where:

L_m = Apparent loss due to meter under-registering (equivalent volume) in a month;

M_{n5} = Number of meters whose age was above 5 years.

Table 5-20 presents a comparison between the original apparent losses due to meter errors obtained from the results for the study areas and the apparent loss calculated from the relationship developed (equation 5-8).

Table 5-20: Error assessment for apparent loss due to meter age

No of meters above 5 yrs	Original apparent loss	Calculated Apparent loss	Error	Error (%)
35	23.0	25.9	2.9	13
119	95.0	75.4	-19.6	-20.6
483	285.5	289.8	4.3	1.5
14	1.0	13.5	12.5	1250
651	404.6	388.8	-15.8	-3.9

In Table 5-20 above, an error of 1250% is an outlier, and if the equation accommodates an error of ±20% (which is the maximum in the table) then the values of calculated apparent losses will be within the values of original apparent losses.

Therefore Loss = $(0.5891\times M_{n5}+5.2662) \pm 20\%$ can be adopted.

Meter change-out program

Apart from use of the above equation, a residential meter change-out program should be put in place for those meters within the City of Zomba. This would include testing a sample of the removed meters, being sure to note age, location, size, and meter type to document inaccuracies. This will provide a better estimate of UFW attributed to the meters. Additionally, this program could be used to develop a schedule for replacing meters that are no longer accurate. The assessment on the meter accuracy showed that most of the meters even between 6 and 10 years had unacceptable errors. A meter change-out program of 10 years is therefore suggested. This will enable a gradual but systematic meter change program than to replace tens of thousands of stopped meters within a few months.

- Apparent losses and number of connections

There exist a direct relationship between apparent losses and number of connection in a water supply system. The form of the equation will differ from one area to the other depending of the characteristics of the meters and how they were installed in an area. Table 5-21 shows the plotting parameters used to develop this relationship.

Table 5-21: Parameters for number of connection and apparent losses

No connections	Apparent loses
52	276.4
179	1,371.2
965	7514
42	26
1238	9,187.6

Fig. 5-14 gives the relationship between apparent losses and the number of meters obtained from the four study areas.

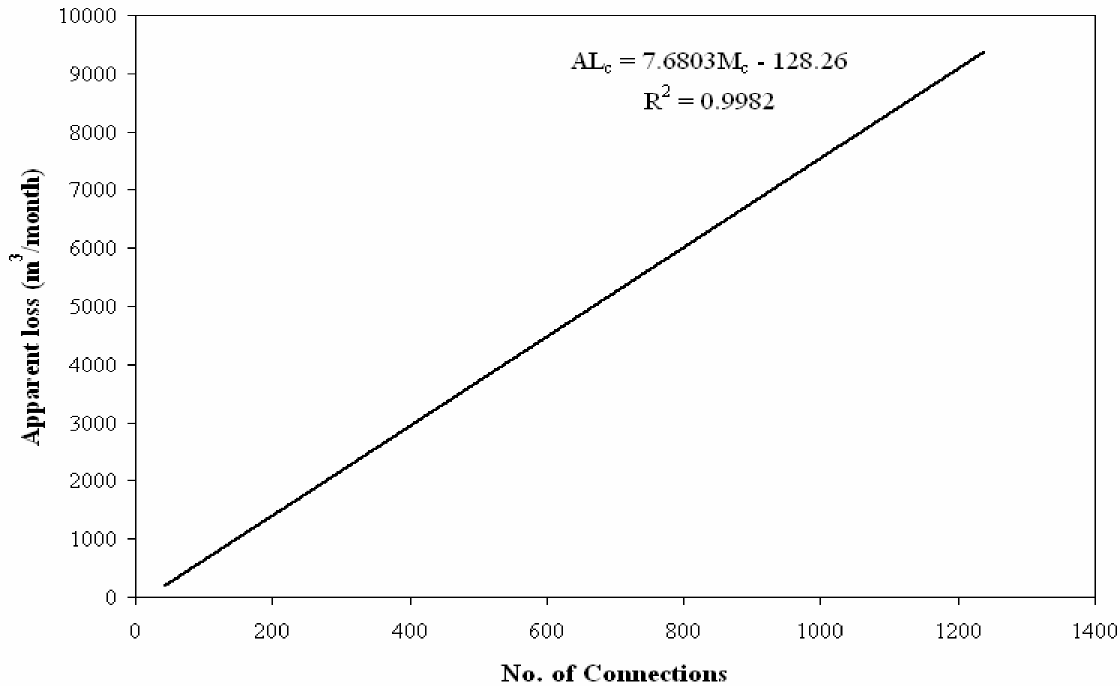


Fig. 5-14: Relationship between apparent losses and number of connections

Fig. 5-14 indicates that apparent losses were directly proportional to number of connections. The relationship obtained was:

AL_c =7.6803M_c-128.26…………………………………………..…….Equation 5-9

Where:
AL_c = Apparent loss (equivalent volume) in a month;
M_c = Number of connections

Table 5-22 presents a comparison between the original apparent loss obtained from the results for the study areas and the apparent loss calculated from the relationship developed above (equation 5-9).

Table 5-22: Error assessment for apparent loss based on number of connections

No of connections	**Original apparent loss (m^3/month)**	**Calculated Apparent loss (m3/month)**	**Error (%)**	**Error (%)**
52	276.4	271.1	-5.3	-1.9
179	1,371.2	1246.5	-124.69	-9.1
965	7514	7283.2	-230.8	-3.7
42	26	194.3	168.3	647
1238	9,187.6	9380	192.35	2.1

In the Table 5-22 above an error of 647% is an outlier, and if the equation accommodates an error of ±10% (which is close to the maximum in the table) then the values of calculated apparent losses will be within the values of original apparent losses.

Therefore Loss = $(7.6803 \times M_c - 128.26) \pm 10\%$ can be adopted.

This relationship can easily be applied to different zones in Zomba City water supply system since their characteristics are similar to those of the study areas. Apart from this relationship, apparent loss due per connection for Airwing, Malonje, and Sadzi were 5.3, 7.7 and 7.8 m^3/conn/month respectively; with an average of 7 m^3/conn/month. In addition, the average loss due to meter error was estimated to be 0.4 m^3/conn/month. This is equivalent to loss of 10 l/day which can be for a household that uses 200 l/day and having a meter error of 5%. Most of the areas in Zomba City have the same characteristics as the three areas above.

- Pressures and bucket filling times

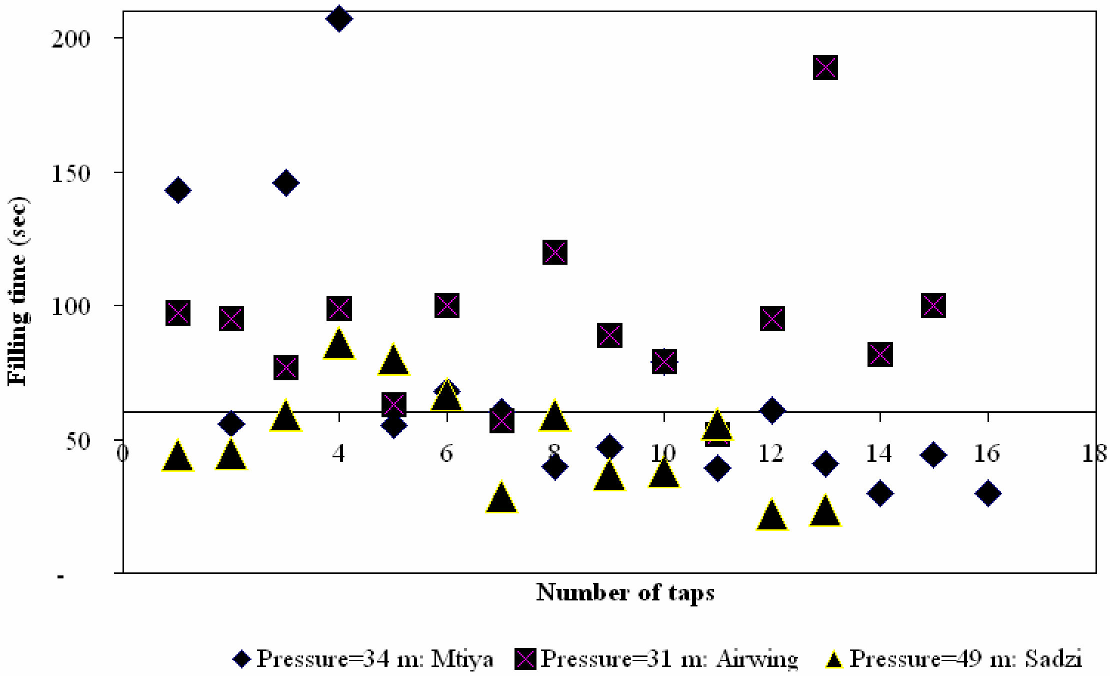


Fig. 5-15: Service quality in terms of pressure and filling times

The bucket tests were carried out in the three areas; Airwing, Sadzi and Mtiya to assess if the pressures were adequate to achieve good service quality to customers. Results of bucket tests are presented in Appendix VII. Although filling times are not directly related to real losses and hence unaccounted for water, the results can be used to answer some questions related to pressure and real losses. From Fig. 5-15, 77% of the taps tested in Sadzi had their discharge time of equal or less than 60 sec/20 *l*, Mtiya had 71% and Airwing had 13%. Level of service quality in terms of pressure was good in Sadzi and

Mtiya and low in Airwing. Pressures were low in Airwing and this can suggest that real losses in Airwing were not very much influenced by pressure but rather age of the mains. Pressures in Sadzi were high hence the filling times in the area were less, mostly at less than 1 minute, hence good service quality to customers. Real losses in Sadzi were affected by both age of mains and pressure.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

From this study the following conclusions were made.

- The average unaccounted for water for Zomba City water supply system from 1999 to 2008 was 27.5%. This was above the recommended UFW for Southern African urban water utilities of 20%.

- Distribution losses in the specific study areas ranged from 6% (in Mtiya) to 62% (in Malonje) with real losses ranging from 23% to 75%. The overall UFW constituted 71% of real losses (404 *l*/connection/day) and 29% of apparent losses. The average real loss for Zomba City was higher than the averages established for the 30 South African water supply systems and for the international data set composed of 27 water utilities.

- Various zones had different levels of distribution, real and apparent losses and therefore different actions can be taken for each zone to combat UFW. It can therefore be concluded that UFW partitioning is an important tool on deciding areas of priority during planning and implementation of UFW reduction strategies. The utility may also be able to schedule activities of UFW control effectively.

- In all the specific study areas, 51% of the UFW were from real losses while 49% came from apparent losses. This can show that apparent losses are as equally important as real losses and as they occur at a retail rate they constitute a high loss of revenue. Therefore UFW control strategies should focus on both components.

- Various system characteristics had shown that they impact differently on levels of UFW in the four zones. Real losses were affected by the age of the distribution mains in Airwing zone. Real losses in Malonje were influenced by pipe burst due to high pressures coupled with distribution mains age. In Sadzi, meter errors had low impact on apparent losses and real losses were due to mains age and pressure. Effects of pressure and mains age in Mtiya had low impact on real losses in the area. Tank overflows were frequent in Malonje and Sadzi. Study of system characteristics also gives a clue on the effects of various factors on real and apparent losses.

6.2 Recommendations

The following recommendations were made:

- Continued MNF assessment to come up with real loss patterns and further UFW partitioning in the remaining areas of the city water supply system.

- Quick location and response to bursts in all the study areas is recommended. Installation of pressure reducing valves (PRVs) in strategic points and investigation on feasibility of pressure management for real loss reduction should be carried out in Malonje area. Pipe replacement should be done in Airwing and Sadzi. A pipe rehabilitation and replacement program for the entire City should be developed in order to replace all the old pipes (over 90 km) that have exceeded their useful service life.

- A further investigation into pipe age, pressure and meter age on UFW in other areas should be done so that when combined with results from this study will allow selection of the most effective UFW control strategy for all the areas in Zomba City.

- Routine meter error assessment, documentation, repair and replacement are recommended to reduce losses due to meter errors. Efficiency in meter readings, timely data sharing and transfer such as transfer of a new water connection from operation section to billing section are also recommended. Thus capacity building for meter readers, billing officers and operation team is very crucial. Investigation on illegal customers in Sadzi should be carried out to minimize the apparent losses which are currently very high.

- Replacement (installation) of automatic flow control devices for the tanks in Malonje and Sadzi to control overflows is recommended. Adequate security should also be available to guard on the tanks to minimise vandalism.

7.0 REFERENCES

Actaris Meter Systems, 2004. Portable Electronic Bench for Residential Hydrometer Calibration. Hidrotest III User Manual. Unpublished.

Baietti, A., Kingdom W, van Ginneken, M., 2006. Characteristics of well performing public water utilities. World Bank Water Supply & Sanitation Working Note No. 9.www.worldbank.org/watsan (accessed 10/8/2008).

Balkaran, C., Wyke, G., 2002. Managing Water Loss: Strategies for the Assessment,Reduction and Control of Non-Revenue Water (NRW) in Trinidad and Tobago. Available on: http://oocur.org/Proceedings/Presentations/Wyke1.pdf (accessed Nov 2008).

Butts, K. H., 1997. The strategic importance of water. US Ar War College Quarterly. Parameters. Spring, 1997: 63-83.

Charalambous, B., 2005. Experiences in DMA redesign at the Water Board of Lemesos, Cyprus. Paper to the IWA Special Conference 'Leakage 2005', September 12-14, Halifax, Canada, available on: http://www.studiomarcofantozzi.it, accessed Feb 2009.

DWSD (Detroit Water and Sewerage Department), 2004. An evaluation of Unaccounted-for water comprehensive water master plan DWSD contract no. Cs-1278. Detroit Water and Sewerage Department Final report. New York.

ESIA (Environmental and Socio Impact Assessment), 2009. Blantyre-Zomba Trunk Road Rehabilitation Project. Project No. P-MW-DB0-011. Lilongwe.

Fanner, P., 2004. Assessing Real Losses, including Component Analysis and Economic Considerations: A Practical Approach. Water21 Article No 6, IWA Publishing, London.

Farley, M., 2001. Leakage Management and Control. A best Practice Training Manual. World Health Organisation, Geneva, Switzerland. http://www.worldwaterweek.org/stockholmwatersymposium/Abstract_Volume_07/Microsoft%20Word%20-%20Workshop%203.pdf (accessed 23/11/08).

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., Jonker L., Robinson P., van der Zaag P., 2003. WaterNet Post-graduate training module on Water demand management. IUCN-World Conservation WDM Phase II Project. Zimbabwe.

ICTR (Institute of Corporate Training and Research), 2005. Water and Sewer Reticulation Design and Management. Course notes. Unpublished.

IWA, 2008. IWA water balance with modified Apparent Loss component. IWA Apparent Loss Manual in Preparation. Unpublished.

Johnson, P.V., 1996. Unaccounted for Water puzzle: More Than Just Leakage. Florida Water Resources Journal, 37-42.

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. World Bank, Washington DC.

KWA (Kansas Water Authority), 2002. Assessment of Unaccounted For Water. Kansas 1998-2010. Available on: http://www.kwo.org/Reports%20Publications/2010%20Assessment/UFW%20 (accessed: 12/11/2008)

Lahmeyer International, 2000. Zomba Water Supply Project Report. National Water Development Project. Zomba, Unpublished.

Lambert, A.O., 2002. Water Loss Management and Techniques. International Report. Water Science and Technology: Water Supply Vol 2. No. 4.

Lambert, A.O., 2003. Assessing non-revenue water and its components: a practical approach. Water 21, August, 50–51.

Lambert, A., Hirner, W., 2000. Losses from Water Supply Systems: Standard Terminology and Recommended Performance Measures. The IWA blue pages: The IWA information source on drinking water issues. London, UK.

Liemberger, R., 2002. Do You Know how Misleading the use of wrong performance indicators can be? A Paper presented at the IWA Managing leakage Conference, November, Cyprus.

Liemberger, R., Brothers, K., Lambert, A., McKenzie, R.S., Rizzo, A., Waldron, T., 2007. Water Loss Performance Indicators. Proceedings of IWA Specialised Conference ‘Water Loss 2007’ held in Bucharest, Cyprus, London, 148-160.

Marques R.C., Monteiro A. J., 2001. Application of performance indicators in water utilities management -A case study in Portugal. Water Science and Technology Vol 44 No 2-3 pp 95-102.

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.

McKenzie, R.S., 1999. SANFLOW User Guide. South Africa Water Research Commission, WRC Report No. TT 109/99, Pretoria, South Africa.

McKenzie, R.S., Lambert, A.O, Kock, J.E., Mtwshweni, W., 2002a. User Guide for the Benchleak Model. South African Water Research Commission. Report No. TT 159/01, January, ISBN 1 86845 773 7, Pretoria, South Africa.

Mckenzie R., Wegelin, W., Meyer N., Buckle H., 2002b. Water Demand Management Cook-Book. United Nations Habitat and Rand Water. Pretoria, South Africa.

Motiee, H., McBean, E., Motiei, A., 2007. Estimating physical unaccounted for water (UFW) in distribution networks using simulation models and GIS. Urban Water Journal, 4(1), 43 – 52.

MWD (Ministry of Water Development), 1994. Water Resources Management Policy and Strategies, Lilongwe.

Mulwafu, W., Chavula, G., Chipeta, C., Ferguson, A., Chilima, G., Nkhoma, B., 2002. The Status of Water Demand Management in Malawi and Strategies for promoting it. IUCN Country Report.

Mvalo and Company, 2002. Assessing Water Resources Management Policy and Strategies (1994). Lilongwe.

Ndokosho, J., Hoko, Z., Makurira, H., 2007. Assessment of management approaches in a public water utility: A case study of the Namibia water corporation (NAMWATER). Physics and Chemistry of the Earth, 32, 1300-1309.

Nkhoma, B., Hoko, Z., Gumbo, B., 2005. Assessment of Leakage Control as a Tool of Infrastructure Water System Demand Management: A Case of Area 49 in the City of Lilongwe, Malawi.In Kuruvilla, M., Nhapi, I., (eds)Water &Wastewater Management for developing Countries (WAMDEC 2004). Selected Proceedings of the Water & Wastewater Management for Developing Countries Conference, 28-30 July, IWA Publishing, London, 175-186.

NSO (National Statistical Office), 2008. Population and Housing Census. Preliminary Report. Government of Malawi, Zomba.

NWDP II, (National Water Development Programme) 2007.Environmental and Social Management Framework. National Water Development Programme. Ministry of Irrigation and Water Development. Malawi. Unpublished.

Nwasco (National Water Supply and Sanitation Council), 2005. Urban and Peri-urban Water Supply and Sanitation Report 2003/2004. Lusaka. Zambia.

OFWAT (Office of Water Services), 2002. International comparison of water and sewerage service 2000-01 Report. IUCN Water Demand Management Guideline Training Module. Unpublished.

Rizzo, A., 2007. Apparent Water Loss Control: Theory and Application. Malta. Available on: http://www.rizzoconsultants.com/Hyperlinks/ApparentLossControl_Theory_Application_Abridged.pdf (accessed 21/03/2009)

Rizzo A., Pearson D., Stephenson M., Harper N., 2004. Apparent water loss control: A practical approach. IWA Water Loss Task Force Water21 article No. 7. Available on:http://www.iwapublishing.com/pdf/June_2004.pdf (accessed 24/03/2009).

SADC, 2005. Regional Water Policy. Available on: www.unep.org/dams/files/country%20dialogues/SADCRegionalWaterPolicy.pdf (accessed 12/12/2008).

Sánchez, E. H., 2007. Calculation, Estimation and Uncertainty in the Apparent Losses Volume in the Water Supply System of Canal de Isabel II. http://waterloss2007.com/pdf_vortraege/Mittwoch/B9-1.pdf (accessed 14/12/08).

Savenije, H.H.G., Van der Zaag, P., 2002. Water as an economic good and water demand management; paradigm with pitfall. Water International Journal, 27(1), 98-104.

Savenije, H.H.G., Van der Zaag, P., 2003. Concepts and Definitions, IWRM 0.1 Lecture Notes, Unpublished, University of Zimbabwe, Harare, Zimbabwe.

Schwartz, K., 2006. Managing Public Water Utilities. An assessment of Bureaucratic and New Public Management models in the water supply and sanitation sectors in low- and middle-income countries. PhD. Thesis UNESCO-IHE Institute for Water Education The Netherlands. Available on: http://publishing.eur.nl/ir/repub/asset/8052/PhD%20Klaas%20Schwartz.pdf. (accessed 21/11/08).

Schwartz, K., 2008. Water Services Management Lecture Notes. Unesco-IHE the Netherlands unpublished.

Schwartz, K., van Dijk, M. P., 2007. Management Reforms in the Water Supply and Sanitation Sector: The Potential of the New Public Management for Improving Services. Available on: http://www.worldwaterweek.org/stockholmwatersymposium/Abstract_Volume_07/Microsoft%20Word%20-%20Workshop%203.pdf (accessed 25/11/2008).

Seago, C., Bhagwan, J., McKenzie, R.S., 2004. Benchmarking leakage from water reticulation systems in South Africa. Journal of Water SA, 30(5), Special edition, 25-32.

SIDA, 2000. Water and Wastewater Management in Large to Medium-sized Urban Centres - Experiences from the Developing World. Colling Water Management AB, Stockholm. IUCN Water Demand Management Guideline Training Module. Unpublished.

SRWB, 2008a. Southern Region Water Board Brief Outline of Zomba. Unpublished.

SRWB, 2008b. Southern Region Water Board Preliminary and Detailed Design and Construction Supervision for Zomba and Mangochi Water Supply Projects. Inception Report. National Water Development Project II. Zomba, Unpublished.

SRWB, 2008c. Southern Region Water Board Annual Report. 2007-2008 Fiscal Year. Zomba, Unpublished.

SRWB, 2009. Southern Region Water Board Preliminary and Detailed Design and Construction Supervision for Zomba and Mangochi Water Supply Projects. Preliminary Design Report. National Water Development Project II. Zomba, Unpublished.

Tabesh, M., Asadiani Yekta, A.H., 2005. A Software Tool for Non-Revenue Water Calculations in Urban Water Systems in Conjunction with Hydraulic and GIS Models. Paper to IWA special Conference 'Leakage 2005', September, Halifax, Canada, http://waterloss2007.com/Leakage2005.com/pdf (accessed Feb, 2009)

Thornton, J., 2002. Water Loss Control Manual. McGraw-Hill. Yew York.

Thornton, J., 2005. Best Management Practice 3: "System Water Audits and Leak Detection". Review and Recommendations for Change. Technical Report, California Urban Water Conservation Council, California.

Thornton, J., Lambert, A.O., 2005. Progress in practical prediction of pressure: leakage, pressure: burst frequency and pressure: consumption relationships. Paper to IWA Special Conference 'Leakage 2005', September 12-14, Halifax, Canada, http://waterloss2007.com/Leakage2005.com/pdf, (accessed Dec 2008)

Thornton, J., Lambert, A.O., 2007. Pressure management extends infrastructure life and reduces unnecessary energy costs. Proceedings of IWA International Specialised Conference 'Water Loss 2007' held in Bucharest, Cyprus, http://waterloss2007.com/Leakage2007.com/pdf (accessed Feb 2009)

Tyanan, N., Kingdom, B., 2002. A Water Scorecard – Setting Performance Targets for Water Utilities, World Bank Private Sector Note 242. http://rru.worldbank.org/documents/publicpolicyjournal/242Tynan-040802.pdf. (accessed 23/11/08)

UNDP (United Nations Development Programme), 2003. Human Development Report 2003, Millennium Development Goals: A compact among nations to end human poverty, Oxford University Press, New York.

UNEP (United Nations Environmental Programme), 1999: Global Environmental Outlook 2000, Earthscan Publications, London.

Van der Zaag, P., 2003. Urban Water Demand, IWRM 0.1 Lecture Notes, University of Zimbabwe, Unpublished, Zimbabwe.

Water Works Act No. 17, 1995. Government Printer Zomba, Malawi.

Water Audit Guidance, 2008. Water Supply Program Annual Water Audit Summary http://www.mde.state.md.us/assets/document/water_cons/Water_Audit_guidance.pdf. (accessed Aug 2008).

Wikipedia, 2009. Zomba www.wikipedia.com assessed 7/01/09.

World Bank, 2007. Project Appraisal Document for Second National Water Development Project for Malawi, Report No. 38457-MW, World bank, Malawi country department.

WHO (World Health Organisation), 2000. Water Supply and Sanitation Sector Assessment in Malawi. Part II. Available on www.afro.who.int/wsh/countryprofiles/malawi.pdf (accessed Jan 2009).

Yepes G., Dianderas A., 1996. Water and Wastewater Utilities Indicators 2nd Edition. Water and Sanitation Division World Bank. Washington DC.

ZDA (Zomba District Assembly), 2008a. Zomba District State of Environment. Zomba, Malawi.

ZDA (Zomba District Assembly), 2008b. Zomba District Socio-economics. Zomba, Malawi.

APPENDICES

Appendix I: Unaccounted for Water for Zomba City from 1999 to 2009

Yr	Mth	Prod (m^3/mth)	Water Billed (m^3/mth)	Apx mains (km)	Cons	UFW			
						Vol (m^3)	Vol % of Prod	m^3/km/yr	m^3/conn/yr
1999	Jan	215,905	179,392	90	2,500	36,513	16.9	4,868	175
	Feb	211,963	176,319	90	2,525	35,644	16.8	4,753	169
	Mar	212,685	173,243	90	2,550	39,442	18.5	5,259	186
	Apr	217,368	165,671	90	2,575	51,697	23.8	6,893	241
	May	226,727	152,087	90	2,600	74,640	32.9	9,952	344
	Jun	197,691	171,330	90	2,625	26,361	13.3	3,515	121
	Jul	208,805	172,387	90	2,650	36,418	17.4	4,856	165
	Aug	218,489	170,000	90	2,675	48,489	22.2	6,465	218
	Sep	220,131	180,000	90	2,700	40,131	18.2	5,351	178
	Oct	215,817	176,072	90	2,725	39,745	18.4	5,299	175
	Nov	222,325	150,404	90	2,750	71,921	32.4	9,589	314
	Dec	267,160	178,386	90	2,775	88,774	33.3	11,837	384
Summary 1999		2,635,066	2,045,291	90	2,775	589,775	22.4	6,553	213
2000	Jan	220,044	174,428	90	2,805	45,616	20.7	6,082	195
	Feb	220,034	168,033	90	2,835	52,001	23.6	6,933	220
	Mar	228,848	170,521	90	2,865	58,327	25.5	7,777	244
	Apr	218,711	176,072	90	2,895	42,639	19.5	5,685	177
	May	217,961	150,404	90	2,925	67,557	31.0	9,008	277
	Jun	267,160	178,382	90	2,955	88,778	33.2	11,837	361
	Jul	209,184	154,669	90	2,985	54,515	26.1	7,269	219
	Aug	308,694	165,521	90	3,015	143,173	46.4	19,090	570
	Sep	318,924	193,876	90	3,045	125,048	39.2	16,673	493
	Oct	326,154	210,000	90	3,075	116,154	35.6	15,487	453
	Nov	335,204	196,120	90	3,105	139,084	41.5	18,545	538
	Dec	348,122	203,543	90	3,135	144,579	41.5	19,277	553
Summary 2000		3,219,040	2,141,569	90	3,135	1,077,471	33.5	11,972	344
2001	Jan	340,849	196,120	132	3,165	144,729	42.5	13,157	549
	Feb	340,464	263,389	132	3,195	77,075	22.6	7,007	289
	Mar	367,498	238,125	132	3,225	129,373	35.2	11,761	481
	Apr	352,388	215,044	132	3,255	137,344	39	12,486	506
	May	350,000	220,782	132	3,285	129,218	36.9	11,747	472
	Jun	350,000	240,622	132	3,315	109,378	31.3	9,943	396
	Jul	350,000	199,337	132	3,345	150,663	43.1	13,697	541
	Aug	350,000	257,632	132	3,375	92,368	26.4	8,397	328
	Sep	377,553	242,122	132	3,405	135,431	35.9	12,312	477
	Oct	377,086	240,561	132	3,435	136,525	36.2	12,411	477
	Nov	431,007	290,050	132	3,465	140,957	32.7	12,814	488

Yr	Mth	Prod (m^3/mth)	Water Billed (m^3/mth)	Apx mains (km)	Cons	UFW			
						Vol (m^3)	Vol % of Prod	m^3/km/yr	m^3/conn/yr
	Dec	444,605	225,214	132	3,495	219,391	49.4	19,945	753
Summary 2001		4,431,450	2,828,998	132	3,495	1,602,452	36.2	12,140	459
2002	Jan	396,482	238,046	132	3,535	158,436	40	14,403	538
	Feb	396,482	218,840	132	3,575	177,642	44.8	16,149	596
	Mar	372,001	245,951	132	3,615	126,050	33.9	11,459	418
	Apr	399,955	278,970	132	3,655	120,985	30.3	10,999	397
	May	362,087	218,420	132	3,695	143,667	39.7	13,061	467
	Jun	354,778	279,842	132	3,735	74,936	21.1	6,812	241
	Jul	426,628	279,172	132	3,775	147,456	34.6	13,405	469
	Aug	420,589	284,792	132	3,820	135,797	32.3	12,345	427
	Sep	415,883	281,982	132	3,865	133,901	32.2	12,173	416
	Oct	420,001	287,619	132	3,910	132,382	31.5	12,035	406
	Nov	410,634	280,035	132	3,955	130,599	31.8	11,873	396
	Dec	392,490	286,331	132	4,000	106,159	27.1	9,651	318
Summary 2002		4,768,010	3,180,000	132	4,000	1,588,010	33.3	12,030	397
2003	Jan	392,690	325,595	132	4,045	67,095	17.1	6,100	199
	Feb	422,692	300,550	132	4,090	122,142	28.9	11,104	358
	Mar	363,033	305,745	132	4,135	57,288	15.8	5,208	166
	Apr	376,368	305,756	132	4,180	70,612	18.8	6,419	203
	May	376,325	282,685	132	4,225	93,640	24.9	8,513	266
	Jun	387,524	321,325	132	4,270	66,199	17.1	6,018	186
	Jul	386,090	301,085	132	4,299	85,005	22.0	7,728	237
	Aug	388,793	328,552	132	4,270	60,241	15.5	5,476	169
	Sep	409,717	306,895	132	4,299	102,822	25.1	9,347	287
	Oct	403,194	287,148	132	4,329	116,046	28.8	10,550	322
	Nov	407,975	280,402	132	4,355	127,573	31.3	11,598	352
	Dec	379,487	317,325	132	4,343	62,162	16.4	5,651	172
Summary 2003		4,693,888	3,663,063	132	4,343	1,030,825	22.0	7,809	237
2004	Jan	374,722	296,394	132	4,284	78,328	20.9	7,121	219
	Feb	371,591	279,830	132	4,318	91,761	24.7	8,342	255
	Mar	385,614	272,058	132	4,346	113,556	29.5	10,323	3145
	Apr	389,048	308,348	132	4,292	80,700	20.7	7,336	226
	May	407,266	266,072	132	4,268	141,194	34.7	12,836	397
	Jun	407,266	298,626	132	4,303	108,640	26.7	9,876	303
	Jul	400,426	269,938	132	4,319	130,488	32.6	11,863	363
	Aug	415,926	294,020	132	4,388	121,906	29.3	11,082	333
	Sep	415,925	275,703	132	4,424	140,222	33.7	12,747	380
	Oct	413,834	351,509	132	4,334	62,325	15.1	5,666	173
	Nov	401,222	331,664	132	4,277	69,558	17.4	6,323	195

Yr	Mth	Prod (m^3/mth)	Water Billed (m^3/mth)	Apx mains (km)	Cons	UFW			
						Vol (m^3)	Vol % of Prod	m^3/km/yr	m^3/conn/yr
	Dec	398,426	320,332	132	4,278	78,094	19.6	7,099	219
Summary 2004		4,781,266	3,564,494	132	4,278	1,216,772	25.5	9,218	284
2005	Jan	405,022	320000	156	4,230	85,022	21.0	6,540	241
	Feb	393,360	298,181	156	4,238	95,179	24.2	7,321	270
	Mar	380,000	222,523	156	4,376	157,477	41.4	12,114	432
	Apr	417,162	282,265	156	4,386	134,897	32.3	10,377	369
	May	384,084	305,729	156	4,477	78,355	20.4	6,027	210
	Jun	452,744	377,344	156	4,467	75,400	16.7	5,800	203
	Jul	351,425	276,210	156	4,580	75,215	21.4	5,786	197
	Aug	324,694	254,195	156	4,598	70,499	21.7	5,423	184
	Sep	413,160	331,401	156	4,602	81,759	19.8	6,289	213
	Oct	427,901	369,492	156	4,618	58,409	13.7	4,493	152
	Nov	408,908	352,482	156	4,467	56,426	13.8	4,340	152
	Dec	390,614	327,996	156	4,512	62,618	16.0	4,817	167
Summary 2005		4,749,074	3,717,818	156	4,512	1,031,256	21.7	6,611	229
2006	Jan	418,758	311,544	156	4,551	107,214	25.6	8,247	283
	Feb	375,351	305,000	156	4,563	70,351	18.7	5,412	185
	Mar	430,149	352,432	156	4,649	77,717	18.1	5,978	201
	Apr	433,789	310,000	156	4,700	123,789	28.5	9,522	316
	May	467,734	271,685	156	4,730	196,049	41.9	15,081	497
	Jun	470,357	262,141	156	4,783	208,216	44.3	16,017 2	522
	Jul	467,679	273,462	156	4,763	194,217	41.5	14,940	489
	Aug	420,015	288,712	156	4,629	131,303	313	10,100	340
	Sep	422,288	304,925	156	4,595	117,363	27.8	9,028	3070
	Oct	441,288	326,516	156	4,724	114,772	26.0	8,829	292
	Nov	403,798	291,377	156	4,691	112,421	27.8	8,648	288
	Dec	381,777	288,334	156	4,708	93,443	24.5	7,188	238
Summary 2006		5,132,983	3,586,128	156	4,708	1,546,855	30.1	9,916	329
2007	Jan	395,293	289,207	156	4,745	106,086	26.8	8,160	268
	Feb	357,489	259,248	156	4,776	98,241	27.5	7,557	247
	Mar	376,339	320,000	156	4,885	56,339	15.0	4,334	138
	Apr	390,000	345,694	156	5,006	44,306	11.4	3,408	106
	May	380,000	329,772	156	5,089	50,228	13.2	3,864	118
	Jun	380,000	328,804	156	5,159	51,196	13.5	3,938	119
	Jul	387,375	329,556	156	5,215	57,819	14.9	4,448	133
	Aug	396,221	339,394	156	5,336	56,827	14.3	4,371	128
	Sep	380,581	300,000	156	5,396	80,581	21.2	6,199	179
	Oct	426,193	371,284	156	5,400	54,909	12.9	4,224	122

Yr	Mth	Prod (m^3/mth)	Water Billed (m^3/mth)	Apx mains (km)	Cons	UFW Vol (m^3)	UFW Vol % of Prod	UFW m^3/km/ yr	UFW m^3/co nn/yr
	Nov	407,982	312,116	156	5,414	95,866	23.5	7,374	212
	Dec	421,464	253,557	156	5,579	167,907	39.8	12,916	361
Summary 2007		4,698,937	3,778,632	156	5,579	920,305	19.6	5,899	165
2008	Jan	432,433	289,935	156	5,601	142,498	33.0	10,961	305
	Feb	411,563	348,772	156	5,657	62,791	15.3	4,830	133
	Mar	435,474	350,528	156	5,649	84,946	19.5	6,534	180
	Apr	435,632	254,785	156	5,654	180,847	41.5	13,911	384
	May	433,257	273,213	156	5,672	160,044	36.9	12,311	3390
	Jun	402,893	298,040	156	5,866	104,853	26.0	8,066	215
	Jul	474,975	313,984	156	5,774	160,991	33.9	12,384	335
	Aug	481,323	327,621	156	5,795	153,702	31.9	11,823	318
	Sep	467,861	326,338	156	5,889	141,523	30.3	10,886	288
	Oct	474,271	343,653	156	5,952	130,618	27.5	10,048	263
	Nov	460,177	305,878	156	5,992	154,299	33.5	11,869	309
	Dec	460,066	305,255	156	5,966	154,811	33.7	11,909	311
Summary 2008		5,369,925	3,738,002	156	5,966	1,631,923	30.4	10,461	274
2009	Jan	463,221	322,494	156	5,972	140,727	30.4	10,825	283
	Feb	418,495	334,779	156	5,968	83,716	20.0	6,440	168

Appendix II: Tank meter readings and monthly consumption

(a) Consumption

Tank	Area supplied [10]	Connections (%)	No. of connections	Consumption billed (m^3)		
				Dec	Jan	Feb
Airwing	Matawale	8.1[11]	52	8293	8194	7642
Malonje	Chinamwali	5	25	839	770	830
	Malonje	81.8	26	413	367	592
	Habitat	100	128	2021	2033	2021
Sadzi	Sadzi	87.3	274	4148	3462	3075
	Thundu	82	50	574	611	745
	Mpunga	100	552	6679	6670	6681
	Chizalo	100	89	1011	1025	1088
Mtiya	Mtiya	100	42	414	405	407

(b) Bulk meter readings

Date	Airwing	Malonje	Sadzi	Mtiya
	Vol (m^3)	Vol (m^3)	Vol (m^3)	Vol (m^3)
25/02/09	1,235,550	694,982	4,216,400	69,730
04/03/09	1,237,760	697,095	4,222,590	69,885
11/03/09	1,239,860	699,459	4,229,160	69,990
16/03/09		701,256		
19/03/09			4,237,130	70,090
20/03/09	1,242,660	702,711		
25/03/09	1,244,200	704,003	4,242,930	70,170
31/03/09	1,246,060	705,504	4,247,720	
01/04/09	1,246,400	705,742		
06/04/09			4,252,920	70,340
08/04/09	1,248,770	707,870	4,253,940	70,380
10/04/09			4,255,470	70,400
20/04/09	1,252,930	711,953	4,256,750	70,550

[10] Corresponding to the area names used in the billing system
[11] One major customer is the Airwing institution but there are individual connections within the institution

Appendix III: Data logging points attributes

(a) Pressure Logging Points Attributes

Pt No.	Area	Installation			Uninstallation			Elev (masl)
		Date	Time	Reading (m^3)	Date	Time	Reading (m^3)	
1	Airwing (Mkangala)	26/03/09	17:15	1214.26	27/03/09	17:20	1215.06	836
2	Airwing (Mdoka	27/03/09	17:30	3,773.49	28/03/09	17:14	3,773.90	800
3	Airwing (Muhommad)	28/03/09	17:21	4,578.91	30/03/09	10:47	4,578.91	810
4	Airwing (Khalidi)	30.03.09	11:06	797.59	31/03/09	11:15	797.97	799
5	Malonje (Pemba)	31/03/09	12:03	197.74	01/04/09	11:55	198.52	959
6	Malonje (Dzimbiri)	01/04/09	12:23	1,786.56	02/04/09	16:35	1,786.56	880
7	Malonje(Pute)	02/04/09	17:00	628.04	03/04/09	16:15	628.40	930
8	Malonje(Jobe)	03/04/09	16:30	1,704.20	04/04/09	17:05	1,704.83	910
9	Sadzi(Sayenda)	06/04/09	17:07	1,281.00	07/04/09	16:56	1,281.00	958
10	Sadzi(Kapalamula)	07/04/09	17:12	827.61	08/04/09	17:30	828.24	892
11	Sadzi (Mboga)	08/04/09	17:41	450.88	09/04/09	16:38	453.56	884
12	Sadzi(Mulima)	09/04/09	16:55	405.38	10/04/09	12:30	406.05	883
13	Mtiya (Juma)	10/04/09	13:45	84.08	11/04/09	16:22	84.37	980
14	Mtiya(Kupempha)	11/04/09	16:45	51.84	12/04/09	15:57	52.07	1005
15	Mtiya(Madula)	12/04/09	16:08	35.20	13/04/09	16:30	36.14	1025
16	Mtiya(Mkulumba)	13/04/09	16:32	212.03	14/04/09	16:07	212.18	990

(b) Flow Logging Points

Tank	Installation			Uninstallation		
	Date	Time	Reading (m^3)	Date	Time	Reading (m^3)
Airwing	26/03/09	16:45	-	31/03/09	11:26	124,6060
Malonje	31/03/09	11:57	705,504	06/04/09	11:30	707,128
Sadzi	06/04/09	14:30	425,2920	10/04/09	12:55	425,5470
Mtiya	10/04/09	13:30	7,0400	14/04/09	16:20	7,0460

Appendix IV-a: Airwing Tank Flow Logging Results

Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr
26/03/09	16:45	0	27/03/09	3:00	8	27/03/09	13:15	16	27/03/09	23:30	8
26/03/09	17:00	20	27/03/09	3:15	8	27/03/09	13:30	16	27/03/09	23:45	8
26/03/09	17:15	16	27/03/09	3:30	8	27/03/09	13:45	16	28/03/09	0:00	12
26/03/09	17:30	12	27/03/09	3:45	12	27/03/09	14:00	20	28/03/09	0:15	8
26/03/09	17:45	12	27/03/09	4:00	8	27/03/09	14:15	16	28/03/09	0:30	8
26/03/09	18:00	12	27/03/09	4:15	8	27/03/09	14:30	16	28/03/09	0:45	12
26/03/09	18:15	16	27/03/09	4:30	8	27/03/09	14:45	12	28/03/09	1:00	8
26/03/09	18:30	16	27/03/09	4:45	12	27/03/09	15:00	16	28/03/09	1:15	8
26/03/09	18:45	12	27/03/09	5:00	12	27/03/09	15:15	16	28/03/09	1:30	8
26/03/09	19:00	12	27/03/09	5:15	12	27/03/09	15:30	12	28/03/09	1:45	12
26/03/09	19:15	12	27/03/09	5:30	16	27/03/09	15:45	16	28/03/09	2:00	8
26/03/09	19:30	12	27/03/09	5:45	16	27/03/09	16:00	16	28/03/09	2:15	8
26/03/09	19:45	12	27/03/09	6:00	20	27/03/09	16:15	16	28/03/09	2:30	8
26/03/09	20:00	12	27/03/09	6:15	20	27/03/09	16:30	12	28/03/09	2:45	8
26/03/09	20:15	12	27/03/09	6:30	20	27/03/09	16:45	16	28/03/09	3:00	12
26/03/09	20:30	12	27/03/09	6:45	20	27/03/09	17:00	12	28/03/09	3:15	8
26/03/09	20:45	12	27/03/09	7:00	20	27/03/09	17:15	12	28/03/09	3:30	8
26/03/09	21:00	12	27/03/09	7:15	20	27/03/09	17:30	16	28/03/09	3:45	8
26/03/09	21:15	8	27/03/09	7:30	20	27/03/09	17:45	12	28/03/09	4:00	12
26/03/09	21:30	8	27/03/09	7:45	20	27/03/09	18:00	12	28/03/09	4:15	8
26/03/09	21:45	12	27/03/09	8:00	20	27/03/09	18:15	16	28/03/09	4:30	12
26/03/09	22:00	8	27/03/09	8:15	20	27/03/09	18:30	16	28/03/09	4:45	8
26/03/09	22:15	8	27/03/09	8:30	16	27/03/09	18:45	12	28/03/09	5:00	12
26/03/09	22:30	12	27/03/09	8:45	16	27/03/09	19:00	12	28/03/09	5:15	8
26/03/09	22:45	8	27/03/09	9:00	16	27/03/09	19:15	12	28/03/09	5:30	12
26/03/09	23:00	8	27/03/09	9:15	16	27/03/09	19:30	12	28/03/09	5:45	16
26/03/09	23:15	8	27/03/09	9:30	16	27/03/09	19:45	12	28/03/09	6:00	16
26/03/09	23:30	8	27/03/09	9:45	16	27/03/09	20:00	12	28/03/09	6:15	16
26/03/09	23:45	8	27/03/09	10:00	16	27/03/09	20:15	12	28/03/09	6:30	20
27/03/09	0:00	8	27/03/09	10:15	16	27/03/09	20:30	8	28/03/09	6:45	20
27/03/09	0:15	12	27/03/09	10:30	16	27/03/09	20:45	12	28/03/09	7:00	20
27/03/09	0:30	8	27/03/09	10:45	16	27/03/09	21:00	12	28/03/09	7:15	20
27/03/09	0:45	8	27/03/09	11:00	16	27/03/09	21:15	8	28/03/09	7:30	24
27/03/09	1:00	8	27/03/09	11:15	16	27/03/09	21:30	12	28/03/09	7:45	20
27/03/09	1:15	8	27/03/09	11:30	16	27/03/09	21:45	8	28/03/09	8:00	24
27/03/09	1:30	8	27/03/09	11:45	16	27/03/09	22:00	12	28/03/09	8:15	20
27/03/09	1:45	8	27/03/09	12:00	16	27/03/09	22:15	8	28/03/09	8:30	20
27/03/09	2:00	8	27/03/09	12:15	12	27/03/09	22:30	8	28/03/09	8:45	20
27/03/09	2:15	8	27/03/09	12:30	16	27/03/09	22:45	12	28/03/09	9:00	20
27/03/09	2:30	8	27/03/09	12:45	16	27/03/09	23:00	8	28/03/09	9:15	20
27/03/09	2:45	8	27/03/09	13:00	16	27/03/09	23:15	12	28/03/09	9:30	16

Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr
28/03/09	9:45	16	28/03/09	21:00	12	29/03/09	8:15	20	29/03/09	19:30	16
28/03/09	10:00	16	28/03/09	21:15	12	29/03/09	8:30	20	29/03/09	19:45	12
28/03/09	10:15	16	28/03/09	21:30	12	29/03/09	8:45	16	29/03/09	20:00	12
28/03/09	10:30	20	28/03/09	21:45	8	29/03/09	9:00	20	29/03/09	20:15	12
28/03/09	10:45	16	28/03/09	22:00	12	29/03/09	9:15	16	29/03/09	20:30	12
28/03/09	11:00	16	28/03/09	22:15	8	29/03/09	9:30	16	29/03/09	20:45	12
28/03/09	11:15	16	28/03/09	22:30	12	29/03/09	9:45	16	29/03/09	21:00	8
28/03/09	11:30	16	28/03/09	22:45	8	29/03/09	10:00	16	29/03/09	21:15	12
28/03/09	11:45	16	28/03/09	23:00	8	29/03/09	10:15	12	29/03/09	21:30	12
28/03/09	12:00	16	28/03/09	23:15	8	29/03/09	10:30	16	29/03/09	21:45	12
28/03/09	12:15	16	28/03/09	23:30	12	29/03/09	10:45	16	29/03/09	22:00	8
28/03/09	12:30	12	28/03/09	23:45	8	29/03/09	11:00	16	29/03/09	22:15	12
28/03/09	12:45	16	29/03/09	0:00	8	29/03/09	11:15	16	29/03/09	22:30	8
28/03/09	13:00	16	29/03/09	0:15	8	29/03/09	11:30	16	29/03/09	22:45	8
28/03/09	13:15	16	29/03/09	0:30	8	29/03/09	11:45	12	29/03/09	23:00	12
28/03/09	13:30	12	29/03/09	0:45	12	29/03/09	12:00	16	29/03/09	23:15	8
28/03/09	13:45	16	29/03/09	1:00	8	29/03/09	12:15	16	29/03/09	23:30	8
28/03/09	14:00	16	29/03/09	1:15	8	29/03/09	12:30	16	29/03/09	23:45	8
28/03/09	14:15	20	29/03/09	1:30	8	29/03/09	12:45	16	30/03/09	0:00	8
28/03/09	14:30	16	29/03/09	1:45	8	29/03/09	13:00	16	30/03/09	0:15	12
28/03/09	14:45	16	29/03/09	2:00	8	29/03/09	13:15	16	30/03/09	0:30	8
28/03/09	15:00	16	29/03/09	2:15	8	29/03/09	13:30	16	30/03/09	0:45	8
28/03/09	15:15	16	29/03/09	2:30	8	29/03/09	13:45	16	30/03/09	1:00	8
28/03/09	15:30	12	29/03/09	2:45	8	29/03/09	14:00	16	30/03/09	1:15	8
28/03/09	15:45	12	29/03/09	3:00	8	29/03/09	14:15	16	30/03/09	1:30	8
28/03/09	16:00	12	29/03/09	3:15	8	29/03/09	14:30	16	30/03/09	1:45	8
28/03/09	16:15	16	29/03/09	3:30	12	29/03/09	14:45	16	30/03/09	2:00	8
28/03/09	16:30	12	29/03/09	3:45	8	29/03/09	15:00	12	30/03/09	2:15	8
28/03/09	16:45	12	29/03/09	4:00	8	29/03/09	15:15	16	30/03/09	2:30	8
28/03/09	17:00	8	29/03/09	4:15	8	29/03/09	15:30	12	30/03/09	2:45	8
28/03/09	17:15	12	29/03/09	4:30	8	29/03/09	15:45	16	30/03/09	3:00	8
28/03/09	17:30	12	29/03/09	4:45	12	29/03/09	16:00	12	30/03/09	3:15	12
28/03/09	17:45	12	29/03/09	5:00	12	29/03/09	16:15	16	30/03/09	3:30	8
28/03/09	18:00	12	29/03/09	5:15	12	29/03/09	16:30	16	30/03/09	3:45	8
28/03/09	18:15	16	29/03/09	5:30	12	29/03/09	16:45	12	30/03/09	4:00	8
28/03/09	18:30	12	29/03/09	5:45	12	29/03/09	17:00	12	30/03/09	4:15	8
28/03/09	18:45	16	29/03/09	6:00	16	29/03/09	17:15	12	30/03/09	4:30	12
28/03/09	19:00	12	29/03/09	6:15	16	29/03/09	17:30	12	30/03/09	4:45	8
28/03/09	19:15	12	29/03/09	6:30	20	29/03/09	17:45	16	30/03/09	5:00	12
28/03/09	19:30	12	29/03/09	6:45	20	29/03/09	18:00	12	30/03/09	5:15	12
28/03/09	19:45	16	29/03/09	7:00	20	29/03/09	18:15	16	30/03/09	5:30	16
28/03/09	20:00	12	29/03/09	7:15	24	29/03/09	18:30	16	30/03/09	5:45	16
28/03/09	20:15	12	29/03/09	7:30	20	29/03/09	18:45	16	30/03/09	6:00	20
28/03/09	20:30	12	29/03/09	7:45	24	29/03/09	19:00	12	30/03/09	6:15	20
28/03/09	20:45	12	29/03/09	8:00	20	29/03/09	19:15	12	30/03/09	6:30	20

Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr
30/03/09	6:45	20	30/03/09	14:00	16	30/03/09	21:15	12	31/03/09	4:30	12
30/03/09	7:00	24	30/03/09	14:15	16	30/03/09	21:30	12	31/03/09	4:45	8
30/03/09	7:15	20	30/03/09	14:30	12	30/03/09	21:45	12	31/03/09	5:00	12
30/03/09	7:30	20	30/03/09	14:45	20	30/03/09	22:00	8	31/03/09	5:15	12
30/03/09	7:45	24	30/03/09	15:00	16	30/03/09	22:15	12	31/03/09	5:30	16
30/03/09	8:00	20	30/03/09	15:15	16	30/03/09	22:30	8	31/03/09	5:45	16
30/03/09	8:15	20	30/03/09	15:30	16	30/03/09	22:45	8	31/03/09	6:00	20
30/03/09	8:30	20	30/03/09	15:45	16	30/03/09	23:00	12	31/03/09	6:15	20
30/03/09	8:45	16	30/03/09	16:00	12	30/03/09	23:15	8	31/03/09	6:30	20
30/03/09	9:00	20	30/03/09	16:15	16	30/03/09	23:30	8	31/03/09	6:45	20
30/03/09	9:15	16	30/03/09	16:30	16	30/03/09	23:45	8	31/03/09	7:00	24
30/03/09	9:30	16	30/03/09	16:45	12	31/03/09	0:00	12	31/03/09	7:15	20
30/03/09	9:45	16	30/03/09	17:00	12	31/03/09	0:15	8	31/03/09	7:30	20
30/03/09	10:00	24	30/03/09	17:15	16	31/03/09	0:30	8	31/03/09	7:45	20
30/03/09	10:15	24	30/03/09	17:30	12	31/03/09	0:45	8	31/03/09	8:00	20
30/03/09	10:30	24	30/03/09	17:45	16	31/03/09	1:00	12	31/03/09	8:15	20
30/03/09	10:45	20	30/03/09	18:00	24	31/03/09	1:15	8	31/03/09	8:30	16
30/03/09	11:00	24	30/03/09	18:15	20	31/03/09	1:30	8	31/03/09	8:45	20
30/03/09	11:15	20	30/03/09	18:30	20	31/03/09	1:45	12	31/03/09	9:00	16
30/03/09	11:30	16	30/03/09	18:45	12	31/03/09	2:00	8	31/03/09	9:15	16
30/03/09	11:45	16	30/03/09	19:00	12	31/03/09	2:15	8	31/03/09	9:30	16
30/03/09	12:00	16	30/03/09	19:15	16	31/03/09	2:30	12	31/03/09	9:45	16
30/03/09	12:15	16	30/03/09	19:30	12	31/03/09	2:45	8	31/03/09	10:00	16
30/03/09	12:30	12	30/03/09	19:45	12	31/03/09	3:00	8	31/03/09	10:15	16
30/03/09	12:45	16	30/03/09	20:00	12	31/03/09	3:15	12	31/03/09	10:30	12
30/03/09	13:00	20	30/03/09	20:15	12	31/03/09	3:30	8	31/03/09	10:45	16
30/03/09	13:15	16	30/03/09	20:30	12	31/03/09	3:45	8	31/03/09	11:00	16
30/03/09	13:30	16	30/03/09	20:45	12	31/03/09	4:00	12			
30/03/09	13:45	20	30/03/09	21:00	12	31/03/09	4:15	8			

Appendix IV-b: Malonje Tank Flow Logging Results

Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr
31/03/09	12:00	8	31/03/09	22:45	4	1/4/09	9:30	12	1/4/09	20:15	8
31/03/09	12:15	24	31/03/09	23:00	8	1/4/09	9:45	16	1/4/09	20:30	8
31/03/09	12:30	12	31/03/09	23:15	4	1/4/09	10:00	12	1/4/09	20:45	8
31/03/09	12:45	8	31/03/09	23:30	8	1/4/09	10:15	16	1/4/09	21:00	8
31/03/09	13:00	12	31/03/09	23:45	4	1/4/09	10:30	12	1/4/09	21:15	8
31/03/09	13:15	12	1/4/09	0:00	8	1/4/09	10:45	12	1/4/09	21:30	8
31/03/09	13:30		1/4/09	0:15	4	1/4/09	11:00	8	1/4/09	21:45	4
31/03/09	13:45	12	1/4/09	0:30	8	1/4/09	11:15	12	1/4/09	22:00	8
31/03/09	14:00	8	1/4/09	0:45	4	1/4/09	11:30	8	1/4/09	22:15	8
31/03/09	14:15	12	1/4/09	1:00	8	1/4/09	11:45	8	1/4/09	22:30	8
31/03/09	14:30	12	1/4/09	1:15	4	1/4/09	12:00	12	1/4/09	22:45	4
31/03/09	14:45	8	1/4/09	1:30	8	1/4/09	12:15	12	1/4/09	23:00	8
31/03/09	15:00	8	1/4/09	1:45	4	1/4/09	12:30	8	1/4/09	23:15	4
31/03/09	15:15	12	1/4/09	2:00	8	1/4/09	12:45	8	1/4/09	23:30	8
31/03/09	15:30	8	1/4/09	2:15	4	1/4/09	13:00	12	1/4/09	23:45	8
31/03/09	15:45	8	1/4/09	2:30	8	1/4/09	13:15	8	2/4/09	0:00	4
31/03/09	16:00	8	1/4/09	2:45	4	1/4/09	13:30	12	2/4/09	0:15	8
31/03/09	16:15	8	1/4/09	3:00	8	1/4/09	13:45	8	2/4/09	0:30	4
31/03/09	16:30	12	1/4/09	3:15	4	1/4/09	14:00	12	2/4/09	0:45	8
31/03/09	16:45	8	1/4/09	3:30	8	1/4/09	14:15	8	2/4/09	1:00	4
31/03/09	17:00	8	1/4/09	3:45	4	1/4/09	14:30	8	2/4/09	1:15	8
31/03/09	17:15	12	1/4/09	4:00	8	1/4/09	14:45	12	2/4/09	1:30	4
31/03/09	17:30	12	1/4/09	4:15	4	1/4/09	15:00	8	2/4/09	1:45	8
31/03/09	17:45	12	1/4/09	4:30	8	1/4/09	15:15	12	2/4/09	2:00	4
31/03/09	18:00	12	1/4/09	4:45	8	1/4/09	15:30	8	2/4/09	2:15	8
31/03/09	18:15	12	1/4/09	5:00	8	1/4/09	15:45	8	2/4/09	2:30	8
31/03/09	18:30	12	1/4/09	5:15	4	1/4/09	16:00	12	2/4/09	2:45	4
31/03/09	18:45	12	1/4/09	5:30	12	1/4/09	16:15	8	2/4/09	3:00	8
31/03/09	19:00	8	1/4/09	5:45	12	1/4/09	16:30	8	2/4/09	3:15	4
31/03/09	19:15	8	1/4/09	6:00	12	1/4/09	16:45	12	2/4/09	3:30	8
31/03/09	19:30	8	1/4/09	6:15	16	1/4/09	17:00	8	2/4/09	3:45	4
31/03/09	19:45	8	1/4/09	6:30	20	1/4/09	17:15	12	2/4/09	4:00	8
31/03/09	20:00	8	1/4/09	6:45	24	1/4/09	17:30	12	2/4/09	4:15	4
31/03/09	20:15	8	1/4/09	7:00	20	1/4/09	17:45	12	2/4/09	4:30	8
31/03/09	20:30	8	1/4/09	7:15	20	1/4/09	18:00	12	2/4/09	4:45	8
31/03/09	20:45	8	1/4/09	7:30	24	1/4/09	18:15	16	2/4/09	5:00	4
31/03/09	21:00	4	1/4/09	7:45	16	1/4/09	18:30	16	2/4/09	5:15	8
31/03/09	21:15	8	1/4/09	8:00	16	1/4/09	18:45	12	2/4/09	5:30	12
31/03/09	21:30	4	1/4/09	8:15	16	1/4/09	19:00	12	2/4/09	5:45	8
31/03/09	21:45	8	1/4/09	8:30	16	1/4/09	19:15	8	2/4/09	6:00	12
31/03/09	22:00	8	1/4/09	8:45	12	1/4/09	19:30	8	2/4/09	6:15	12
31/03/09	22:15	4	1/4/09	9:00	16	1/4/09	19:45	8	2/4/09	6:30	16
31/03/09	22:30	8	1/4/09	9:15	16	1/4/09	20:00	12	2/4/09	6:45	16

Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr
2/4/09	7:00	16	2/4/09	18:45	0	3/4/09	6:30	20	3/4/09	18:15	32
2/4/09	7:15	16	2/4/09	19:00	0	3/4/09	6:45	32	3/4/09	18:30	16
2/4/09	7:30	12	2/4/09	19:15	0	3/4/09	7:00	24	3/4/09	18:45	12
2/4/09	7:45	12	2/4/09	19:30	0	3/4/09	7:15	20	3/4/09	19:00	20
2/4/09	8:00	16	2/4/09	19:45	80	3/4/09	7:30	20	3/4/09	19:15	12
2/4/09	8:15	20	2/4/09	20:00	80	3/4/09	7:45	20	3/4/09	19:30	20
2/4/09	8:30	16	2/4/09	20:15	32	3/4/09	8:00	28	3/4/09	19:45	20
2/4/09	8:45	24	2/4/09	20:30	24	3/4/09	8:15	24	3/4/09	20:00	16
2/4/09	9:00	32	2/4/09	20:45	44	3/4/09	8:30	24	3/4/09	20:15	20
2/4/09	9:15	28	2/4/09	21:00	52	3/4/09	8:45	28	3/4/09	20:30	12
2/4/09	9:30	52	2/4/09	21:15	32	3/4/09	9:00	28	3/4/09	20:45	24
2/4/09	9:45	40	2/4/09	21:30	20	3/4/09	9:15	20	3/4/09	21:00	12
2/4/09	10:00	132	2/4/09	21:45	116	3/4/09	9:30	16	3/4/09	21:15	16
2/4/09	10:15	188	2/4/09	22:00	68	3/4/09	9:45	20	3/4/09	21:30	16
2/4/09	10:30	244	2/4/09	22:15	76	3/4/09	10:00	20	3/4/09	21:45	36
2/4/09	10:45	184	2/4/09	22:30	36	3/4/09	10:15	24	3/4/09	22:00	8
2/4/09	11:00	432	2/4/09	22:45	64	3/4/09	10:30	12	3/4/09	22:15	12
2/4/09	11:15	56	2/4/09	23:00	76	3/4/09	10:45	48	3/4/09	22:30	16
2/4/09	11:30	556	2/4/09	23:15	48	3/4/09	11:00	24	3/4/09	22:45	28
2/4/09	11:45	148	2/4/09	23:30	56	3/4/09	11:15	16	3/4/09	23:00	16
2/4/09	12:00	92	2/4/09	23:45	56	3/4/09	11:30	16	3/4/09	23:15	20
2/4/09	12:15	416	3/4/09	0:00	32	3/4/09	11:45	16	3/4/09	23:30	8
2/4/09	12:30	4	3/4/09	0:15	32	3/4/09	12:00	28	3/4/09	23:45	20
2/4/09	12:45	8	3/4/09	0:30	84	3/4/09	12:15	28	4/4/09	0:00	24
2/4/09	13:00	164	3/4/09	0:45	24	3/4/09	12:30	20	4/4/09	0:15	24
2/4/09	13:15	12	3/4/09	1:00	28	3/4/09	12:45	24	4/4/09	0:30	12
2/4/09	13:30	4	3/4/09	1:15	40	3/4/09	13:00	16	4/4/09	0:45	12
2/4/09	13:45	552	3/4/09	1:30	24	3/4/09	13:15	20	4/4/09	1:00	12
2/4/09	14:00	0	3/4/09	1:45	24	3/4/09	13:30	16	4/4/09	1:15	8
2/4/09	14:15	0	3/4/09	2:00	32	3/4/09	13:45	16	4/4/09	1:30	16
2/4/09	14:30	0	3/4/09	2:15	48	3/4/09	14:00	28	4/4/09	1:45	20
2/4/09	14:45	0	3/4/09	2:30	64	3/4/09	14:15	12	4/4/09	2:00	20
2/4/09	15:00	0	3/4/09	2:45	28	3/4/09	14:30	16	4/4/09	2:15	20
2/4/09	15:15	0	3/4/09	3:00	52	3/4/09	14:45	16	4/4/09	2:30	16
2/4/09	15:30	0	3/4/09	3:15	40	3/4/09	15:00	36	4/4/09	2:45	24
2/4/09	15:45	0	3/4/09	3:30	52	3/4/09	15:15	40	4/4/09	3:00	20
2/4/09	16:00	0	3/4/09	3:45	56	3/4/09	15:30	36	4/4/09	3:15	20
2/4/09	16:15	0	3/4/09	4:00	24	3/4/09	15:45	20	4/4/09	3:30	12
2/4/09	16:30	0	3/4/09	4:15	40	3/4/09	16:00	24	4/4/09	3:45	28
2/4/09	16:45	0	3/4/09	4:30	28	3/4/09	16:15	24	4/4/09	4:00	36
2/4/09	17:00	0	3/4/09	4:45	16	3/4/09	16:30	12	4/4/09	4:15	8
2/4/09	17:15	0	3/4/09	5:00	24	3/4/09	16:45	20	4/4/09	4:30	16
2/4/09	17:30	0	3/4/09	5:15	24	3/4/09	17:00	16	4/4/09	4:45	8
2/4/09	17:45	0	3/4/09	5:30	16	3/4/09	17:15	16	4/4/09	5:00	8
2/4/09	18:00	0	3/4/09	5:45	20	3/4/09	17:30	20	4/4/09	5:15	24
2/4/09	18:15	0	3/4/09	6:00	20	3/4/09	17:45	16	4/4/09	5:30	24
2/4/09	18:30	32	3/4/09	6:15	28	3/4/09	18:00	24	4/4/09	5:45	16

Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr
4/4/09	6:00	20	4/4/09	17:45	32	5/4/09	5:30	208	5/4/09	17:15	228
4/4/09	6:15	20	4/4/09	18:00	16	5/4/09	5:45	172	5/4/09	17:30	320
4/4/09	6:30	32	4/4/09	18:15	28	5/4/09	6:00	0	5/4/09	17:45	292
4/4/09	6:45	20	4/4/09	18:30	12	5/4/09	6:15	292	5/4/09	18:00	216
4/4/09	7:00	20	4/4/09	18:45	24	5/4/09	6:30	96	5/4/09	18:15	508
4/4/09	7:15	24	4/4/09	19:00	24	5/4/09	6:45	548	5/4/09	18:30	196
4/4/09	7:30	24	4/4/09	19:15	36	5/4/09	7:00	388	5/4/09	18:45	188
4/4/09	7:45	36	4/4/09	19:30	56	5/4/09	7:15	364	5/4/09	19:00	300
4/4/09	8:00	44	4/4/09	19:45	60	5/4/09	7:30	208	5/4/09	19:15	212
4/4/09	8:15	24	4/4/09	20:00	216	5/4/09	7:45	228	5/4/09	19:30	256
4/4/09	8:30	24	4/4/09	20:15	212	5/4/09	8:00	240	5/4/09	19:45	492
4/4/09	8:45	20	4/4/09	20:30	376	5/4/09	8:15	168	5/4/09	20:00	220
4/4/09	9:00	24	4/4/09	20:45	0	5/4/09	8:30	232	5/4/09	20:15	176
4/4/09	9:15	20	4/4/09	21:00	0	5/4/09	8:45	200	5/4/09	20:30	340
4/4/09	9:30	24	4/4/09	21:15	0	5/4/09	9:00	192	5/4/09	20:45	140
4/4/09	9:45	28	4/4/09	21:30	0	5/4/09	9:15	164	5/4/09	21:00	192
4/4/09	10:00	24	4/4/09	21:45	0	5/4/09	9:30	144	5/4/09	21:15	408
4/4/09	10:15	52	4/4/09	22:00	0	5/4/09	9:45	176	5/4/09	21:30	220
4/4/09	10:30	16	4/4/09	22:15	0	5/4/09	10:00	172	5/4/09	21:45	0
4/4/09	10:45	16	4/4/09	22:30	0	5/4/09	10:15	224	5/4/09	22:00	0
4/4/09	11:00	28	4/4/09	22:45	0	5/4/09	10:30	156	5/4/09	22:15	0
4/4/09	11:15	20	4/4/09	23:00	0	5/4/09	10:45	152	5/4/09	22:30	0
4/4/09	11:30	16	4/4/09	23:15	0	5/4/09	11:00	128	5/4/09	22:45	0
4/4/09	11:45	24	4/4/09	23:30	0	5/4/09	11:15	212	5/4/09	23:00	0
4/4/09	12:00	20	4/4/09	23:45	0	5/4/09	11:30	128	5/4/09	23:15	0
4/4/09	12:15	16	5/4/09	0:00	0	5/4/09	11:45	260	5/4/09	23:30	0
4/4/09	12:30	16	5/4/09	0:15	0	5/4/09	12:00	284	5/4/09	23:45	0
4/4/09	12:45	16	5/4/09	0:30	0	5/4/09	12:15	180	6/4/09	0:00	0
4/4/09	13:00	20	5/4/09	0:45	0	5/4/09	12:30	164	6/4/09	0:15	0
4/4/09	13:15	12	5/4/09	1:00	0	5/4/09	12:45	160	6/4/09	0:30	0
4/4/09	13:30	20	5/4/09	1:15	0	5/4/09	13:00	236	6/4/09	0:45	0
4/4/09	13:45	16	5/4/09	1:30	0	5/4/09	13:15	212	6/4/09	1:00	0
4/4/09	14:00	12	5/4/09	1:45	0	5/4/09	13:30	168	6/4/09	1:15	0
4/4/09	14:15	20	5/4/09	2:00	0	5/4/09	13:45	200	6/4/09	1:30	0
4/4/09	14:30	12	5/4/09	2:15	0	5/4/09	14:00	204	6/4/09	1:45	0
4/4/09	14:45	24	5/4/09	2:30	0	5/4/09	14:15	200	6/4/09	2:00	0
4/4/09	15:00	20	5/4/09	2:45	0	5/4/09	14:30	268	6/4/09	2:15	0
4/4/09	15:15	16	5/4/09	3:00	0	5/4/09	14:45	276	6/4/09	2:30	0
4/4/09	15:30	24	5/4/09	3:15	0	5/4/09	15:00	416	6/4/09	2:45	0
4/4/09	15:45	16	5/4/09	3:30	0	5/4/09	15:15	252	6/4/09	3:00	0
4/4/09	16:00	20	5/4/09	3:45	0	5/4/09	15:30	428	6/4/09	3:15	0
4/4/09	16:15	12	5/4/09	4:00	0	5/4/09	15:45	292	6/4/09	3:30	0
4/4/09	16:30	16	5/4/09	4:15	0	5/4/09	16:00	184	6/4/09	3:45	0
4/4/09	16:45	20	5/4/09	4:30	0	5/4/09	16:15	416	6/4/09	4:00	0
4/4/09	17:00	24	5/4/09	4:45	0	5/4/09	16:30	348	6/4/09	4:15	0
4/4/09	17:15	20	5/4/09	5:00	0	5/4/09	16:45	304	6/4/09	4:30	0
4/4/09	17:30	16	5/4/09	5:15	0	5/4/09	17:00	280	6/4/09	4:45	0

Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr
6/4/09	5:00	0	6/4/09	6:45	0	6/4/09	8:30	336	6/4/09	10:15	64
6/4/09	5:15	0	6/4/09	7:00	0	6/4/09	8:45	280	6/4/09	10:30	48
6/4/09	5:30	0	6/4/09	7:15	0	6/4/09	9:00	248	6/4/09	10:45	48
6/4/09	5:45	0	6/4/09	7:30	0	6/4/09	9:15	264	6/4/09	11:00	28
6/4/09	6:00	0	6/4/09	7:45	0	6/4/09	9:30	212	6/4/09	11:15	44
6/4/09	6:15	0	6/4/09	8:00	88	6/4/09	9:45	148			
6/4/09	6:30	0	6/4/09	8:15	196	6/4/09	10:00	152			

Appendix IV-c: Sadzi Tank Flow Logging Results

Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr
6/4/09	15:00	12	7/4/09	1:30	16	7/4/09	12:00	56	7/4/09	22:30	32
6/4/09	15:15	0	7/4/09	1:45	20	7/4/09	12:15	48	7/4/09	22:45	24
6/4/09	15:30	0	7/4/09	2:00	16	7/4/09	12:30	48	7/4/09	23:00	24
6/4/09	15:45	0	7/4/09	2:15	16	7/4/09	12:45	60	7/4/09	23:15	24
6/4/09	16:00	0	7/4/09	2:30	36	7/4/09	13:00	48	7/4/09	23:30	32
6/4/09	16:15	0	7/4/09	2:45	12	7/4/09	13:15	56	7/4/09	23:45	28
6/4/09	16:30	0	7/4/09	3:00	16	7/4/09	13:30	56	8/4/09	0:00	24
6/4/09	16:45	0	7/4/09	3:15	16	7/4/09	13:45	64	8/4/09	0:15	20
6/4/09	17:00	0	7/4/09	3:30	20	7/4/09	14:00	48	8/4/09	0:30	28
6/4/09	17:15	0	7/4/09	3:45	16	7/4/09	14:15	56	8/4/09	0:45	32
6/4/09	17:30	0	7/4/09	4:00	12	7/4/09	14:30	64	8/4/09	1:00	28
6/4/09	17:45	0	7/4/09	4:15	20	7/4/09	14:45	48	8/4/09	1:15	28
6/4/09	18:00	0	7/4/09	4:30	28	7/4/09	15:00	56	8/4/09	1:30	16
6/4/09	18:15	0	7/4/09	4:45	20	7/4/09	15:15	52	8/4/09	1:45	28
6/4/09	18:30	0	7/4/09	5:00	24	7/4/09	15:30	68	8/4/09	2:00	16
6/4/09	18:45	0	7/4/09	5:15	28	7/4/09	15:45	52	8/4/09	2:15	24
6/4/09	19:00	0	7/4/09	5:30	36	7/4/09	16:00	44	8/4/09	2:30	32
6/4/09	19:15	0	7/4/09	5:45	44	7/4/09	16:15	36	8/4/09	2:45	32
6/4/09	19:30	0	7/4/09	6:00	68	7/4/09	16:30	52	8/4/09	3:00	20
6/4/09	19:45	0	7/4/09	6:15	80	7/4/09	16:45	44	8/4/09	3:15	20
6/4/09	20:00	0	7/4/09	6:30	88	7/4/09	17:00	44	8/4/09	3:30	28
6/4/09	20:15	0	7/4/09	6:45	124	7/4/09	17:15	68	8/4/09	3:45	40
6/4/09	20:30	0	7/4/09	7:00	108	7/4/09	17:30	48	8/4/09	4:00	32
6/4/09	20:45	0	7/4/09	7:15	108	7/4/09	17:45	52	8/4/09	4:15	24
6/4/09	21:00	0	7/4/09	7:30	88	7/4/09	18:00	68	8/4/09	4:30	16
6/4/09	21:15	152	7/4/09	7:45	96	7/4/09	18:15	68	8/4/09	4:45	36
6/4/09	21:30	276	7/4/09	8:00	96	7/4/09	18:30	64	8/4/09	5:00	36
6/4/09	21:45	80	7/4/09	8:15	88	7/4/09	18:45	56	8/4/09	5:15	36
6/4/09	22:00	60	7/4/09	8:30	88	7/4/09	19:00	48	8/4/09	5:30	32
6/4/09	22:15	36	7/4/09	8:45	80	7/4/09	19:15	52	8/4/09	5:45	48
6/4/09	22:30	96	7/4/09	9:00	72	7/4/09	19:30	56	8/4/09	6:00	80
6/4/09	22:45	44	7/4/09	9:15	72	7/4/09	19:45	48	8/4/09	6:15	100
6/4/09	23:00	24	7/4/09	9:30	68	7/4/09	20:00	48	8/4/09	6:30	108
6/4/09	23:15	12	7/4/09	9:45	64	7/4/09	20:15	52	8/4/09	6:45	112
6/4/09	23:30	16	7/4/09	10:00	64	7/4/09	20:30	48	8/4/09	7:00	116
6/4/09	23:45	12	7/4/09	10:15	56	7/4/09	20:45	28	8/4/09	7:15	96
7/4/09	0:00	20	7/4/09	10:30	52	7/4/09	21:00	40	8/4/09	7:30	100
7/4/09	0:15	12	7/4/09	10:45	48	7/4/09	21:15	36	8/4/09	7:45	100
7/4/09	0:30	24	7/4/09	11:00	48	7/4/09	21:30	28	8/4/09	8:00	96
7/4/09	0:45	16	7/4/09	11:15	60	7/4/09	21:45	20	8/4/09	8:15	92
7/4/09	1:00	16	7/4/09	11:30	68	7/4/09	22:00	36	8/4/09	8:30	88
7/4/09	1:15	16	7/4/09	11:45	52	7/4/09	22:15	20	8/4/09	8:45	76

Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr
8/4/09	9:00	72	8/4/09	20:45	24	9/4/09	8:30	72	9/4/09	20:15	44
8/4/09	9:15	60	8/4/09	21:00	32	9/4/09	8:45	88	9/4/09	20:30	56
8/4/09	9:30	60	8/4/09	21:15	36	9/4/09	9:00	96	9/4/09	20:45	24
8/4/09	9:45	64	8/4/09	21:30	32	9/4/09	9:15	104	9/4/09	21:00	-80
8/4/09	10:00	52	8/4/09	21:45	28	9/4/09	9:30	72	9/4/09	21:15	-84
8/4/09	10:15	60	8/4/09	22:00	28	9/4/09	9:45	76	9/4/09	21:30	-52
8/4/09	10:30	52	8/4/09	22:15	28	9/4/09	10:00	80	9/4/09	21:45	-80
8/4/09	10:45	44	8/4/09	22:30	20	9/4/09	10:15	64	9/4/09	22:00	-116
8/4/09	11:00	56	8/4/09	22:45	36	9/4/09	10:30	56	9/4/09	22:15	-44
8/4/09	11:15	84	8/4/09	23:00	28	9/4/09	10:45	64	9/4/09	22:30	-36
8/4/09	11:30	56	8/4/09	23:15	32	9/4/09	11:00	64	9/4/09	22:45	-44
8/4/09	11:45	56	8/4/09	23:30	20	9/4/09	11:15	76	9/4/09	23:00	-48
8/4/09	12:00	68	8/4/09	23:45	16	9/4/09	11:30	56	9/4/09	23:15	-52
8/4/09	12:15	56	9/4/09	0:00	20	9/4/09	11:45	60	9/4/09	23:30	-40
8/4/09	12:30	64	9/4/09	0:15	12	9/4/09	12:00	76	9/4/09	23:45	-32
8/4/09	12:45	68	9/4/09	0:30	36	9/4/09	12:15	60	10/4/09	0:00	-40
8/4/09	13:00	64	9/4/09	0:45	16	9/4/09	12:30	48	10/4/09	0:15	-76
8/4/09	13:15	56	9/4/09	1:00	24	9/4/09	12:45	56	10/4/09	0:30	-44
8/4/09	13:30	68	9/4/09	1:15	28	9/4/09	13:00	60	10/4/09	0:45	-48
8/4/09	13:45	60	9/4/09	1:30	20	9/4/09	13:15	64	10/4/09	1:00	-36
8/4/09	14:00	72	9/4/09	1:45	32	9/4/09	13:30	72	10/4/09	1:15	-60
8/4/09	14:15	80	9/4/09	2:00	20	9/4/09	13:45	52	10/4/09	1:30	-64
8/4/09	14:30	64	9/4/09	2:15	24	9/4/09	14:00	72	10/4/09	1:45	-48
8/4/09	14:45	68	9/4/09	2:30	20	9/4/09	14:15	76	10/4/09	2:00	-68
8/4/09	15:00	52	9/4/09	2:45	24	9/4/09	14:30	60	10/4/09	2:15	-136
8/4/09	15:15	52	9/4/09	3:00	28	9/4/09	14:45	56	10/4/09	2:30	-40
8/4/09	15:30	44	9/4/09	3:15	24	9/4/09	15:00	52	10/4/09	2:45	-40
8/4/09	15:45	36	9/4/09	3:30	28	9/4/09	15:15	52	10/4/09	3:00	-36
8/4/09	16:00	40	9/4/09	3:45	24	9/4/09	15:30	64	10/4/09	3:15	-44
8/4/09	16:15	48	9/4/09	4:00	36	9/4/09	15:45	52	10/4/09	3:30	-44
8/4/09	16:30	40	9/4/09	4:15	24	9/4/09	16:00	60	10/4/09	3:45	-40
8/4/09	16:45	60	9/4/09	4:30	40	9/4/09	16:15	56	10/4/09	4:00	-64
8/4/09	17:00	44	9/4/09	4:45	32	9/4/09	16:30	40	10/4/09	4:15	-64
8/4/09	17:15	52	9/4/09	5:00	36	9/4/09	16:45	60	10/4/09	4:30	-64
8/4/09	17:30	56	9/4/09	5:15	40	9/4/09	17:00	52	10/4/09	4:45	-36
8/4/09	17:45	60	9/4/09	5:30	44	9/4/09	17:15	48	10/4/09	5:00	-88
8/4/09	18:00	64	9/4/09	5:45	72	9/4/09	17:30	48	10/4/09	5:15	-88
8/4/09	18:15	44	9/4/09	6:00	72	9/4/09	17:45	48	10/4/09	5:30	-104
8/4/09	18:30	56	9/4/09	6:15	84	9/4/09	18:00	72	10/4/09	5:45	-88
8/4/09	18:45	52	9/4/09	6:30	96	9/4/09	18:15	76	10/4/09	6:00	-140
8/4/09	19:00	44	9/4/09	6:45	132	9/4/09	18:30	80	10/4/09	6:15	-136
8/4/09	19:15	44	9/4/09	7:00	104	9/4/09	18:45	56	10/4/09	6:30	-148
8/4/09	19:30	40	9/4/09	7:15	140	9/4/09	19:00	56	10/4/09	6:45	-228
8/4/09	19:45	44	9/4/09	7:30	124	9/4/09	19:15	48	10/4/09	7:00	-164
8/4/09	20:00	40	9/4/09	7:45	120	9/4/09	19:30	48	10/4/09	7:15	-160
8/4/09	20:15	52	9/4/09	8:00	108	9/4/09	19:45	48	10/4/09	7:30	-200
8/4/09	20:30	32	9/4/09	8:15	100	9/4/09	20:00	60	10/4/09	7:45	-204

Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr	Date	Time	Flow m^3/hr
10/4/09	8:00	-232	10/4/09	9:15	-200	10/4/09	10:30	-168	10/4/09	11:45	-1332
10/4/09	8:15	-220	10/4/09	9:30	-180	10/4/09	10:45	-248	10/4/09	12:00	-28
10/4/09	8:30	-240	10/4/09	9:45	-168	10/4/09	11:00	-272	10/4/09	12:15	-44
10/4/09	8:45	-208	10/4/09	10:00	-188	10/4/09	11:15	-316	10/4/09	12:30	-100
10/4/09	9:00	-164	10/4/09	10:15	-184	10/4/09	11:30	-292			

Appendix IV-d: Mtiya Tank Flow Logging Results

DATE	TIME	Flow m^3/hr	DATE	TIME	Flow m^3/hr	DATE	TIME	Flow m^3/hr	DATE	TIME	Flow m^3/hr
10/4/09	13:30	1244	11/4/09	0:30	0	11/4/09	11:30	0	11/4/09	22:30	0
10/4/09	13:45	888	11/4/09	0:45	0	11/4/09	11:45	-4	11/4/09	22:45	0
10/4/09	14:00	24	11/4/09	1:00	0	11/4/09	12:00	-1204	11/4/09	23:00	0
10/4/09	14:15	0	11/4/09	1:15	0	11/4/09	12:15	-92	11/4/09	23:15	0
10/4/09	14:30	0	11/4/09	1:30	0	11/4/09	12:30	0	11/4/09	23:30	0
10/4/09	14:45	516	11/4/09	1:45	0	11/4/09	12:45	-4	11/4/09	23:45	0
10/4/09	15:00	40	11/4/09	2:00	0	11/4/09	13:00	-188	12/4/09	0:00	0
10/4/09	15:15	4	11/4/09	2:15	0	11/4/09	13:15	-16	12/4/09	0:15	0
10/4/09	15:30	0	11/4/09	2:30	0	11/4/09	13:30	0	12/4/09	0:30	0
10/4/09	15:45	0	11/4/09	2:45	0	11/4/09	13:45	-4	12/4/09	0:45	0
10/4/09	16:00	588	11/4/09	3:00	0	11/4/09	14:00	-264	12/4/09	1:00	0
10/4/09	16:15	192	11/4/09	3:15	0	11/4/09	14:15	0	12/4/09	1:15	0
10/4/09	16:30	0	11/4/09	3:30	0	11/4/09	14:30	0	12/4/09	1:30	0
10/4/09	16:45	0	11/4/09	3:45	0	11/4/09	14:45	0	12/4/09	1:45	0
10/4/09	17:00	4	11/4/09	4:00	0	11/4/09	15:00	-4	12/4/09	2:00	0
10/4/09	17:15	0	11/4/09	4:15	0	11/4/09	15:15	-164	12/4/09	2:15	0
10/4/09	17:30	0	11/4/09	4:30	0	11/4/09	15:30	-624	12/4/09	2:30	0
10/4/09	17:45	0	11/4/09	4:45	0	11/4/09	15:45	0	12/4/09	2:45	0
10/4/09	18:00	588	11/4/09	5:00	0	11/4/09	16:00	0	12/4/09	3:00	0
10/4/09	18:15	0	11/4/09	5:15	0	11/4/09	16:15	0	12/4/09	3:15	0
10/4/09	18:30	0	11/4/09	5:30	0	11/4/09	16:30	0	12/4/09	3:30	0
10/4/09	18:45	4	11/4/09	5:45	0	11/4/09	16:45	-4	12/4/09	3:45	0
10/4/09	19:00	0	11/4/09	6:00	0	11/4/09	17:00	-332	12/4/09	4:00	0
10/4/09	19:15	0	11/4/09	6:15	0	11/4/09	17:15	-4	12/4/09	4:15	0
10/4/09	19:30	0	11/4/09	6:30	96	11/4/09	17:30	-324	12/4/09	4:30	0
10/4/09	19:45	0	11/4/09	6:45	-836	11/4/09	17:45	0	12/4/09	4:45	0
10/4/09	20:00	216	11/4/09	7:00	0	11/4/09	18:00	-4	12/4/09	5:00	0
10/4/09	20:15	124	11/4/09	7:15	-428	11/4/09	18:15	-44	12/4/09	5:15	0
10/4/09	20:30	-1228	11/4/09	7:30	-12	11/4/09	18:30	0	12/4/09	5:30	0
10/4/09	20:45	-2968	11/4/09	7:45	-44	11/4/09	18:45	0	12/4/09	5:45	0
10/4/09	21:00	-44	11/4/09	8:00	-4	11/4/09	19:00	0	12/4/09	6:00	0
10/4/09	21:15	-20	11/4/09	8:15	-124	11/4/09	19:15	0	12/4/09	6:15	0
10/4/09	21:30	0	11/4/09	8:30	0	11/4/09	19:30	0	12/4/09	6:30	0
10/4/09	21:45	0	11/4/09	8:45	0	11/4/09	19:45	0	12/4/09	6:45	0
10/4/09	22:00	0	11/4/09	9:00	-4	11/4/09	20:00	0	12/4/09	7:00	0
10/4/09	22:15	0	11/4/09	9:15	-288	11/4/09	20:15	0	12/4/09	7:15	0
10/4/09	22:30	0	11/4/09	9:30	0	11/4/09	20:30	0	12/4/09	7:30	0
10/4/09	22:45	0	11/4/09	9:45	0	11/4/09	20:45	0	12/4/09	7:45	0
10/4/09	23:00	0	11/4/09	10:00	0	11/4/09	21:00	0	12/4/09	8:00	0
10/4/09	23:15	0	11/4/09	10:15	-4	11/4/09	21:15	0	12/4/09	8:15	0
10/4/09	23:30	0	11/4/09	10:30	-128	11/4/09	21:30	-4	12/4/09	8:30	0
10/4/09	23:45	0	11/4/09	10:45	-184	11/4/09	21:45	0	12/4/09	8:45	0
11/4/09	0:00	0	11/4/09	11:00	0	11/4/09	22:00	0	12/4/09	9:00	0
11/4/09	0:15	0	11/4/09	11:15	0	11/4/09	22:15	0	12/4/09	9:15	0

DATE	TIME	Flow m^3/hr	DATE	TIME	Flow m^3/hr	DATE	TIME	Flow m^3/hr	DATE	TIME	Flow m^3/hr
12/4/09	9:30	0	12/4/09	21:30	0	13/04/09	9:30	-536	13/04/09	21:30	0
12/4/09	9:45	0	12/4/09	21:45	0	13/04/09	9:45	0	13/04/09	21:45	0
12/4/09	10:00	0	12/4/09	22:00	0	13/04/09	10:00	0	13/04/09	22	0
12/4/09	10:15	-468	12/4/09	22:15	0	13/04/09	10:15	-4	13/04/09	22:15	0
12/4/09	10:30	-388	12/4/09	22:30	0	13/04/09	10:30	-256	13/04/09	22:30	0
12/4/09	10:45	0	12/4/09	22:45	0	13/04/09	10:45	0	13/04/09	22:45	0
12/4/09	11:00	-80	12/4/09	23:00	0	13/04/09	11:00	0	13/04/09	23:00	0
12/4/09	11:15	0	12/4/09	23:15	0	13/04/09	11:15	0	13/04/09	23:15	0
12/4/09	11:30	-4	12/4/09	23:30	0	13/04/09	11:30	-4	13/04/09	23:30	0
12/4/09	11:45	0	12/4/09	23:45	0	13/04/09	11:45	-24	13/04/09	23:45	0
12/4/09	12:00	0	13/04/09	0:00	0	13/04/09	12:00	-368	14/04/09	0:00	0
12/4/09	12:15	-308	13/04/09	0:15	0	13/04/09	12:15	0	14/04/09	0:15	0
12/4/09	12:30	0	13/04/09	0:30	0	13/04/09	12:30	0	14/04/09	0:30	0
12/4/09	12:45	-4	13/04/09	0:45	0	13/04/09	12:45	-4	14/04/09	0:45	0
12/4/09	13:00	-200	13/04/09	1:00	0	13/04/09	13:00	0	14/04/09	1:00	0
12/4/09	13:15	-20	13/04/09	1:15	0	13/04/09	13:15	-732	14/04/09	1:15	0
12/4/09	13:30	0	13/04/09	1:30	0	13/04/09	13:30	-16	14/04/09	1:30	0
12/4/09	13:45	0	13/04/09	1:45	0	13/04/09	13:45	-4	14/04/09	1:45	0
12/4/09	14:00	-4	13/04/09	2:00	0	13/04/09	14:00	-392	14/04/09	2:00	0
12/4/09	14:15	-124	13/04/09	2:15	0	13/04/09	14:15	-76	14/04/09	2:15	0
12/4/09	14:30	0	13/04/09	2:30	0	13/04/09	14:30	0	14/04/09	2:30	0
12/4/09	14:45	0	13/04/09	2:45	0	13/04/09	14:45	-4	14/04/09	2:45	0
12/4/09	15:00	0	13/04/09	3:00	0	13/04/09	15:00	-236	14/04/09	3:00	0
12/4/09	15:15	-4	13/04/09	3:15	0	13/04/09	15:15	0	14/04/09	3:15	0
12/4/09	15:30	0	13/04/09	3:30	0	13/04/09	15:30	0	14/04/09	3:30	0
12/4/09	15:45	-88	13/04/09	3:45	0	13/04/09	15:45	-4	14/04/09	3:45	0
12/4/09	16:00	0	13/04/09	4:00	0	13/04/09	16:00	-340	14/04/09	4:00	0
12/4/09	16:15	0	13/04/09	4:15	0	13/04/09	16:15	0	14/04/09	4:15	0
12/4/09	16:30	0	13/04/09	4:30	0	13/04/09	16:30	0	14/04/09	4:30	0
12/4/09	16:45	0	13/04/09	4:45	0	13/04/09	16:45	0	14/04/09	4:45	0
12/4/09	17:00	-4	13/04/09	5:00	0	13/04/09	17:00	-4	14/04/09	5:00	0
12/4/09	17:15	-28	13/04/09	5:15	0	13/04/09	17:15	-8	14/04/09	5:15	0
12/4/09	17:30	0	13/04/09	5:30	0	13/04/09	17:30	-952	14/04/09	5:30	-4
12/4/09	17:45	-4	13/04/09	5:45	0	13/04/09	17:45	-132	14/04/09	5:45	0
12/4/09	18:00	-56	13/04/09	6:00	0	13/04/09	18:00	0	14/04/09	6:00	-144
12/4/09	18:15	0	13/04/09	6:15	-4	13/04/09	18:15	-4	14/04/09	6:15	0
12/4/09	18:30	0	13/04/09	6:30	-168	13/04/09	18:30	-568	14/04/09	6:30	-52
12/4/09	18:45	-104	13/04/09	6:45	-4	13/04/09	18:45	0	14/04/09	6:45	0
12/4/09	19:00	0	13/04/09	7:00	-108	13/04/09	19:00	0	14/04/09	7:00	-36
12/4/09	19:15	0	13/04/09	7:15	-4	13/04/09	19:15	0	14/04/09	7:15	0
12/4/09	19:30	0	13/04/09	7:30	-80	13/04/09	19:30	0	14/04/09	7:30	-24
12/4/09	19:45	0	13/04/09	7:45	-4	13/04/09	19:45	0	14/04/09	7:45	0
12/4/09	20:00	0	13/04/09	8:00	-236	13/04/09	20:00	0	14/04/09	8:00	-4
12/4/09	20:15	0	13/04/09	8:15	-4	13/04/09	20:15	0	14/04/09	8:15	-88
12/4/09	20:30	0	13/04/09	8:30	-232	13/04/09	20:30	0	14/04/09	8:30	0
12/4/09	20:45	0	13/04/09	8:45	0	13/04/09	20:45	0	14/04/09	8:45	0
12/4/09	21:00	0	13/04/09	9:00	-4	13/04/09	21:00	0	14/04/09	9:00	-4
12/4/09	21:15	0	13/04/09	9:15	-4	13/04/09	21:15	0	14/04/09	9:15	-220

DATE	TIME	Flow m^3/hr	DATE	TIME	Flow m^3/hr	DATE	TIME	Flow m^3/hr	DATE	TIME	Flow m^3/hr
14/04/09	9:30	0	14/04/09	11:30	-4	14/04/09	13:30	0	14/04/09	15:30	0
14/04/09	9:45	0	14/04/09	11:45	-64	14/04/09	13:45	-4	14/04/09	15:45	0
14/04/09	10:00	-4	14/04/09	12:00	0	14/04/09	14:00	-88	14/04/09	16:00	-4
14/04/09	10:15	-104	14/04/09	12:15	0	14/04/09	14:15	0	14/04/09	16:15	-116
14/04/09	10:30	0	14/04/09	12:30	0	14/04/09	14:30	0	14/04/09	16:30	0
14/04/09	10:45	0	14/04/09	12:45	-4	14/04/09	14:45	-4			
14/04/09	11:00	0	14/04/09	13:00	-128	14/04/09	15:00	-116			
14/04/09	11:15	0	14/04/09	13:15	0	14/04/09	15:15	0			

Appendix V-a: Airwing Zone Pressure Logging Results

Date	Time	Press (m)	Date	Time	Press (m)	Date	Time	Press (m)	Date	Time	Press (m)
27/03/09	0:00	7	27/03/09	10:45	6.5	27/03/09	21:30	28.3	28/03/09	8:15	22.4
27/03/09	0:15	7	27/03/09	11:00	6.4	27/03/09	21:45	28.8	28/03/09	8:30	19.2
27/03/09	0:30	7	27/03/09	11:15	6.6	27/03/09	22:00	29.2	28/03/09	8:45	18.6
27/03/09	0:45	7	27/03/09	11:30	6.5	27/03/09	22:15	29.4	28/03/09	9:00	20.9
27/03/09	1:00	7	27/03/09	11:45	6.7	27/03/09	22:30	29	28/03/09	9:15	22.6
27/03/09	1:15	7	27/03/09	12:00	6.5	27/03/09	22:45	29.3	28/03/09	9:30	23.1
27/03/09	1:30	7.1	27/03/09	12:15	6.6	27/03/09	23:00	29.4	28/03/09	9:45	22
27/03/09	1:45	7.1	27/03/09	12:30	6.3	27/03/09	23:15	29.4	28/03/09	10:00	23
27/03/09	2:00	7.1	27/03/09	12:45	6.6	27/03/09	23:30	29.2	28/03/09	10:15	23.5
27/03/09	2:15	7.1	27/03/09	13:00	6.5	27/03/09	23:45	29.6	28/03/09	10:30	20.6
27/03/09	2:30	7.1	27/03/09	13:15	6.5	28/03/09	0:00	29.8	28/03/09	10:45	24.7
27/03/09	2:45	7.1	27/03/09	13:30	6.2	28/03/09	0:15	29.9	28/03/09	11:00	22.9
27/03/09	3:00	7.1	27/03/09	13:45	6.4	28/03/09	0:30	29.9	28/03/09	11:15	24.2
27/03/09	3:15	7.1	27/03/09	14:00	6.4	28/03/09	0:45	29.9	28/03/09	11:30	25.6
27/03/09	3:30	7.2	27/03/09	14:15	6.4	28/03/09	1:00	29.7	28/03/09	11:45	25.7
27/03/09	3:45	7.2	27/03/09	14:30	6.4	28/03/09	1:15	30	28/03/09	12:00	20.7
27/03/09	4:00	7.2	27/03/09	14:45	6.4	28/03/09	1:30	30.1	28/03/09	12:15	24.1
27/03/09	4:15	7.2	27/03/09	15:00	6.4	28/03/09	1:45	30.1	28/03/09	12:30	26.2
27/03/09	4:30	7.3	27/03/09	15:15	6.4	28/03/09	2:00	30	28/03/09	12:45	25.9
27/03/09	4:45	7.3	27/03/09	15:30	6.4	28/03/09	2:15	29.8	28/03/09	13:00	24.8
27/03/09	5:00	7.3	27/03/09	15:45	6.4	28/03/09	2:30	30.1	28/03/09	13:15	24.4
27/03/09	5:15	7.2	27/03/09	16:00	6.4	28/03/09	2:45	30.1	28/03/09	13:30	21.8
27/03/09	5:30	7.3	27/03/09	16:15	6.4	28/03/09	3:00	30.1	28/03/09	13:45	24.1
27/03/09	5:45	7.1	27/03/09	16:30	6.4	28/03/09	3:15	30.1	28/03/09	14:00	24.7
27/03/09	6:00	7	27/03/09	16:45	6.4	28/03/09	3:30	30	28/03/09	14:15	25
27/03/09	6:15	7	27/03/09	17:00	4.5	28/03/09	3:45	29.8	28/03/09	14:30	24.7
27/03/09	6:30	7	27/03/09	17:15	2	28/03/09	4:00	30	28/03/09	14:45	24.1
27/03/09	6:45	6.9	27/03/09	17:30	26.5	28/03/09	4:15	30	28/03/09	15:00	22.8
27/03/09	7:00	6.9	27/03/09	17:45	26.5	28/03/09	4:30	29.7	28/03/09	15:15	25.9
27/03/09	7:15	6.9	27/03/09	18:00	27.4	28/03/09	4:45	29.7	28/03/09	15:30	27.4
27/03/09	7:30	6.9	27/03/09	18:15	26.4	28/03/09	5:00	28.8	28/03/09	15:45	28.4
27/03/09	7:45	6.8	27/03/09	18:30	25.8	28/03/09	5:15	28.3	28/03/09	16:00	26.8
27/03/09	8:00	6.5	27/03/09	18:45	26.7	28/03/09	5:30	25.9	28/03/09	16:15	28.1
27/03/09	8:15	6.3	27/03/09	19:00	26.8	28/03/09	5:45	26.1	28/03/09	16:30	28.6
27/03/09	8:30	6.6	27/03/09	19:15	26.7	28/03/09	6:00	26.1	28/03/09	16:45	28.7
27/03/09	8:45	6.6	27/03/09	19:30	28.2	28/03/09	6:15	25.5	28/03/09	17:00	28.2
27/03/09	9:00	6.6	27/03/09	19:45	28	28/03/09	6:30	23.3	28/03/09	17:15	20
27/03/09	9:15	6.6	27/03/09	20:00	26.3	28/03/09	6:45	23.2	28/03/09	17:30	7.7
27/03/09	9:30	6.6	27/03/09	20:15	27.8	28/03/09	7:00	22.9	28/03/09	17:45	35.1
27/03/09	9:45	7	27/03/09	20:30	28.2	28/03/09	7:15	23.7	28/03/09	18:00	34.7
27/03/09	10:00	6.8	27/03/09	20:45	26.5	28/03/09	7:30	23.6	28/03/09	18:15	34.6
27/03/09	10:15	6.5	27/03/09	21:00	28	28/03/09	7:45	23.7	28/03/09	18:30	34.9
27/03/09	10:30	6.6	27/03/09	21:15	29	28/03/09	8:00	24.2	28/03/09	18:45	34.5

Date	Time	Press (m)	Date	Time	Press (m)	Date	Time	Press (m)	Date	Time	Press (m)
28/03/09	19:00	35	29/03/09	7:00	28.7	29/03/09	19:00	34.3	30/03/09	7:00	31.8
28/03/09	19:15	34.7	29/03/09	7:15	31.3	29/03/09	19:15	34.4	30/03/09	7:15	29.3
28/03/09	19:30	33.9	29/03/09	7:30	30	29/03/09	19:30	34.5	30/03/09	7:30	31.8
28/03/09	19:45	34.9	29/03/09	7:45	32.2	29/03/09	19:45	34.3	30/03/09	7:45	31.9
28/03/09	20:00	34.4	29/03/09	8:00	31.2	29/03/09	20:00	34.5	30/03/09	8:00	31.9
28/03/09	20:15	34.9	29/03/09	8:15	31.9	29/03/09	20:15	34.3	30/03/09	8:15	32.1
28/03/09	20:30	34.9	29/03/09	8:30	32.8	29/03/09	20:30	34.6	30/03/09	8:30	31.9
28/03/09	20:45	34.8	29/03/09	8:45	33	29/03/09	20:45	35	30/03/09	8:45	32.7
28/03/09	21:00	34.1	29/03/09	9:00	33.2	29/03/09	21:00	35.1	30/03/09	9:00	32.7
28/03/09	21:15	35.1	29/03/09	9:15	32.5	29/03/09	21:15	34.4	30/03/09	9:15	33.4
28/03/09	21:30	35.6	29/03/09	9:30	34.1	29/03/09	21:30	34.8	30/03/09	9:30	33.5
28/03/09	21:45	35.2	29/03/09	9:45	33.6	29/03/09	21:45	35.3	30/03/09	9:45	33.6
28/03/09	22:00	35.8	29/03/09	10:00	34	29/03/09	22:00	35.5	30/03/09	10:00	29.1
28/03/09	22:15	35.5	29/03/09	10:15	34.2	29/03/09	22:15	35.5	30/03/09	10:15	27.4
28/03/09	22:30	35.8	29/03/09	10:30	33.5	29/03/09	22:30	35.5	30/03/09	10:30	29.8
28/03/09	22:45	36	29/03/09	10:45	33.7	29/03/09	22:45	35.7	30/03/09	10:45	29.6
28/03/09	23:00	36.1	29/03/09	11:00	34.2	29/03/09	23:00	35.8	30/03/09	11:00	3.3
28/03/09	23:15	36.1	29/03/09	11:15	33.6	29/03/09	23:15	35.8	30/03/09	11:15	14.2
28/03/09	23:30	36.2	29/03/09	11:30	33.6	29/03/09	23:30	35.8	30/03/09	11:30	36.4
28/03/09	23:45	36.2	29/03/09	11:45	33.6	29/03/09	23:45	35.8	30/03/09	11:45	37.5
29/03/09	0:00	36.2	29/03/09	12:00	33.5	30/03/09	0:00	35.8	30/03/09	12:00	38
29/03/09	0:15	36.2	29/03/09	12:15	33.9	30/03/09	0:15	35.9	30/03/09	12:15	38.1
29/03/09	0:30	36.1	29/03/09	12:30	33	30/03/09	0:30	35.9	30/03/09	12:30	38.1
29/03/09	0:45	36.2	29/03/09	12:45	33.4	30/03/09	0:45	35.9	30/03/09	12:45	37.8
29/03/09	1:00	36.3	29/03/09	13:00	33.4	30/03/09	1:00	35.9	30/03/09	13:00	35.5
29/03/09	1:15	36.3	29/03/09	13:15	33	30/03/09	1:15	36	30/03/09	13:15	37.2
29/03/09	1:30	36.3	29/03/09	13:30	32.5	30/03/09	1:30	36	30/03/09	13:30	37.5
29/03/09	1:45	36.3	29/03/09	13:45	33.4	30/03/09	1:45	36	30/03/09	13:45	35.8
29/03/09	2:00	36.4	29/03/09	14:00	33.7	30/03/09	2:00	36	30/03/09	14:00	37.6
29/03/09	2:15	36.4	29/03/09	14:15	33.5	30/03/09	2:15	36	30/03/09	14:15	37.7
29/03/09	2:30	36.4	29/03/09	14:30	34.3	30/03/09	2:30	36	30/03/09	14:30	38.2
29/03/09	2:45	36.4	29/03/09	14:45	33.6	30/03/09	2:45	36	30/03/09	14:45	38
29/03/09	3:00	36.4	29/03/09	15:00	33.9	30/03/09	3:00	36	30/03/09	15:00	36.3
29/03/09	3:15	36.4	29/03/09	15:15	34.2	30/03/09	3:15	36	30/03/09	15:15	37.9
29/03/09	3:30	36.4	29/03/09	15:30	34.2	30/03/09	3:30	36	30/03/09	15:30	37.8
29/03/09	3:45	36.4	29/03/09	15:45	33.9	30/03/09	3:45	36	30/03/09	15:45	38.4
29/03/09	4:00	36.4	29/03/09	16:00	34.1	30/03/09	4:00	36	30/03/09	16:00	38.2
29/03/09	4:15	36.2	29/03/09	16:15	34.1	30/03/09	4:15	35.9	30/03/09	16:15	38.7
29/03/09	4:30	36	29/03/09	16:30	34.2	30/03/09	4:30	35.9	30/03/09	16:30	38.8
29/03/09	4:45	35.4	29/03/09	16:45	34.2	30/03/09	4:45	35.5	30/03/09	16:45	38.9
29/03/09	5:00	35.8	29/03/09	17:00	34.3	30/03/09	5:00	35.1	30/03/09	17:00	38.7
29/03/09	5:15	35.5	29/03/09	17:15	33.9	30/03/09	5:15	34.2	30/03/09	17:15	38.7
29/03/09	5:30	35.1	29/03/09	17:30	34.7	30/03/09	5:30	32.6	30/03/09	17:30	39
29/03/09	5:45	35	29/03/09	17:45	34.4	30/03/09	5:45	32.3	30/03/09	17:45	36.3
29/03/09	6:00	33.2	29/03/09	18:00	33.7	30/03/09	6:00	31	30/03/09	18:00	34.9
29/03/09	6:15	32.9	29/03/09	18:15	33.5	30/03/09	6:15	31	30/03/09	18:15	34.7
29/03/09	6:30	32.1	29/03/09	18:30	33.6	30/03/09	6:30	30.1	30/03/09	18:30	38.4
29/03/09	6:45	31.8	29/03/09	18:45	34.1	30/03/09	6:45	31.4	30/03/09	18:45	38.9

Date	Time	Press (m)	Date	Time	Press (m)	Date	Time	Press (m)	Date	Time	Press (m)
30/03/09	19:00	38.9	30/03/09	23:15	40	31/03/09	3:30	40.2	31/03/09	7:45	35.9
30/03/09	19:15	38.9	30/03/09	23:30	40.1	31/03/09	3:45	40.2	31/03/09	8:00	37.1
30/03/09	19:30	38.7	30/03/09	23:45	40.1	31/03/09	4:00	40.2	31/03/09	8:15	36.9
30/03/09	19:45	39	31/03/09	0:00	40.1	31/03/09	4:15	39.9	31/03/09	8:30	37.2
30/03/09	20:00	39	31/03/09	0:15	40.1	31/03/09	4:30	39.9	31/03/09	8:45	37.5
30/03/09	20:15	38.5	31/03/09	0:30	40	31/03/09	4:45	40	31/03/09	9:00	37.3
30/03/09	20:30	39.1	31/03/09	0:45	40	31/03/09	5:00	39.3	31/03/09	9:15	37.2
30/03/09	20:45	39.1	31/03/09	1:00	40.1	31/03/09	5:15	39.1	31/03/09	9:30	37.5
30/03/09	21:00	39.3	31/03/09	1:15	40.1	31/03/09	5:30	38.7	31/03/09	9:45	37.7
30/03/09	21:15	39.4	31/03/09	1:30	40.1	31/03/09	5:45	37.2	31/03/09	10:00	37.3
30/03/09	21:30	39.4	31/03/09	1:45	40.1	31/03/09	6:00	35	31/03/09	10:15	38.1
30/03/09	21:45	39.7	31/03/09	2:00	40.1	31/03/09	6:15	36.7	31/03/09	10:30	38.2
30/03/09	22:00	39.8	31/03/09	2:15	39.9	31/03/09	6:30	34.3	31/03/09	10:45	37.8
30/03/09	22:15	39.8	31/03/09	2:30	40.1	31/03/09	6:45	34.4	31/03/09	11:00	37.7
30/03/09	22:30	40	31/03/09	2:45	40.1	31/03/09	7:00	34.2	31/03/09	11:15	25.4
30/03/09	22:45	40	31/03/09	3:00	40.1	31/03/09	7:15	35.5			
30/03/09	23:00	40	31/03/09	3:15	40.1	31/03/09	7:30	36.2			

Appendix V-b: Malonje Zone Pressure Logging Results

Date	Time	Press (m)	Date	Time	Press (m)	Date	Time	Press (m)	Date	Time	Press (m)
31/03/09	12:00	-0.9	31/03/09	22:45	56.9	1/4/09	9:30	38.4	1/4/09	20:15	107.2
31/03/09	12:15	8.8	31/03/09	23:00	57.4	1/4/09	9:45	42.9	1/4/09	20:30	106.3
31/03/09	12:30	42.7	31/03/09	23:15	57.5	1/4/09	10:00	38.3	1/4/09	20:45	107.1
31/03/09	12:45	43.9	31/03/09	23:30	57.3	1/4/09	10:15	36.7	1/4/09	21:00	109.9
31/03/09	13:00	46.3	31/03/09	23:45	57.9	1/4/09	10:30	28	1/4/09	21:15	111.5
31/03/09	13:15	44.2	1/4/09	0:00	57.2	1/4/09	10:45	35.4	1/4/09	21:30	111.1
31/03/09	13:30	45.3	1/4/09	0:15	57.1	1/4/09	11:00	39.3	1/4/09	21:45	111.3
31/03/09	13:45	44.7	1/4/09	0:30	58.3	1/4/09	11:15	41	1/4/09	22:00	112.1
31/03/09	14:00	43.1	1/4/09	0:45	58	1/4/09	11:30	37.3	1/4/09	22:15	112.2
31/03/09	14:15	44	1/4/09	1:00	58.1	1/4/09	11:45	39.6	1/4/09	22:30	112
31/03/09	14:30	44.4	1/4/09	1:15	58.2	1/4/09	12:00	31	1/4/09	22:45	113.5
31/03/09	14:45	44.8	1/4/09	1:30	57.4	1/4/09	12:15	-1	1/4/09	23:00	113.7
31/03/09	15:00	37.5	1/4/09	1:45	57.9	1/4/09	12:30	21.3	1/4/09	23:15	113.9
31/03/09	15:15	39.5	1/4/09	2:00	58.5	1/4/09	12:45	104.7	1/4/09	23:30	113.8
31/03/09	15:30	41.8	1/4/09	2:15	57.8	1/4/09	13:00	104.3	1/4/09	23:45	113.9
31/03/09	15:45	40.8	1/4/09	2:30	58.1	1/4/09	13:15	100	2/4/09	0:00	113.9
31/03/09	16:00	45.7	1/4/09	2:45	57.9	1/4/09	13:30	101.8	2/4/09	0:15	113.9
31/03/09	16:15	46.4	1/4/09	3:00	57.6	1/4/09	13:45	102.3	2/4/09	0:30	113.9
31/03/09	16:30	49.7	1/4/09	3:15	57.6	1/4/09	14:00	104.5	2/4/09	0:45	114
31/03/09	16:45	48.6	1/4/09	3:30	56.6	1/4/09	14:15	107.2	2/4/09	1:00	114
31/03/09	17:00	50.8	1/4/09	3:45	56.3	1/4/09	14:30	103.1	2/4/09	1:15	113.8
31/03/09	17:15	50.7	1/4/09	4:00	57.7	1/4/09	14:45	102.2	2/4/09	1:30	113.8
31/03/09	17:30	44.8	1/4/09	4:15	57.5	1/4/09	15:00	102	2/4/09	1:45	113.9
31/03/09	17:45	44.2	1/4/09	4:30	54.5	1/4/09	15:15	104.2	2/4/09	2:00	113.8
31/03/09	18:00	40	1/4/09	4:45	51.7	1/4/09	15:30	105.7	2/4/09	2:15	113.8
31/03/09	18:15	43.6	1/4/09	5:00	47.6	1/4/09	15:45	103.9	2/4/09	2:30	113.8
31/03/09	18:30	46.5	1/4/09	5:15	48.3	1/4/09	16:00	107.2	2/4/09	2:45	113.6
31/03/09	18:45	54	1/4/09	5:30	48.1	1/4/09	16:15	105.2	2/4/09	3:00	113.8
31/03/09	19:00	52.4	1/4/09	5:45	45.6	1/4/09	16:30	104.8	2/4/09	3:15	113.5
31/03/09	19:15	50.6	1/4/09	6:00	41.7	1/4/09	16:45	103.7	2/4/09	3:30	113.9
31/03/09	19:30	50.8	1/4/09	6:15	27.2	1/4/09	17:00	103	2/4/09	3:45	113.9
31/03/09	19:45	51.2	1/4/09	6:30	26.9	1/4/09	17:15	104.1	2/4/09	4:00	113.7
31/03/09	20:00	47.4	1/4/09	6:45	22.9	1/4/09	17:30	98	2/4/09	4:15	113.1
31/03/09	20:15	48.9	1/4/09	7:00	27.7	1/4/09	17:45	90.3	2/4/09	4:30	112.8
31/03/09	20:30	49.8	1/4/09	7:15	31.4	1/4/09	18:00	77.8	2/4/09	4:45	112.3
31/03/09	20:45	49.6	1/4/09	7:30	39.4	1/4/09	18:15	74.9	2/4/09	5:00	110.8
31/03/09	21:00	53.3	1/4/09	7:45	38.4	1/4/09	18:30	79.7	2/4/09	5:15	108.9
31/03/09	21:15	53	1/4/09	8:00	40.4	1/4/09	18:45	93.6	2/4/09	5:30	104.6
31/03/09	21:30	54.7	1/4/09	8:15	39.1	1/4/09	19:00	104.7	2/4/09	5:45	98.2
31/03/09	21:45	54.6	1/4/09	8:30	32.3	1/4/09	19:15	103.7	2/4/09	6:00	91.5
31/03/09	22:00	54.4	1/4/09	8:45	24.2	1/4/09	19:30	105.5	2/4/09	6:15	81.8
31/03/09	22:15	57	1/4/09	9:00	32.5	1/4/09	19:45	104.5	2/4/09	6:30	74.7
31/03/09	22:30	55.6	1/4/09	9:15	35.6	1/4/09	20:00	104.5	2/4/09	6:45	68.7

Date	Time	Press (m)	Date	Time	Press (m)	Date	Time	Press (m)	Date	Time	Press (m)
2/4/09	7:00	86.9	2/4/09	18:45	78.1	3/4/09	6:30	57.5	3/4/09	18:15	76.4
2/4/09	7:15	87.6	2/4/09	19:00	82.6	3/4/09	6:45	54.2	3/4/09	18:30	86.9
2/4/09	7:30	96	2/4/09	19:15	82.6	3/4/09	7:00	55.5	3/4/09	18:45	89
2/4/09	7:45	91.1	2/4/09	19:30	71.1	3/4/09	7:15	49.4	3/4/09	19:00	91.9
2/4/09	8:00	75	2/4/09	19:45	72.3	3/4/09	7:30	56.1	3/4/09	19:15	93.3
2/4/09	8:15	70.2	2/4/09	20:00	73.4	3/4/09	7:45	62.8	3/4/09	19:30	93.2
2/4/09	8:30	70.5	2/4/09	20:15	73.2	3/4/09	8:00	67.7	3/4/09	19:45	94.2
2/4/09	8:45	75.4	2/4/09	20:30	74.4	3/4/09	8:15	62.9	3/4/09	20:00	93.6
2/4/09	9:00	79.6	2/4/09	20:45	76.6	3/4/09	8:30	70.5	3/4/09	20:15	92.1
2/4/09	9:15	78.6	2/4/09	21:00	76.5	3/4/09	8:45	72.5	3/4/09	20:30	92.3
2/4/09	9:30	76.1	2/4/09	21:15	80.1	3/4/09	9:00	69.6	3/4/09	20:45	92.4
2/4/09	9:45	87.2	2/4/09	21:30	80.3	3/4/09	9:15	71.4	3/4/09	21:00	94.9
2/4/09	10:00	84.3	2/4/09	21:45	80.2	3/4/09	9:30	77.5	3/4/09	21:15	95.8
2/4/09	10:15	84.9	2/4/09	22:00	80	3/4/09	9:45	76.6	3/4/09	21:30	94.3
2/4/09	10:30	96	2/4/09	22:15	80.8	3/4/09	10:00	73.2	3/4/09	21:45	95.6
2/4/09	10:45	91.4	2/4/09	22:30	80.9	3/4/09	10:15	74.3	3/4/09	22:00	97.6
2/4/09	11:00	90.3	2/4/09	22:45	80.8	3/4/09	10:30	74.5	3/4/09	22:15	97.7
2/4/09	11:15	96.8	2/4/09	23:00	81	3/4/09	10:45	79.5	3/4/09	22:30	98.4
2/4/09	11:30	99.9	2/4/09	23:15	81.2	3/4/09	11:00	83.2	3/4/09	22:45	98.5
2/4/09	11:45	102.5	2/4/09	23:30	81.1	3/4/09	11:15	77.1	3/4/09	23:00	97.8
2/4/09	12:00	101.2	2/4/09	23:45	81.1	3/4/09	11:30	75.1	3/4/09	23:15	97.9
2/4/09	12:15	98.9	3/4/09	0:00	81.4	3/4/09	11:45	76.4	3/4/09	23:30	98.1
2/4/09	12:30	106.8	3/4/09	0:15	81.3	3/4/09	12:00	80.3	3/4/09	23:45	98.4
2/4/09	12:45	105.4	3/4/09	0:30	81.3	3/4/09	12:15	77.8	4/4/09	0:00	98.8
2/4/09	13:00	101.3	3/4/09	0:45	81.3	3/4/09	12:30	77.1	4/4/09	0:15	98.7
2/4/09	13:15	103.4	3/4/09	1:00	81.4	3/4/09	12:45	76.6	4/4/09	0:30	98.7
2/4/09	13:30	99.1	3/4/09	1:15	81.4	3/4/09	13:00	78.3	4/4/09	0:45	98.9
2/4/09	13:45	97.2	3/4/09	1:30	81.5	3/4/09	13:15	75.5	4/4/09	1:00	98.9
2/4/09	14:00	88.6	3/4/09	1:45	81.5	3/4/09	13:30	77.5	4/4/09	1:15	99
2/4/09	14:15	94.6	3/4/09	2:00	81.5	3/4/09	13:45	79.3	4/4/09	1:30	99
2/4/09	14:30	101.8	3/4/09	2:15	81.4	3/4/09	14:00	81.4	4/4/09	1:45	98.1
2/4/09	14:45	102	3/4/09	2:30	81.5	3/4/09	14:15	83.4	4/4/09	2:00	97.9
2/4/09	15:00	102.1	3/4/09	2:45	81.3	3/4/09	14:30	80.1	4/4/09	2:15	97.8
2/4/09	15:15	100.1	3/4/09	3:00	81.2	3/4/09	14:45	36	4/4/09	2:30	97.7
2/4/09	15:30	99.4	3/4/09	3:15	81.5	3/4/09	15:00	48.9	4/4/09	2:45	97.8
2/4/09	15:45	103.4	3/4/09	3:30	81.6	3/4/09	15:15	60.6	4/4/09	3:00	97.2
2/4/09	16:00	102.7	3/4/09	3:45	81.6	3/4/09	15:30	69.3	4/4/09	3:15	98.2
2/4/09	16:15	102.8	3/4/09	4:00	81.6	3/4/09	15:45	73.7	4/4/09	3:30	97.8
2/4/09	16:30	104.4	3/4/09	4:15	81.4	3/4/09	16:00	77.4	4/4/09	3:45	98.6
2/4/09	16:45	77.2	3/4/09	4:30	79.9	3/4/09	16:15	53.5	4/4/09	4:00	98.6
2/4/09	17:00	-0.6	3/4/09	4:45	80.6	3/4/09	16:30	-0.7	4/4/09	4:15	97.4
2/4/09	17:15	74.2	3/4/09	5:00	80.2	3/4/09	16:45	64.6	4/4/09	4:30	96.9
2/4/09	17:30	73.2	3/4/09	5:15	78.8	3/4/09	17:00	74.7	4/4/09	4:45	98.1
2/4/09	17:45	74.1	3/4/09	5:30	90.1	3/4/09	17:15	82.7	4/4/09	5:00	95.8
2/4/09	18:00	64.7	3/4/09	5:45	73.8	3/4/09	17:30	78.9	4/4/09	5:15	95.6
2/4/09	18:15	66.9	3/4/09	6:00	67.9	3/4/09	17:45	77.3	4/4/09	5:30	95.8
2/4/09	18:30	72.5	3/4/09	6:15	66.2	3/4/09	18:00	70.4	4/4/09	5:45	91.1

Date	Time	Press (m)	Date	Time	Press (m)	Date	Time	Press (m)	Date	Time	Press (m)
4/4/09	6:00	82.4	4/4/09	9:00	54.2	4/4/09	12:00	84	4/4/09	15:00	89.4
4/4/09	6:15	73.8	4/4/09	9:15	62.9	4/4/09	12:15	83.1	4/4/09	15:15	91.4
4/4/09	6:30	62.1	4/4/09	9:30	63.4	4/4/09	12:30	89.4	4/4/09	15:30	91.5
4/4/09	6:45	49.7	4/4/09	9:45	70.1	4/4/09	12:45	96.2	4/4/09	15:45	94.5
4/4/09	7:00	52.1	4/4/09	10:00	71.9	4/4/09	13:00	95.9	4/4/09	16:00	94.1
4/4/09	7:15	49	4/4/09	10:15	70.7	4/4/09	13:15	77.6	4/4/09	16:15	90.4
4/4/09	7:30	39.8	4/4/09	10:30	75.3	4/4/09	13:30	85.2	4/4/09	16:30	89.2
4/4/09	7:45	46.9	4/4/09	10:45	74.4	4/4/09	13:45	90.3	4/4/09	16:45	88.7
4/4/09	8:00	44.5	4/4/09	11:00	83.8	4/4/09	14:00	87.6	4/4/09	17:00	86.7
4/4/09	8:15	43.9	4/4/09	11:15	82.9	4/4/09	14:15	83.9	4/4/09	17:15	66.8
4/4/09	8:30	50	4/4/09	11:30	84	4/4/09	14:30	88.1			
4/4/09	8:45	52.7	4/4/09	11:45	84.7	4/4/09	14:45	83.7			

Appendix Vc: Sadzi Zone Pressure Logging Results

Date	Time	Press (m)	Date	Time	Press (m)	Date	Time	Press (m)	Date	Time	Press (m)
6/4/09	17:15	1.2	7/4/09	4:00	31.8	7/4/09	14:45	31.3	8/4/09	1:30	56.1
6/4/09	17:30	11.1	7/4/09	4:15	31.9	7/4/09	15:00	30.7	8/4/09	1:45	56.1
6/4/09	17:45	10.7	7/4/09	4:30	31.9	7/4/09	15:15	31.4	8/4/09	2:00	56.1
6/4/09	18:00	11.1	7/4/09	4:45	31.9	7/4/09	15:30	31.4	8/4/09	2:15	56.2
6/4/09	18:15	11.2	7/4/09	5:00	31.9	7/4/09	15:45	31.4	8/4/09	2:30	56.2
6/4/09	18:30	11.1	7/4/09	5:15	31.9	7/4/09	16:00	31.4	8/4/09	2:45	56.2
6/4/09	18:45	11.3	7/4/09	5:30	31.9	7/4/09	16:15	31.4	8/4/09	3:00	56.3
6/4/09	19:00	10.7	7/4/09	5:45	31.9	7/4/09	16:30	31.4	8/4/09	3:15	56.3
6/4/09	19:15	11.3	7/4/09	6:00	31.8	7/4/09	16:45	31.5	8/4/09	3:30	56.3
6/4/09	19:30	12.6	7/4/09	6:15	31	7/4/09	17:00	11.5	8/4/09	3:45	56.4
6/4/09	19:45	21.5	7/4/09	6:30	30.3	7/4/09	17:15	14.8	8/4/09	4:00	56.4
6/4/09	20:00	28.4	7/4/09	6:45	31.4	7/4/09	17:30	53.1	8/4/09	4:15	56.4
6/4/09	20:15	30.9	7/4/09	7:00	30.1	7/4/09	17:45	53.4	8/4/09	4:30	56.4
6/4/09	20:30	31	7/4/09	7:15	29	7/4/09	18:00	52.8	8/4/09	4:45	56.3
6/4/09	20:45	29.1	7/4/09	7:30	25.1	7/4/09	18:15	52.6	8/4/09	5:00	56
6/4/09	21:00	30.3	7/4/09	7:45	25.5	7/4/09	18:30	52.7	8/4/09	5:15	55.2
6/4/09	21:15	31.1	7/4/09	8:00	30.4	7/4/09	18:45	53.4	8/4/09	5:30	55.2
6/4/09	21:30	31.1	7/4/09	8:15	28.8	7/4/09	19:00	53.8	8/4/09	5:45	53.5
6/4/09	21:45	31.2	7/4/09	8:30	29.7	7/4/09	19:15	54.4	8/4/09	6:00	52.1
6/4/09	22:00	31.2	7/4/09	8:45	31.3	7/4/09	19:30	54.4	8/4/09	6:15	50.3
6/4/09	22:15	30.4	7/4/09	9:00	28.5	7/4/09	19:45	54.7	8/4/09	6:30	48.6
6/4/09	22:30	31.2	7/4/09	9:15	26.3	7/4/09	20:00	54.5	8/4/09	6:45	47.6
6/4/09	22:45	31.3	7/4/09	9:30	28.8	7/4/09	20:15	54.8	8/4/09	7:00	45.9
6/4/09	23:00	31.3	7/4/09	9:45	27.4	7/4/09	20:30	54.8	8/4/09	7:15	47.8
6/4/09	23:15	31.3	7/4/09	10:00	30.9	7/4/09	20:45	54.8	8/4/09	7:30	49.2
6/4/09	23:30	30.7	7/4/09	10:15	30.4	7/4/09	21:00	55.1	8/4/09	7:45	47.4
6/4/09	23:45	31.4	7/4/09	10:30	30.3	7/4/09	21:15	55.2	8/4/09	8:00	48.5
7/4/09	0:00	31.4	7/4/09	10:45	31.2	7/4/09	21:30	55.2	8/4/09	8:15	48.9
7/4/09	0:15	31.4	7/4/09	11:00	31.2	7/4/09	21:45	55.3	8/4/09	8:30	51.2
7/4/09	0:30	31.4	7/4/09	11:15	31.2	7/4/09	22:00	55.4	8/4/09	8:45	51.2
7/4/09	0:45	31.5	7/4/09	11:30	31.2	7/4/09	22:15	55.3	8/4/09	9:00	52.1
7/4/09	1:00	31.5	7/4/09	11:45	31.2	7/4/09	22:30	55.7	8/4/09	9:15	52.6
7/4/09	1:15	31.6	7/4/09	12:00	29	7/4/09	22:45	55.7	8/4/09	9:30	54.3
7/4/09	1:30	31.6	7/4/09	12:15	31.2	7/4/09	23:00	55.7	8/4/09	9:45	54
7/4/09	1:45	31.6	7/4/09	12:30	31.2	7/4/09	23:15	55.8	8/4/09	10:00	52.9
7/4/09	2:00	31.6	7/4/09	12:45	31.3	7/4/09	23:30	55.8	8/4/09	10:15	54
7/4/09	2:15	31.7	7/4/09	13:00	31.3	7/4/09	23:45	55.8	8/4/09	10:30	54.4
7/4/09	2:30	31.7	7/4/09	13:15	31.3	8/4/09	0:00	55.9	8/4/09	10:45	54.8
7/4/09	2:45	31.7	7/4/09	13:30	31.3	8/4/09	0:15	56	8/4/09	11:00	54.6
7/4/09	3:00	31.7	7/4/09	13:45	31.3	8/4/09	0:30	56	8/4/09	11:15	53.9
7/4/09	3:15	31.8	7/4/09	14:00	30.7	8/4/09	0:45	56	8/4/09	11:30	52.4
7/4/09	3:30	31.8	7/4/09	14:15	30.9	8/4/09	1:00	56	8/4/09	11:45	54
7/4/09	3:45	31.8	7/4/09	14:30	31.3	8/4/09	1:15	56.1	8/4/09	12:00	54.1

Date	Time	Press (m)	Date	Time	Press (m)	Date	Time	Press (m)	Date	Time	Press (m)
8/4/09	12:15	54	9/4/09	0:00	0.4	9/4/09	11:45	72.9	9/4/09	23:30	65.7
8/4/09	12:30	53.9	9/4/09	0:15	0.4	9/4/09	12:00	71.6	9/4/09	23:45	65.7
8/4/09	12:45	54.1	9/4/09	0:30	0.4	9/4/09	12:15	73.6	10/4/09	0:00	65.7
8/4/09	13:00	53.9	9/4/09	0:45	0.4	9/4/09	12:30	69.1	10/4/09	0:15	65.8
8/4/09	13:15	53.4	9/4/09	1:00	0.4	9/4/09	12:45	69	10/4/09	0:30	65.8
8/4/09	13:30	53.6	9/4/09	1:15	0.4	9/4/09	13:00	70.9	10/4/09	0:45	65.9
8/4/09	13:45	53.2	9/4/09	1:30	0.4	9/4/09	13:15	66.1	10/4/09	1:00	65.9
8/4/09	14:00	52.2	9/4/09	1:45	0.4	9/4/09	13:30	61.5	10/4/09	1:15	65.9
8/4/09	14:15	52.2	9/4/09	2:00	0.4	9/4/09	13:45	67	10/4/09	1:30	65.9
8/4/09	14:30	52.6	9/4/09	2:15	0.4	9/4/09	14:00	66.6	10/4/09	1:45	65.9
8/4/09	14:45	53.8	9/4/09	2:30	0.4	9/4/09	14:15	70.9	10/4/09	2:00	65.9
8/4/09	15:00	55.8	9/4/09	2:45	0.4	9/4/09	14:30	73.6	10/4/09	2:15	65.9
8/4/09	15:15	56	9/4/09	3:00	0.4	9/4/09	14:45	75.6	10/4/09	2:30	66
8/4/09	15:30	56	9/4/09	3:15	0.4	9/4/09	15:00	76.6	10/4/09	2:45	66
8/4/09	15:45	56	9/4/09	3:30	0.4	9/4/09	15:15	73.9	10/4/09	3:00	66
8/4/09	16:00	56.4	9/4/09	3:45	0.4	9/4/09	15:30	70.3	10/4/09	3:15	66
8/4/09	16:15	56.4	9/4/09	4:00	0.3	9/4/09	15:45	70.1	10/4/09	3:30	66
8/4/09	16:30	56.3	9/4/09	4:15	0.2	9/4/09	16:00	71.4	10/4/09	3:45	66.1
8/4/09	16:45	56.4	9/4/09	4:30	0.2	9/4/09	16:15	71.8	10/4/09	4:00	66
8/4/09	17:00	56.3	9/4/09	4:45	0.2	9/4/09	16:30	69.6	10/4/09	4:15	66
8/4/09	17:15	56	9/4/09	5:00	0.2	9/4/09	16:45	50.6	10/4/09	4:30	66
8/4/09	17:30	56	9/4/09	5:15	0.4	9/4/09	17:00	4.7	10/4/09	4:45	65.9
8/4/09	17:45	12.5	9/4/09	5:30	14.7	9/4/09	17:15	63.3	10/4/09	5:00	65.6
8/4/09	18:00	0	9/4/09	5:45	43.7	9/4/09	17:30	63.4	10/4/09	5:15	62.3
8/4/09	18:15	0.1	9/4/09	6:00	45.3	9/4/09	17:45	62.8	10/4/09	5:30	63.5
8/4/09	18:30	0.2	9/4/09	6:15	39.8	9/4/09	18:00	61.3	10/4/09	5:45	61.2
8/4/09	18:45	0.2	9/4/09	6:30	39.2	9/4/09	18:15	60.3	10/4/09	6:00	57.8
8/4/09	19:00	0.1	9/4/09	6:45	35.1	9/4/09	18:30	62	10/4/09	6:15	51
8/4/09	19:15	0.2	9/4/09	7:00	32.4	9/4/09	18:45	62.6	10/4/09	6:30	51.4
8/4/09	19:30	0.2	9/4/09	7:15	47.6	9/4/09	19:00	62.7	10/4/09	6:45	48.1
8/4/09	19:45	0.2	9/4/09	7:30	50.4	9/4/09	19:15	63.5	10/4/09	7:00	47.5
8/4/09	20:00	0.1	9/4/09	7:45	54.8	9/4/09	19:30	64.2	10/4/09	7:15	49.8
8/4/09	20:15	0.1	9/4/09	8:00	57.1	9/4/09	19:45	63.9	10/4/09	7:30	46.8
8/4/09	20:30	0.1	9/4/09	8:15	58	9/4/09	20:00	64.6	10/4/09	7:45	48.3
8/4/09	20:45	0.1	9/4/09	8:30	65.2	9/4/09	20:15	64.2	10/4/09	8:00	48.6
8/4/09	21:00	0.2	9/4/09	8:45	61.6	9/4/09	20:30	64.6	10/4/09	8:15	50.2
8/4/09	21:15	0.2	9/4/09	9:00	65	9/4/09	20:45	64.8	10/4/09	8:30	54.3
8/4/09	21:30	0.2	9/4/09	9:15	67.1	9/4/09	21:00	64.8	10/4/09	8:45	55.3
8/4/09	21:45	0.2	9/4/09	9:30	65.7	9/4/09	21:15	64.9	10/4/09	9:00	56.7
8/4/09	22:00	0.2	9/4/09	9:45	74.9	9/4/09	21:30	64.8	10/4/09	9:15	56.2
8/4/09	22:15	0.3	9/4/09	10:00	74.3	9/4/09	21:45	65.3	10/4/09	9:30	58.9
8/4/09	22:30	0.5	9/4/09	10:15	75.7	9/4/09	22:00	65.3	10/4/09	9:45	59.2
8/4/09	22:45	0.4	9/4/09	10:30	74.8	9/4/09	22:15	65.5	10/4/09	10:00	56.4
8/4/09	23:00	0.5	9/4/09	10:45	76.8	9/4/09	22:30	65.6	10/4/09	10:15	59.4
8/4/09	23:15	0.4	9/4/09	11:00	71.1	9/4/09	22:45	65.5	10/4/09	10:30	61.2
8/4/09	23:30	0.4	9/4/09	11:15	66.5	9/4/09	23:00	65.6	10/4/09	10:45	61
8/4/09	23:45	0.4	9/4/09	11:30	72.9	9/4/09	23:15	65.6	10/4/09	11:00	60.1

Date	Time	Press (m)	Date	Time	Press (m)	Date	Time	Press (m)	Date	Time	Press (m)
10/4/09	11:15	60.3	10/4/09	11:45	59.2	10/4/09	12:15	60	10/4/09	12:45	6.4
10/4/09	11:30	61.6	10/4/09	12:00	57.4	10/4/09	12:30	61.7			

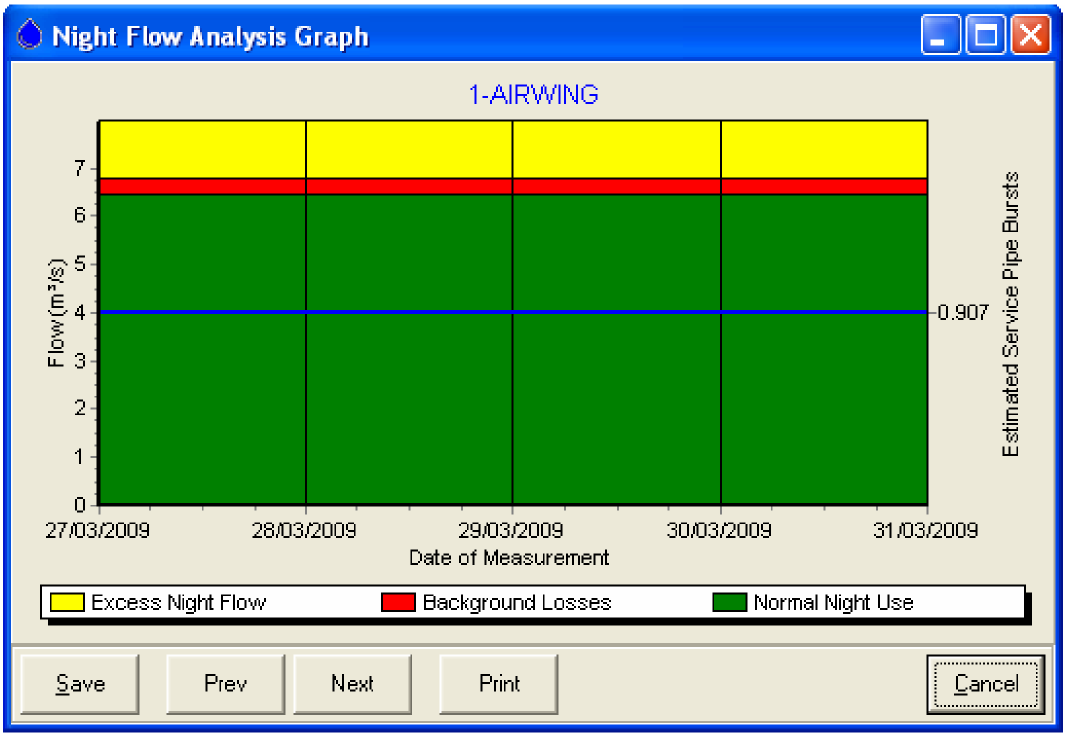
Appendix V-d: Mtiya Zone Pressure Logging Results

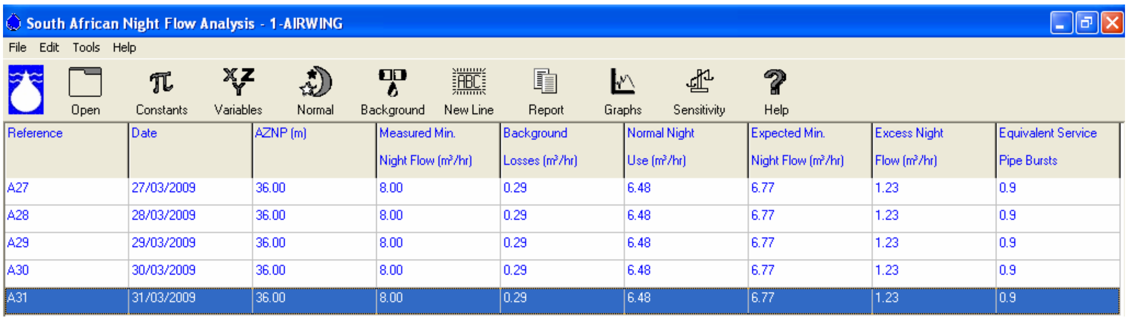
Date	Time	Press (m)	Date	Time	Press (m)	Date	Time	Press (m)	Date	Time	Press (m)
10/4/09	14:00	20.1	11/4/09	0:45	34.6	11/4/09	11:30	34.4	11/4/09	22:15	17.5
10/4/09	14:15	34.6	11/4/09	1:00	34.6	11/4/09	11:45	34.4	11/4/09	22:30	17.3
10/4/09	14:30	34.5	11/4/09	1:15	34.6	11/4/09	12:00	34	11/4/09	22:45	17
10/4/09	14:45	34.5	11/4/09	1:30	34.6	11/4/09	12:15	34.4	11/4/09	23:00	16.7
10/4/09	15:00	34.5	11/4/09	1:45	34.7	11/4/09	12:30	34.1	11/4/09	23:15	16.5
10/4/09	15:15	34.5	11/4/09	2:00	34.7	11/4/09	12:45	34.4	11/4/09	23:30	16.3
10/4/09	15:30	33.5	11/4/09	2:15	34.7	11/4/09	13:00	34.4	11/4/09	23:45	16.1
10/4/09	15:45	34.3	11/4/09	2:30	34.7	11/4/09	13:15	34.3	12/4/09	0:00	16
10/4/09	16:00	34.6	11/4/09	2:45	34.7	11/4/09	13:30	33.4	12/4/09	0:15	15.9
10/4/09	16:15	34.6	11/4/09	3:00	34.7	11/4/09	13:45	33.6	12/4/09	0:30	15.8
10/4/09	16:30	34.6	11/4/09	3:15	34.7	11/4/09	14:00	34.4	12/4/09	0:45	15.7
10/4/09	16:45	34.6	11/4/09	3:30	34.7	11/4/09	14:15	34.4	12/4/09	1:00	15.6
10/4/09	17:00	34.6	11/4/09	3:45	34.7	11/4/09	14:30	34.2	12/4/09	1:15	15.5
10/4/09	17:15	34.5	11/4/09	4:00	34.7	11/4/09	14:45	34.4	12/4/09	1:30	15.4
10/4/09	17:30	34.6	11/4/09	4:15	34.7	11/4/09	15:00	34.4	12/4/09	1:45	15.3
10/4/09	17:45	34.6	11/4/09	4:30	34.7	11/4/09	15:15	34.4	12/4/09	2:00	15.2
10/4/09	18:00	34.6	11/4/09	4:45	34.7	11/4/09	15:30	34.4	12/4/09	2:15	15.1
10/4/09	18:15	34.6	11/4/09	5:00	34.7	11/4/09	15:45	33.8	12/4/09	2:30	15
10/4/09	18:30	34.6	11/4/09	5:15	34.7	11/4/09	16:00	34.4	12/4/09	2:45	14.9
10/4/09	18:45	34.6	11/4/09	5:30	34.7	11/4/09	16:15	34.2	12/4/09	3:00	14.9
10/4/09	19:00	34.4	11/4/09	5:45	34.7	11/4/09	16:30	16.5	12/4/09	3:15	14.8
10/4/09	19:15	34.6	11/4/09	6:00	34.7	11/4/09	16:45	2.7	12/4/09	3:30	14.7
10/4/09	19:30	34.6	11/4/09	6:15	34.7	11/4/09	17:00	21.7	12/4/09	3:45	14.7
10/4/09	19:45	34.6	11/4/09	6:30	34.7	11/4/09	17:15	21.9	12/4/09	4:00	14.6
10/4/09	20:00	34.6	11/4/09	6:45	34.5	11/4/09	17:30	21.9	12/4/09	4:15	14.6
10/4/09	20:15	34.6	11/4/09	7:00	34.6	11/4/09	17:45	21.8	12/4/09	4:30	14.5
10/4/09	20:30	34.6	11/4/09	7:15	34	11/4/09	18:00	21.9	12/4/09	4:45	14.4
10/4/09	20:45	34.6	11/4/09	7:30	34	11/4/09	18:15	21.9	12/4/09	5:00	14.4
10/4/09	21:00	34.6	11/4/09	7:45	34.6	11/4/09	18:30	21.9	12/4/09	5:15	14.3
10/4/09	21:15	34.6	11/4/09	8:00	34.6	11/4/09	18:45	21.9	12/4/09	5:30	14.5
10/4/09	21:30	34.6	11/4/09	8:15	34.6	11/4/09	19:00	22	12/4/09	5:45	14.5
10/4/09	21:45	34.6	11/4/09	8:30	34.5	11/4/09	19:15	21.9	12/4/09	6:00	14.8
10/4/09	22:00	34.6	11/4/09	8:45	34.5	11/4/09	19:30	21.9	12/4/09	6:15	19.3
10/4/09	22:15	34.6	11/4/09	9:00	34.5	11/4/09	19:45	21.9	12/4/09	6:30	21.9
10/4/09	22:30	34.6	11/4/09	9:15	34.5	11/4/09	20:00	21.9	12/4/09	6:45	21.8
10/4/09	22:45	34.6	11/4/09	9:30	34.5	11/4/09	20:15	21.9	12/4/09	7:00	21.8
10/4/09	23:00	34.6	11/4/09	9:45	34.2	11/4/09	20:30	21.9	12/4/09	7:15	21.8
10/4/09	23:15	34.6	11/4/09	10:00	34.4	11/4/09	20:45	21.9	12/4/09	7:30	21.4
10/4/09	23:30	34.6	11/4/09	10:15	34.1	11/4/09	21:00	21.9	12/4/09	7:45	21.8
10/4/09	23:45	34.6	11/4/09	10:30	34.4	11/4/09	21:15	21.9	12/4/09	8:00	21.5
11/4/09	0:00	34.6	11/4/09	10:45	34.4	11/4/09	21:30	21.9	12/4/09	8:15	21.8
11/4/09	0:15	34.6	11/4/09	11:00	34.4	11/4/09	21:45	19.7	12/4/09	8:30	21.8
11/4/09	0:30	34.6	11/4/09	11:15	34.4	11/4/09	22:00	17.9	12/4/09	8:45	20.6

Date	Time	Press (m)	Date	Time	Press (m)	Date	Time	Press (m)	Date	Time	Press (m)
12/4/09	9:00	21.4	12/4/09	20:45	8.2	13/04/09	8:30	7.9	13/04/09	20:15	32.5
12/4/09	9:15	21.4	12/4/09	21:00	7.9	13/04/09	8:45	8.2	13/04/09	20:30	32.6
12/4/09	9:30	21.1	12/4/09	21:15	8.2	13/04/09	9:00	7.8	13/04/09	20:45	32.5
12/4/09	9:45	21	12/4/09	21:30	8.2	13/04/09	9:15	8	13/04/09	21:00	32.6
12/4/09	10:00	20.4	12/4/09	21:45	8.2	13/04/09	9:30	7.1	13/04/09	21:15	32.6
12/4/09	10:15	21.7	12/4/09	22:00	8.2	13/04/09	9:45	8	13/04/09	21:30	32.6
12/4/09	10:30	21.5	12/4/09	22:15	8.3	13/04/09	10:00	7.9	13/04/09	21:45	32.6
12/4/09	10:45	21.5	12/4/09	22:30	8.3	13/04/09	10:15	8	13/04/09	22:00	32.6
12/4/09	11:00	21.8	12/4/09	22:45	8.3	13/04/09	10:30	7.6	13/04/09	22:15	32.6
12/4/09	11:15	21.7	12/4/09	23:00	8.3	13/04/09	10:45	8	13/04/09	22:30	32.6
12/4/09	11:30	21.1	12/4/09	23:15	8.3	13/04/09	11:00	8.1	13/04/09	22:45	32.6
12/4/09	11:45	21.5	12/4/09	23:30	8.3	13/04/09	11:15	8.1	13/04/09	23:00	32.6
12/4/09	12:00	21.4	12/4/09	23:45	8.3	13/04/09	11:30	8	13/04/09	23:15	32.6
12/4/09	12:15	21.5	13/04/09	0:00	8.3	13/04/09	11:45	7.8	13/04/09	23:30	32.6
12/4/09	12:30	21.7	13/04/09	0:15	8.3	13/04/09	12:00	7.7	13/04/09	23:45	32.6
12/4/09	12:45	21.7	13/04/09	0:30	8.3	13/04/09	12:15	7	14/04/09	0:00	32.6
12/4/09	13:00	20.5	13/04/09	0:45	8.3	13/04/09	12:30	8	14/04/09	0:15	32.6
12/4/09	13:15	21.8	13/04/09	1:00	8.3	13/04/09	12:45	7.9	14/04/09	0:30	32.6
12/4/09	13:30	21.7	13/04/09	1:15	8.3	13/04/09	13:00	7.9	14/04/09	0:45	32.6
12/4/09	13:45	21.7	13/04/09	1:30	8.3	13/04/09	13:15	8.1	14/04/09	1:00	32.6
12/4/09	14:00	20.9	13/04/09	1:45	8.3	13/04/09	13:30	7.6	14/04/09	1:15	32.6
12/4/09	14:15	21.7	13/04/09	2:00	8.3	13/04/09	13:45	7.9	14/04/09	1:30	32.6
12/4/09	14:30	21.2	13/04/09	2:15	8.3	13/04/09	14:00	6.6	14/04/09	1:45	32.6
12/4/09	14:45	20.9	13/04/09	2:30	8.3	13/04/09	14:15	7.4	14/04/09	2:00	32.6
12/4/09	15:00	21.5	13/04/09	2:45	8.3	13/04/09	14:30	7.9	14/04/09	2:15	32.6
12/4/09	15:15	21.8	13/04/09	3:00	8.3	13/04/09	14:45	8	14/04/09	2:30	32.6
12/4/09	15:30	21.8	13/04/09	3:15	8.3	13/04/09	15:00	8.1	14/04/09	2:45	32.6
12/4/09	15:45	21.8	13/04/09	3:30	8.3	13/04/09	15:15	8	14/04/09	3:00	32.6
12/4/09	16:00	21.3	13/04/09	3:45	8.3	13/04/09	15:30	8	14/04/09	3:15	32.6
12/4/09	16:15	0.4	13/04/09	4:00	8.3	13/04/09	15:45	8	14/04/09	3:30	32.5
12/4/09	16:30	7.5	13/04/09	4:15	8.3	13/04/09	16:00	8	14/04/09	3:45	32.6
12/4/09	16:45	7.8	13/04/09	4:30	8.3	13/04/09	16:15	8	14/04/09	4:00	32.6
12/4/09	17:00	7.9	13/04/09	4:45	8.3	13/04/09	16:30	3	14/04/09	4:15	32.6
12/4/09	17:15	7.8	13/04/09	5:00	8.3	13/04/09	16:45	-1	14/04/09	4:30	32.6
12/4/09	17:30	7.9	13/04/09	5:15	8.3	13/04/09	17:00	19.7	14/04/09	4:45	32.6
12/4/09	17:45	7.7	13/04/09	5:30	8.2	13/04/09	17:15	32.3	14/04/09	5:00	32.6
12/4/09	18:00	6.6	13/04/09	5:45	7.9	13/04/09	17:30	29.4	14/04/09	5:15	32.6
12/4/09	18:15	8	13/04/09	6:00	7.9	13/04/09	17:45	32.4	14/04/09	5:30	32.6
12/4/09	18:30	8.1	13/04/09	6:15	7.4	13/04/09	18:00	32.4	14/04/09	5:45	32.5
12/4/09	18:45	7.3	13/04/09	6:30	8.2	13/04/09	18:15	32.5	14/04/09	6:00	32.6
12/4/09	19:00	8.2	13/04/09	6:45	8.2	13/04/09	18:30	32.3	14/04/09	6:15	32.6
12/4/09	19:15	8	13/04/09	7:00	6.9	13/04/09	18:45	32.5	14/04/09	6:30	32.4
12/4/09	19:30	7.9	13/04/09	7:15	7.5	13/04/09	19:00	32.7	14/04/09	6:45	32.6
12/4/09	19:45	8.2	13/04/09	7:30	8.1	13/04/09	19:15	32.4	14/04/09	7:00	32.3
12/4/09	20:00	8.2	13/04/09	7:45	8.1	13/04/09	19:30	32.6	14/04/09	7:15	32.5
12/4/09	20:15	8.2	13/04/09	8:00	8.1	13/04/09	19:45	32.5	14/04/09	7:30	32.6
12/4/09	20:30	8.2	13/04/09	8:15	7.6	13/04/09	20:00	32.5	14/04/09	7:45	32.4

Date	Time	Press (m)	Date	Time	Press (m)	Date	Time	Press (m)	Date	Time	Press (m)
14/04/09	8:00	31.7	14/04/09	10:15	32.5	14/04/09	12:30	32.1	14/04/09	14:45	32
14/04/09	8:15	32.5	14/04/09	10:30	32.4	14/04/09	12:45	32.3	14/04/09	15:00	31.4
14/04/09	8:30	32.5	14/04/09	10:45	32.4	14/04/09	13:00	32.2	14/04/09	15:15	32.3
14/04/09	8:45	32.5	14/04/09	11:00	32.3	14/04/09	13:15	27.4	14/04/09	15:30	32.3
14/04/09	9:00	32.5	14/04/09	11:15	32.3	14/04/09	13:30	31.7	14/04/09	15:45	31.9
14/04/09	9:15	32.5	14/04/09	11:30	32.3	14/04/09	13:45	32.2	14/04/09	16:00	32.2
14/04/09	9:30	32.5	14/04/09	11:45	32.3	14/04/09	14:00	31.6	14/04/09	16:15	18.4
14/04/09	9:45	31.8	14/04/09	12:00	32.2	14/04/09	14:15	31.7			
14/04/09	10:00	32.4	14/04/09	12:15	32.3	14/04/09	14:30	32.3			

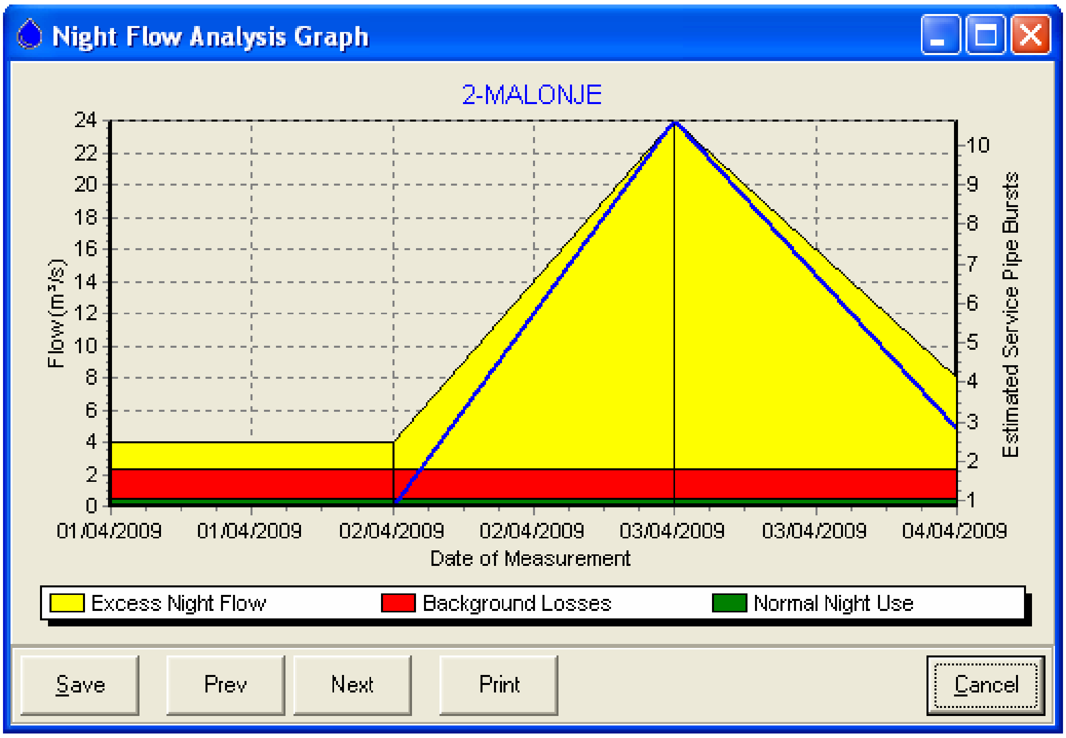
Appendix VI-a: Airwing MNF Analysis using SANFLOW Model

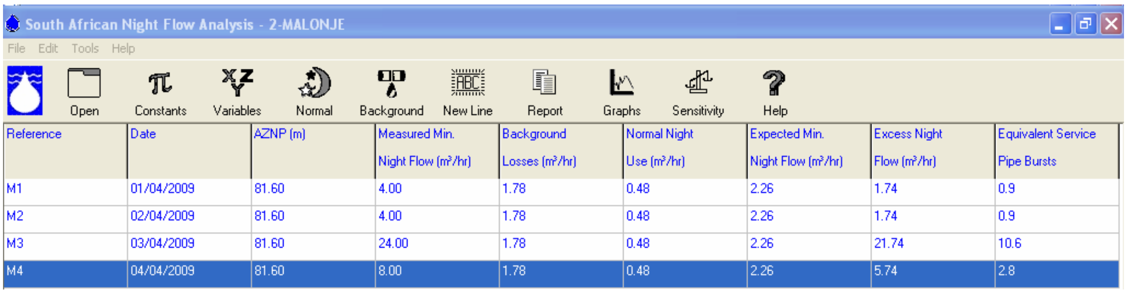




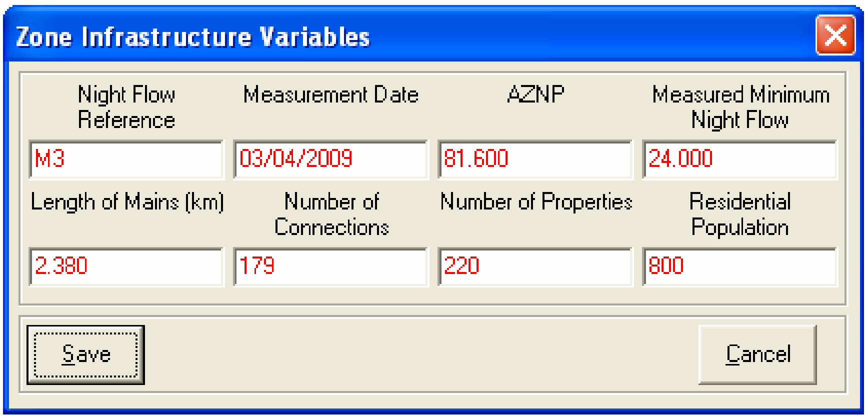
Reference	Date	AZNP (m)	Measured Min. Night Flow (m³/hr)	Background Losses (m³/hr)	Normal Night Use (m³/hr)	Expected Min. Night Flow (m³/hr)	Excess Night Flow (m³/hr)	Equivalent Service Pipe Bursts
A27	27/03/2009	36.00	8.00	0.29	6.48	6.77	1.23	0.9
A28	28/03/2009	36.00	8.00	0.29	6.48	6.77	1.23	0.9
A29	29/03/2009	36.00	8.00	0.29	6.48	6.77	1.23	0.9
A30	30/03/2009	36.00	8.00	0.29	6.48	6.77	1.23	0.9
A31	31/03/2009	36.00	8.00	0.29	6.48	6.77	1.23	0.9

Appendix VI-b: Malonje MNF Analysis

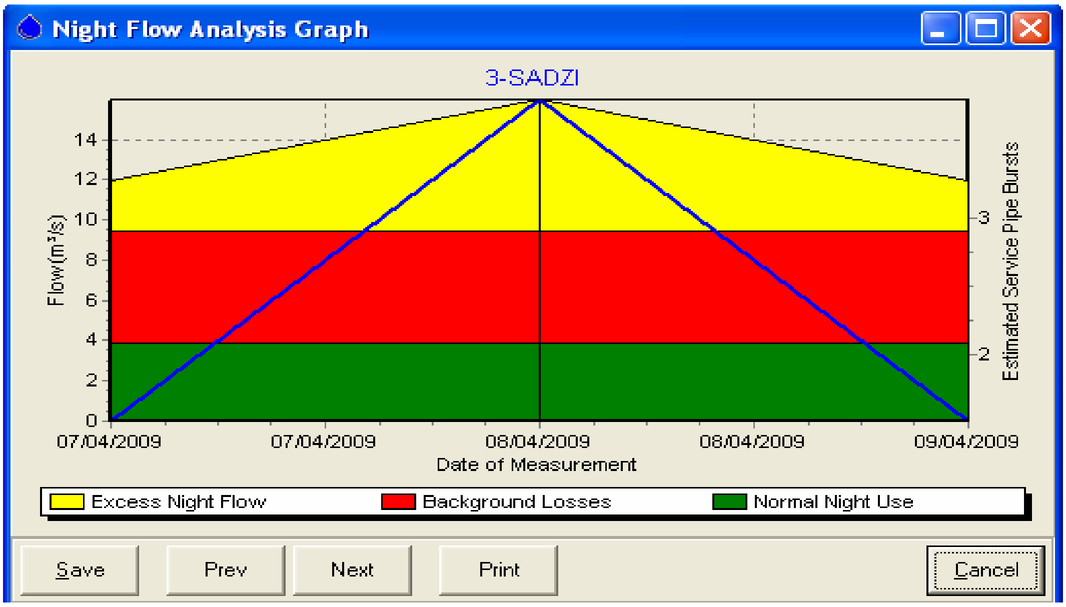


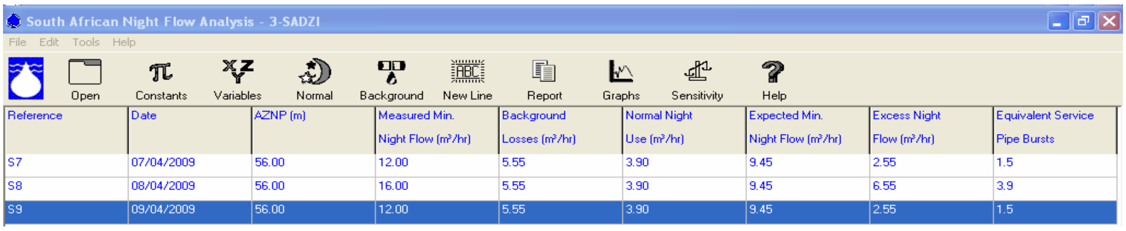

South African Night Flow Analysis - 2-MALONJE

Reference	Date	AZNP (m)	Measured Min. Night Flow (m³/hr)	Background Losses (m³/hr)	Normal Night Use (m³/hr)	Expected Min. Night Flow (m³/hr)	Excess Night Flow (m³/hr)	Equivalent Service Pipe Bursts
M1	01/04/2009	81.60	4.00	1.78	0.48	2.26	1.74	0.9
M2	02/04/2009	81.60	4.00	1.78	0.48	2.26	1.74	0.9
M3	03/04/2009	81.60	24.00	1.78	0.48	2.26	21.74	10.6
M4	04/04/2009	81.60	8.00	1.78	0.48	2.26	5.74	2.8

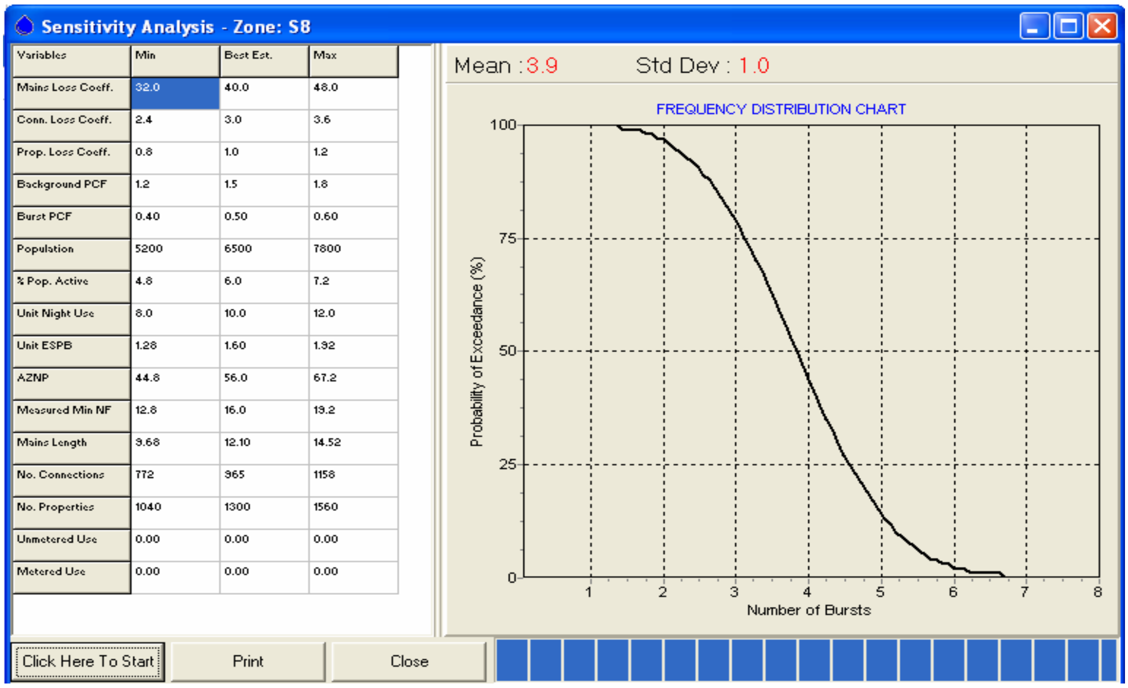


Appendix VI-c: Sadzi MNF Analysis





Reference	Date	AZNP (m)	Measured Min. Night Flow (m³/hr)	Background Losses (m³/hr)	Normal Night Use (m³/hr)	Expected Min. Night Flow (m³/hr)	Excess Night Flow (m³/hr)	Equivalent Service Pipe Bursts
S7	07/04/2009	56.00	12.00	5.55	3.90	9.45	2.55	1.5
S8	08/04/2009	56.00	16.00	5.55	3.90	9.45	6.55	3.9
S9	09/04/2009	56.00	12.00	5.55	3.90	9.45	2.55	1.5



Variables	Min	Best Est.	Max
Mains Loss Coeff.	32.0	40.0	48.0
Conn. Loss Coeff.	2.4	3.0	3.6
Prop. Loss Coeff.	0.8	1.0	1.2
Background PCF	1.2	1.5	1.8
Burst PCF	0.40	0.50	0.60
Population	5200	6500	7800
% Pop. Active	4.8	6.0	7.2
Unit Night Use	8.0	10.0	12.0
Unit ESPB	1.28	1.60	1.92
AZNP	44.8	56.0	67.2
Measured Min NF	12.8	16.0	19.2
Mains Length	9.68	12.10	14.52
No. Connections	772	965	1158
No. Properties	1040	1300	1560
Unmetered Use	0.00	0.00	0.00
Metered Use	0.00	0.00	0.00

Appendix VII: Bucket tests results and pipe network installed in 2001

(a) Bucket tests results

Airwing		Sadzi		Mtiya	
Bucket size (litre)	Average filling time (mm:ss)	Bucket size (litre)	Average filling time (mm:ss)	Bucket size (litre)	Average filling time (mm:ss)
20	1:37	20	0:44	20	2:23
20	1:35	20	0:45	25	0:56
20	1:17	20	0:59	20	2:26
20	1:39	20	1:26	25	3:27
25	1:03	25	1:20	20	0:55
20	6:56	20	1:07	20	1:08
20	0:57	20	0:29	20	1:00
20	2:00	20	0:59	20	0:40
25	1:29	20	0:37	20	0:47
20	1:19	20	0:38	20	1:19
20	0:52	20	0:56	20	0:39
20	1:35	20	0:22	20	1:01
20	3:09	20	0:24	20	0:41
20	1:22			20	0:30
20	1:40			20	0:44
				20	0:30

(b) Pipe network installed in 2001

Pipe Type	**Size (mm)**	**Length (m)**	**% type of Total**
GI	80	580	12.8
	100	1,360	
	150	3,355	
DI	200	1,715	13.7
	250	1,800	
	300	1,745	
	350	430	
PVC	75	990	73.5
	110	5,240	
	150	11,940	
	200	8,540	
	250	3,750	
Total		41445	100.00

Appendix VIII: Summary of pipe burst records for 2007 and 2008

Zone	Area	2009				2008				Type	Sizes	Notes
		Jan	Feb	Mar	Apr	Jan	Feb	Mar	Apr		(mm)	
Airwing	Airwing	0	1	1	2	0	0	0	1	PVC, AC	32, 100	April 2009 100mm AC
Mtiya	Mtiya	1	0	0	0	0	0	0	0	PVC	63	
Sadzi	Sadzi	7	8	9	9	11	12	10	12	PVC, GI	20, 25, 50, 63,90	20, 25, 50 common.
	Chizalo	7	5	5	1	5	4	3	7	PVC	20, 25, 50	
	Thundu	6	2	5	1	3	2	5	8	PVC, GI	25, 50, 160	160 mm X2 April 08.
	Mpunga	10	11	3	1	9	6	5	6	PVC, GI	20-32, 75, - 150	80, 150 mm GI bursts
Malonje	Malonje	4	3	1	2	0	1	2	1	PVC	20, 25, 63, 90	90 mm burst in April 2009
	Habitat	5	4	1	5	0	6	6	7	PVC, AC	20, 25, 50, 63	50 mm AC burst Mar08
	China mwali	7	2	5	1	0	7	3	7	PVC	50, 63	90% bursts - 63mm

Appendix IX: Some high bills between 2007 and 2009

Query No.	cause	Description	Resolution
1	Wrong meter readings	780-702 instead of 750-702	Credit adjustment
2	Wrong meter readings	236-216 instead of 223-215	Credit adjustment
3	Wrong meter readings	207-102 instead of 107-102	Credit adjustment
4		45 m^3 instead of 28 m^3	Credit adjustment
5	Meter leakage	SRWB not attend to problem after complaint	Credit adjustment
6	Broken valve	SRWB not attend to problem after complaint	Credit adjustment of MK4872
7	Computer feeding error	Missed the actual meter readings	Credit adjustment
8	Computer feeding error	Missed the actual meter readings	Credit adjustment
9	Computer feeding error	1279-1183 instead of 1229-1183 (50 m^3 error)	Credit adjustment of MK3477 was made
10	Error on posting of readings	300-224 instead of 255-224 (45m^3 error)	Credit adjustment of MK3127
11	Error on posting of readings	54m^3 instead of 12 m3	Credit adjustment of Mk3000
12	error at the recording of readings	205-120 instead of 205 -190	Credit adjustment
13	Error at the collection of meter readings		credit of MK14430
14	Error at the collection of meter readings	1772-1368 instead of 1372-1368	Credit adjustment
15	Error at the collection of meter readings	302-0 instead of average 6-0	Credit adjustment
16	Average charge	Due to inaccessibility of meter. Average charge was ‘high’	Credit adjustment of MK35000
17	Wrong billing	Billing a disconnected account	Credit adjustment of MK444,338
18	error at the posting of readings	1680-160 instead of 180-160	credit adjustment of MK153,000

Appendix X-a: Airwing Meter Inaccuracy Tests

Meter Type	Age	Pressure (m)	Volume tested(l)	Flow rate (l/hr)	Error%
Kent	0-5	3.5	10	300	-6.3
				500	-2.6
				800	-1.6
				1500	-1.0
Kent	5-10	3.8	10	300	-4.8
				500	-5.2
				800	-4.0
				1400	-3.4
Kent	5-10	3.4	10	150	-0.9
				300	-0.8
				500	-0.2
				1000	-0.2
Aquadis	0-5	3.4	10	300	-0.7
				500	-1.9
				1000	-1.5
Kent	0-5	3.6	10	300	-6.0
				500	-4.8
				1000	-3.0
Kent	10-15	3.7	10	300	-16.7
				500	-10.0
				1000	-6.8
				1500	-5.3
PSM Kent	5-10	3.2	10	300	-0.3
				500	-0.2
				1000	-0.2
Kent PSM	5-10	3.3	10	300	-6.5
				500	-4.3
				1000	-3.0
Kent	5-10	3.4	10	150	-0.7
				300	-0.5
				500	-0.2
				1000	-0.2

Appendix X-b: Malonje Meter Inaccuracy Tests

Meter Type	Age	Pressure (m)	Volume tested(l)	Flow rate (l/hr)	Error%
Kent	5-10	34	10	300	-8.0
				500	-6.3
				1000	-5.2
Kent	5-10	20	10	300	-6.0
				500	-4.1
				1000	-4.3
Kent	10-15	33	10	300	11.6
				500	-7.8
				1500	-5.9
PSM Kent	0-5	32	10	300	-0.2
				500	-0.2
				1000	-0.1
Kent	0-5	33	10	300	-0.8
				500	-1.8
				1000	-0.5
Kent	5-10	34	10	150	-5.0
				300	-4.5
				500	-2.7
				1000	-2.2
Aquadis	0-5	34	10	300	-0.9
				500	-1.3
				1000	-1.2
Kent	5-10	25	10	300	-6.0
				500	-5.2
				1000	-4.7
Kent	10-15	22	10	300	11.9
				500	-11.8
				1000	-8.8
				1500	-5.6
Kent	0-5	40	10	300	-1.0
				500	0.1
				1000	-1.0
Kent	5-10	33	10	300	-5.6
				500	-4.1
				1000	-3.9
Kent	0-5	34	10	150	-0.9
				300	-0.7
				500	-0.3
				1000	-0.2
Aquadis	5-10	40	10	300	-3.8
				500	-1.7
				1000	-1.1
Kent	5-10	35	10	300	-3.0
				500	-2.7
				1000	-1.7

Meter Type	Age	Pressure (m)	Volume tested(l)	Flow rate (l/hr)	Error%
Kent	10-15	35	10	300	-8.3
				500	-8.0
				1000	-6.8
				1500	-4.9

Appendix X-c: Sadzi Meter Inaccuracy Tests

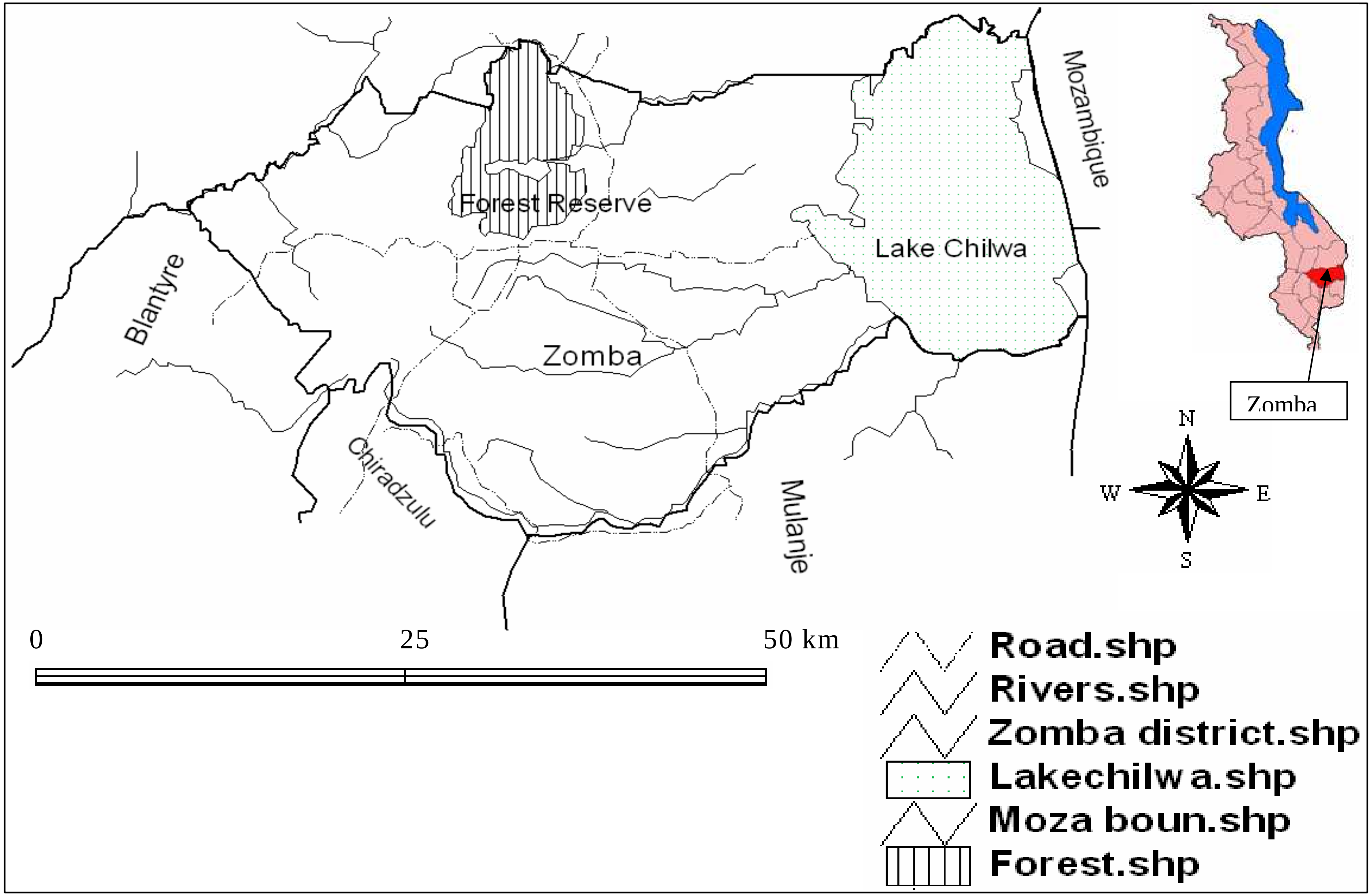
Meter Type	Age	Pressure (m)	Volume tested(l)	Flow rate (l/hr)	Error%
PSM Kent	0-5	32	10	300	-2.3
				500	-2.1
				1000	-1.6
Kent PSM	5-10	31	10	300	-0.8
				500	-1.3
				1000	-0.9
Kent	0-5	34	10	150	-0.8
				300	-0.8
				500	-0.1
				1000	-0.1
Aquadis DN15	0-5	34	10	300	-0.8
				500	-1.7
				1000	-1.2
Kent	0-5	36	10	300	-2.0
				500	-2.2
				1000	-1.7
Kent	10-15	35	10	300	13.7
				500	-11.7
				1000	-7.3
				1500	-6.2
PSM Kent	5-10	40	10	300	-5.7
				500	-4.3
				1000	-3.6
Kent PSM	5-10	33	10	300	-7.0
				500	-6.2
				1000	-6.1
Kent	5-10	34	10	150	-7.8
				300	-5.8
				500	-4.1
				1000	-2.1
Aquadis	0-5	34	10	300	-1.3
				500	-1.1
				1000	-1.2
Kent	0-5	35	10	300	-2.4
				500	-2.3
				1000	-1.8
Kent	10-15	31	10	300	11.7
				500	9.4
				1000	-7.8
				1500	-5.9
PSM Kent	0-5	40	10	300	-0.1
				500	-0.1
				1000	-0.1
Kent	0-5	33	10	300	-0.8

Meter Type	Age	Pressure (m)	Volume tested(l)	Flow rate (l/hr)	Error%
				500	-1.0
				1000	-0.9
Kent	5-10	34	10	150	-9.8
				300	-6.8
				500	-6.1
				1000	-5.1
Kent	0-5	34	10	300	-0.3
				500	-0.7
				1000	-2.2
Kent	0-5	35	10	300	-1.8
				500	-2.2
				1000	-1.7
Kent	10-15	25	10	300	-7.9
				500	-6.2
				1000	-8.8
				1500	-7.9
PSM Kent	0-5	40	10	300	-1.2
				500	-1.0
				1000	-0.1
Kent PSM	5-10	33	10	300	-8.7
				500	-6.1
				1000	-5.6
Kent DN15	10-15	32	10	150	-3.5
				300	-4.5
				500	-4.0
				1000	-7.7
KentPSM	5-10	35	10	300	-5.5
				500	-7.5
				1000	-2.4

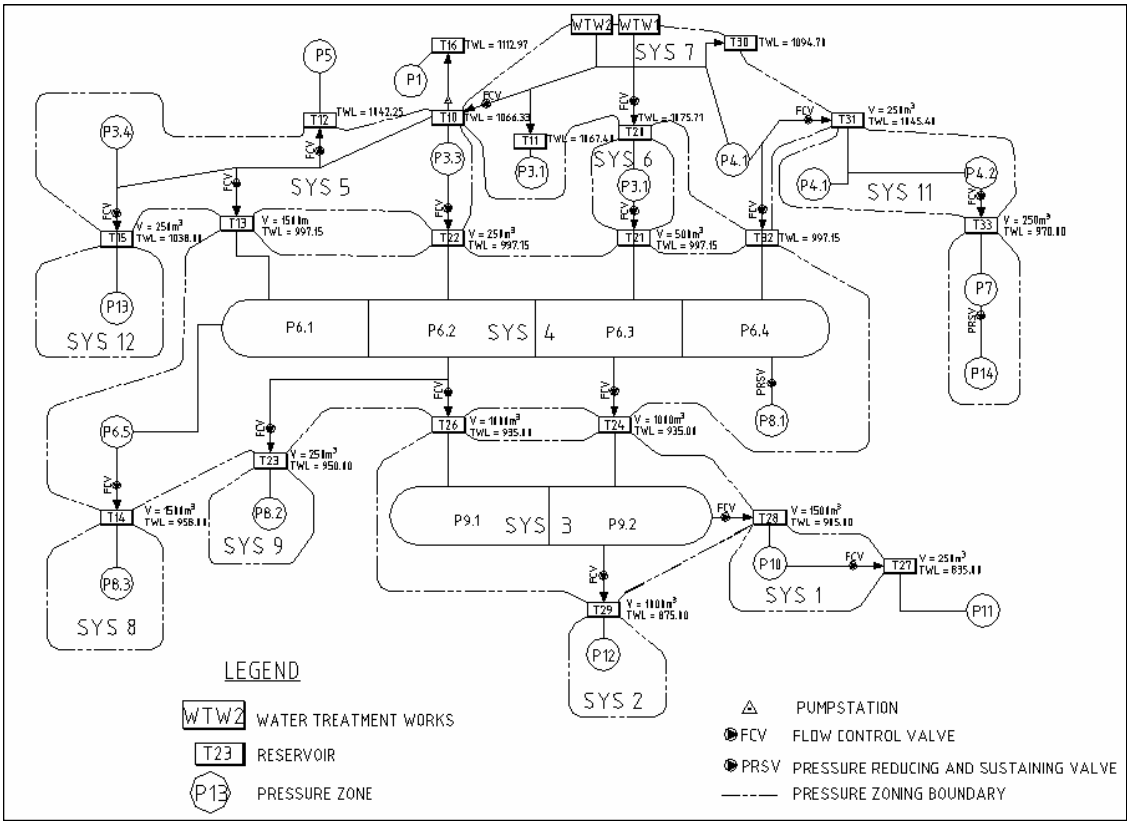
Appendix X-d: Mtiya Meter Inaccuracy Tests

Meter Type	Age	Pressure (m)	Volume tested(l)	Flow rate (l/hr)	Error%
Kent M05134676	5-10	34	10	150	-0.8
				300	-0.8
				500	-0.1
				1000	-0.1
Aquadis DN15 D08LA410612	0-5	34	10	300	-0.8
				500	-1.7
				1000	-1.2
Kent 96A137364	0-5	20	10	300	-2.0
				500	-2.2
				1000	-1.7
Kent 931006047	5-10	13	10	below 600	meter not moving
				600	-11.3
				1000	-7.8
				1500	-5.9
PSM Kent 930806255	5-10	33	10	300	0.0
				500	0.0
				1000	0.0
Kent PSM 96A137202	5-10	33	10	300	-0.7
				500	-1.1
				1000	-0.6

Appendix XI: Map of Zomba



Appendix XII Zomba City water supply pressure zones



Appendix XIII Research Pictures


(a)


(b)


(c)


(d)


(e)


(f)


(g)


(h)

(a): Flow logger installed on a bulk meter (b): Pressure logger installed on a customer tap with a Tee (c): Pressure logger installed without Tee. (d): Manual pressure gauge inserted on customer tap (e): Plumber closing tank inlet valve to control overflow
(f) Meter inaccuracy testing bench installed in series with customer meter under test. (g) Properly working tank meter
(h) Vandalised tank meter.